Briefing Notes for the President
GTAP Analysis on the Potential Economic Impact of COVID-19
Economic Research and Regional Cooperation Department
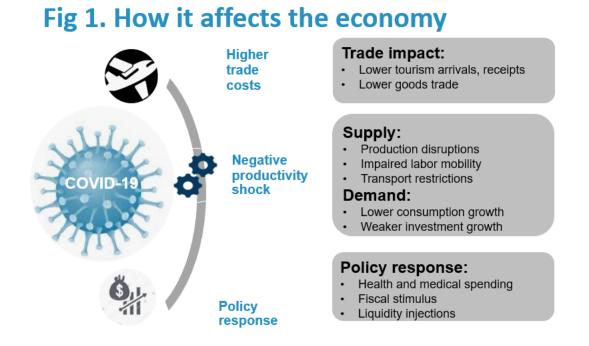**15 April 2020**

Introduction

1.   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 184 countries, infecting 1,852,572 people and claiming 114,122 lives; and the situation in the US and Europe is spreading out of control.

2.   To suppress the spread of COVID-19, many affected countries have closed their borders fully or partially and 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.

3.   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 spending 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.

4.   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

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

Negative productivity shock

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

Demand:
- Lower consumption growth
- Weaker investment growth

Policy response

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

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

Table 1: Assumptions[2]

	Baseline data	Short Containment Scenario (*for comparison with ADO*)	Long Containment Scenario
1.1 Productivity shifter calibrated to cut consumption by	PRC: $5.6 trillion ROW[3]: $33.6 trillion+	5% ($280 billion) 2% ($672.3 billion+)	5% ($280 billion) 5% (1.7 trillion+)

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[1] The short containment scenario is kept for purposes of comparing with the ADO analysis and a 3rd scenario depicting tail-end risk assessment could be examined after discussion with OPR.

[2] Appendix 1 explains how the shocks are put in GTAP

[3] ROW includes Australia, Brazil, Canada, Turkey, EU, Iran, Japan, Norway, PRC, Rep. of Korea, Switzerland, UK, and US.

1.2 Productivity shifter calibrated to cut investment by	$6.5 trillion $11 trillion	5% ($324 billion) 2% ($220 billion)	6.25% ($405.4billion) 6.25% ($540.6 billion)
1.3 Decline in tourism receipts calculated by ADO	$186.5 billion $4,516 billion	11.4% ($21.397 billion) 4.4% ($268.4 billion)	22.9% ($42.4 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	Medical expenditures double due to doubling of cases
3.2 Fiscal stimulus and liquidity injections was split as subsidy to labor and capital (50/50)	See Appendix 2	Half of fiscal stimulus injected as subsidy to consumers and producers	Full amount of fiscal Stimulus + 10% liquidity injections injected as subsidy to consumers and producers

GTAP Model and Database

8.   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

9. **Comparison with the ADO 2020 results:** The ADB has released two sets of estimates on the potential economic impact of the COVID-19 outbreak. The first estimate was released on March 6 and suggested a global impact of **$77 billion** to **$347 billion** or **0.1% to 0.4%** of global GDP, with a moderate case estimate of **$156 billion or 0.2%** of global GDP. Two-thirds of the impact falls on the PRC, where the outbreak has been concentrated so far. However, since then, COVID-19 has spread all over the world with many countries exceeding the number of infections and deaths recorded in the PRC. Last 3 April, the Asian Development Outlook 2020 released a higher estimate of the global impact which ranged from **over $2 trillion** to **over $4 trillion**. This note revisits these estimates using the GTAP CGE model. Based on the GTAP analysis, **the ADO's Covid-19 impact assessment of $2.0 to $4.1 trillion, or 2.3% to 4.8% of global GDP, is now upgraded to $2.5 to $4.9 trillion, or 2.8% to 5.4 % of**

global GDP. Broadly, the GTAP estimates are about **5%** to **20%** higher than the ADO estimates, except for Asia ex-PRC where the difference are huge (see Appendix 2 for fuller comparison).

Table 2. Comparative Results: MRIOTADO 2020 and GTAP

	Short Containment		Long Containment	
	ADO 2020	**GTAP**	ADO 2020	**GTAP**
Global	-2.3	**-2.8**	-4.8	**-5.4**
Asia ex-PRC	-1.0	**-2.3**	-2.2	**-5.4**
PRC	-4.6	**-5.4**	-5.1	**-6.3**
ROW	-2.0	**-2.3**	-5.1	**-5.4**

Source: ADO 2020 and Staff Estimates

10. 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.

11. 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) the use of productivity shock in GTAP to bring down consumption and investment levels, which also brings down production on the supply side; 3) presence of price and unemployment effects in GTAP which is not present in the ADO analysis; and 4) the general equilibrium nature of GTAP where the 2nd, 3rd, and nth round effects are incorporated.

12. **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.

Table 3. GDP Impact (Deviation from World without COVID-19)

	GDP ($ million)		GDP (%)	
	Short containment	Long Containment	Short containment	Long Containment
Global	-2,534,687	-4,935,014	-2.8	-5.4
Asia	-1,205,122	-1,887,949	-3.7	-5.8
Central Asia	-11,900	-24,697	-2.0	-4.1
East Asia ex PRC	-178,628	-405,843	-2.2	-4.9
PRC	-782,395	-908,405	-5.4	-6.3
Southeast Asia	-99,893	-234,074	-2.8	-6.6
South Asia	-81,184	-195,198	-2.2	-5.4
Oceania	-49,994	-117,719	-2.5	-5.9
Pacific	-1,128	-2,013	-1.6	-2.8
US	-422,690	-980,254	-2.0	-4.7
EU+UK	-552,965	-1,226,614	-2.5	-5.5

Source: Staff Estimates

13.   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.

14.   **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%** to **4.1% and** in the Pacific by between **1.6%** to **2.8%.**

15.   **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.

16.   **Effects on trade:** the COVID-19 outbreak will also cut global trade by between **$905 billion** to **$2,095 billion** or **1.0** and **2.3%** of GDP in the 2 scenarios.

Table 4. Trade Impact (Deviation from World without COVID-19)

	Trade ($ million)		Trade (% of GDP)	
	Short containment	Long Containment	Short containment	Long Containment
Global	-905,408	-2,094,937	-1.0	-2.3
Asia	-198,994	-472,279	-0.6	-1.5
Central Asia	-1,724	1,221	-0.3	0.2
East Asia ex PRC	-130,667	-291,177	-1.6	-3.5
PRC	-10,528	-109,399	-0.1	-0.8
Southeast Asia	-38,245	-57,361	-1.1	-1.6
South Asia	-2,081	17,491	-0.1	0.5
Oceania	-15,490	-32,571	-0.8	-1.6
Pacific	-259	-484	-0.4	-0.7
US	-109,695	-209,590	-0.5	-1.0
EU+UK	-471,171	-1,135,655	-2.1	-5.1

Source: Staff Estimates

17.   **Employment impacts:** Globally, employment value equivalent to between **106 million** to **195 million** person-months will be lost in the 2 scenarios. For Asia, the employment fall will be by between **77 million** to **129 million** person-months or **66%-72%** of the total employment fall. For the PRC, employment will fall by between **45 million** to **53 million** person-months. 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 people in full-time job equivalent (ILO report)[4].

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[4] According to the ILO, COVID-19 related full or partial lockdown are affecting roughly 2.7 billion or 80% of the global workforce. More so, ILO's new global estimates indicate that working hours will decline by 6.7 per cent in the second quarter of 2020, which is equivalent to 195 million people in full-time job equivalent.

Table 5. Employment Impact (Deviation from World without COVID-19)[5]

	Employment (million)		Employment (%)	
	Short containment	Long Containment	Short containment	Long Containment
Global	-106.1	-195.3	-4.0	-7.4
Asia	-76.8	-129.4	-4.8	-8.0
Central Asia	-1.3	-2.8	-4.7	-9.9
East Asia ex PRC	-2.1	-4.5	-2.8	-6.0
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	-5.0	-10.4	-3.4	-7.0

Source: Staff Estimates

18. **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**.

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

	Wage Income ($ million)		Wage Income (%)	
	Short containment	Long Containment	Short containment	Long Containment
Global	-535,314	-1,053,262	-2.9	-5.8
Asia	-254,763	-395,138	-4.0	-6.2
Central Asia	-2,002	-4,442	-2.2	-5.0
East Asia ex PRC	-33,736	-78,325	-2.2	-5.2
PRC	-177,715	-209,488	-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	-3.0
US	-102,755	-253,481	-2.1	-5.2
EU+UK	-87,797	-194,711	-2.6	-5.8

Source: Staff Estimates

19. **Impacts of medical expenditures:** spending on medical equipment will have small economic impact, ranging from between **0.07%** to **0.1%**. However, these expenditures are important to control and contain the disease, protect the frontline workers, and save lives.

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[5] Employment losses are losses in working hours expressed in person-months of a full-time job equivalent

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

GDP Results	GDP ($ million)		GDP (%)	
	Short containment	Long Containment	Short containment	Long Containment
Global	61,403	92,103	0.07	0.10
Asia	5,201	7,801	0.02	0.02
Central Asia	95	143	0.02	0.02
E-Asia ex PRC	966	1,449	0.01	0.02
PRC	2,850	4,276	0.02	0.03
Southeast Asia	530	794	0.01	0.02
South Asia	337	506	0.01	0.01
Oceania	418	627	0.02	0.03
Pacific	5	7	0.01	0.01
US	24,362	36,542	0.12	0.18
EU+UK	29,167	43,751	0.13	0.20

Source: Staff Estimates

20.   **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[6]. These macroeconomic stimuli will potentially raise GDP growth by between **0.6%** to **1.7%** globally. For Asia, these could also add by between **0.5%** to **1.3%** to the region's growth. For the PRC, they could add from **0.2%** to **0.7%** of its growth. For the EU+UK and the US they could raise growth from: **1.6%** to **3.7%**, to **0.1%** to **1.4%**, respectively.

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

GDP Results	GDP ($ million)		GDP (%)	
	Short containment	Long Containment	Short containment	Long Containment
Global	535,190	1,516,722	0.59	1.67
Asia	166,626	407,140	0.51	1.25
Central Asia	90	300	0.02	0.05
E-Asia ex PRC	71,335	172,670	0.86	2.09
PRC	29,411	102,527	0.20	0.71
Southeast Asia	9,173	18,693	0.26	0.53
South Asia	2,300	3,961	0.06	0.11
Oceania	54,451	109,212	2.74	5.50
Pacific	-134	-223	-0.19	-0.31
US	336,282	767,146	1.62	3.69
EU+UK	14,754	304,172	0.07	1.37

Source: Staff Estimates

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[6] See Appendix 3 for macroeconomic stimulus include in the analysis.

21.   **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 trillion** or **3.2%**. In the *long containment*, global output will fall by about **$3.3 trillion** or **3.7%** with output in the Asia falling by **$1.5 trillion** or **4.5%**. 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.

Table 9. GDP Impact with Health and Macro Policy Response

	GDP ($ million)		GDP (%)	
	Short containment	Long Containment	Short containment	Long Containment
Global	-1,938,094	-3,326,189	-2.1	-3.7
Asia	-1,033,295	-1,473,007	-3.2	-4.5
Central Asia	-11,715	-24,255	-2.0	-4.1
East Asia ex PRC	-106,327	-231,723	-1.3	-2.8
PRC	-750,134	-801,602	-5.2	-5.5
Southeast Asia	-90,190	-214,587	-2.6	-6.1
South Asia	-78,547	-190,731	-2.2	-5.3
Oceania	4,875	-7,880	0.2	-0.4
Pacific	-1,257	-2,229	-1.8	-3.1
US	-62,046	-176,566	-0.3	-0.8
EU+UK	-509,044	-878,691	-2.3	-4.0

Source: Staff Estimates

Policy Implications:

22.   **Avoid the occurrence of long containment 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, growth should be 2.8% higher than potential growth.

23.   We cannot discount a possibility in which a long containment will trigger a financial crisis, which, in turn, 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.

24.   **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.

25.   **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.

26.   **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.

27.   **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: Explanation of shocks for the simulations
Shock 1: Tourism

In the GTAP dataset, travelers' expenditure is merged with the other cross-border trade flows, in both goods and services, based on their shares[7]; here's a quote from GTAP Data Base Documentation[8]:

""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 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 used the magnitudes of tourism expenditure losses by the country, divide each of them 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 introduce a new variable named qor(REG) in the model, which is the aggregate output across all sectors. The variable is qor(REG). This is endogenous by default, so it needs to be swapped by an exogenous variable of the same dimension. We choose the technological change or 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, which is qo. Following is a sequence of equations that connect qo with aoreg:

1. Market clearing equation ensures the 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 that 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 passthrough from prices to demand for domestic consumption by each agent.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) – following shows the example of the private domestic consumption price:
   ppd(i,r) = atpd(i,r) + pm(i,r);

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[7] See this link for example:
https://www.gtap.agecon.purdue.edu/events/Conferences/2009/documents/SvcTrd.pdf

[8] See this link: https://www.gtap.agecon.purdue.edu/resources/download/2865.pdf

5. 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 this 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 shock

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.

1. The following equation links the 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);

2. Following equation connects ppriv with each of the different commodity prices:

ppriv(r) = **sum**(i,TRAD_COMM, CONSHR(i,r) * pp(i,r));

3. 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);

4. 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);

5. 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);

6. Finally this 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 shock

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 China. This means that there will be more or less investment, relative to savings.

Shock 4: Medical Expenditures

We assumed that for developed countries, the expenditure per person is $40,000 and for developing countries, this is $20,000, based on the literature on SARS, assuming that treating Covid-19 is twice as expensive as SARS. We the multiply this per capita expenditure by the number of cases based on WHO situation report, as on April 6, 2020, for the base case. For the long containment, we assume the expenditure is just double that of base case.

Shock 4: Fiscal Stimulus and Liquidity Injections

We take all the fiscal stimulus numbers and equally divide them as subsidies for consumption and those for labor (inputs to production). We take the liquidity injections, and use the literature on the real economic impact of such injections, which suggest that roughly an injection that is 15% of GDP can lead to a real GDP boost of 1.4%. Therefore, we multiply the liquidity injections' share in GDP by a factor of (1.4/15), to get the effect on total factor productivity (afereg), which acts as a 'GDP shifter'.

Appendix 2: GDP Results: MRIOT ADO 2020 and GTAP (% of GDP)

BY COUNTRY	Short containment		Long containment	
	MRIOT	GTAP	MRIOT	GTAP
People's Republic of China	-4.6	-5.4	-5.1	-6.3
Bangladesh	-0.2	-2.2	-0.4	-5.4
Bhutan a	-0.4	-2.9	-0.8	-6.4
Brunei Darussalam	-1.0	-1.5	-2.1	-2.4
Cambodia	-3.6	-2.4	-7.4	-4.0
Fiji	-3.7	-1.6	-7.6	-2.8
Hong Kong, China	-1.4	-2.8	-2.7	-6.2
India	-0.2	-2.2	-0.5	-5.4
Indonesia	-2.2	-2.6	-0.9	-6.2
Kazakhstan	-1.0	-1.1	-2.0	-1.6
Kyrgyz Republic	-1.1	-2.9	-2.2	-1.9
Lao People's Democratic Republic	-1.0	-2.8	-2.0	-6.6
Malaysia	-1.1	-2.8	-2.2	-6.5
Mongolia	-2.0	-1.8	-2.7	-3.2
Nepal	-0.4	-2.9	-0.8	-5.2
Pakistan	-0.1	-2.0	-0.3	-4.8
Philippines	-0.8	-2.3	-1.6	-5.3
Republic of Korea	-2.2	-2.7	-5.4	-6.0
Singapore	-1.3	-4.4	-2.6	-11.0
Sri Lanka	-1.7	-3.0	-3.4	-7.0
Taipei,China	-1.4	-1.4	-2.5	-2.5
Thailand	-2.3	-3.0	-4.6	-6.8
Viet Nam	-1.4	-2.0	-2.9	-3.2
Japan	-2.1	-2.0	-5.4	-4.8
United States	-2.2	-2.0	-5.6	-4.7
United Kingdom	-2.4	-2.2	-6.0	-4.8
Australia	-2.8	-2.6	-6.5	-6.0
Russia	-0.9	-2.5	-1.8	-6.0
Turkey	-3.1	-2.7	-7.8	-6.3

Appendix 3: COVID-19 Stimulus Package, $ Billion

	Fiscal Stimulus	EROD's Data	Liquidity Injections	EROD's Data
A. National Initiatives				
People's Rep. of China	$183.2 billion	same	$422.7 billion liquidity injection $112.7 billion extension of loan facilities (rate reduction of reverse repo rates and medium-term lending facilities) $49.3 billion credit extension to MSMEs	$427.8 billion (RMB3.02 trillion) $255 billion (RMB 1.8 trillion) expansion of re-lending and re-discounting facilities $49.6 billion (RMB350 billion)
South Korea	$13.2 billion	$13.1 billion (KRW16 trillion)	(base rate reduction) $1.2 billion repurchase of treasury bonds $4.1 billion increase in bank-intermediated lending support facility $82 billion financial stabilization plan	 same same same
Japan	$4 billion emergency response package (Japan is expected to announce a stimulus package, fiscal and monetary, exceeding $500 billion soon)	$4.1 billion (JPY446 billion) $240.7 billion (JPY26 trillion) stimulus package	(expansion of overnight and term repos facility) $14.8 billion special financing and guarantees for MSMEs	 same $144.4 billion (JPY15.6 trillion) swap line
Hong Kong	$19.6 billion	$19.3 billion (HK$152 billion)	(base rate reduction) (introduction of government-guaranteed low-interest loans for SMEs)	

	Fiscal Stimulus	EROD's Data	Liquidity Injections	EROD's Data
Taipei,China	$3.3 billion	same	$6.6 billion expansion of repurchase facility, rate cut	
Singapore	$38.1 billion	same	none	
Indonesia	$8.4 billion tax incentives and subsidies $720 million support to consumer spending and tourism	$12.9 billion (IDR22.5 trillion) $4.9 billion (IDR8.5 trillion)	(policy rate cut) (reserve requirement reduction)	
Malaysia	$57.8 billion	$7.2 billion (MYR31.6 billion)	$6.9 billion cut to reserve requirements (overnight policy rate reduction)	$6.8 billion (MYR30 billion) $0.9 billion (MYR4 billion) increase in financing facility
Philippines	$3.9 billion	$4.5 billion (PHP245 billion)	$5.9 billion repurchase of government securities, policy rate cut	same
Thailand	$15.9 billion	same	(policy rate cut) $3.1 billion repurchase of government bonds	 same
Australia	$195.9 billion	$275 billion	(policy rate cut) $55.5 billion SME lending facility	 $55.2 billion (AUD90 billion) $60 billion swap line between RBA and the US Fed A$15 billion investment in residential mortgage-backed and asset-backed securities

	Fiscal Stimulus	EROD's Data	Liquidity Injections	EROD's Data
New Zealand	$9.8 billion	$10.7 billion (NZD17.9 billion)	$18.1 billion repurchase of government bonds (official cash rate cut)	$18 billion
US	$8.3 billion (Coronavirus Preparedness and Response Supplemental Appropriations Act) $104 billion (Families First Coronavirus Response Act) $2 trillion	same same same	(federal funds rate cut) (introduction and expansion of credit facilities)	
Canada	$143.2 billion	$193 billion	(overnight policy rate cut) (extension of bond buyback program) (introduction of new credit facilities)	$65 billion in credit facilities to lend to firms under stress $5 billion in lending capacity to producers, agribusinesses, and food processors $150 billion of insured mortgage pools through the Canada Mortgage and Housing Corporation (CMHC)
France	$50.3 billion	$49.8 billion (EUR45 billion)	$335 billion guarantee to bank loans (temporary and selected relaxation of capital requirements)	$332.2 billion (EUR300 billion)
Italy	$27.9 billion	$28.2 billion (EUR25.5 billion)	(temporary relaxation of capital requirements)	
Germany	$174.2 billion	$172.8 billion (EUR156 billion)	$918 billion allocation for public loan guarantees	$910.3 billion (EUR822 billion)

	Fiscal Stimulus	EROD's Data	Liquidity Injections	EROD's Data
				$110.7 billion (EUR100 billion) short-term liquidity provision to companies $110.7 billion (EUR100 billion) acquisition of equity of large affected companies
UK	$81.1 billion	$48.2 billion ($6.2 billion [GBP5 billion] funding for the National Health Service and other public services; $33.4 billion [GBP27 billion] to support businesses; $8.6 billion [GBP7 billion] social safety net to support vulnerable people)	(bank rate reduction) $249.1 billion securities repurchase $411 billion business loans and guarantees	$247.3 billion (GBP200 billion) purchase of government and non-financial corporate bonds $408.1 billion (GBP330 billion) loans and guarantees available to businesses
India	$22.5 billion	$1.99 billion (INR150 billion) health infrastructure $2.65 billion (INR200 billion direct transfer to poor households	(various asset repurchases)	$2 billion foreign exchange swap
Brazil	$29.4 billion (note: these are reallocated funds)	$64.6 billion (3.5% of GDP)	(policy rate cut) (reserve requirement reduction)	
Russia	$3.8 billion	$20.6 billion (1.5% of GDP)	$6.3 billion credit facility for SMEs	same
Spain	$9.9 billion	$15.4 billion (EUR13.9 billion) $15.5 billion (EUR14 billion) deferred tax payment for SMEs	$113.9 billion government loan guarantees for firms, self-employed, and exporters	$112.9 billion (EUR102 billion) $11.5 billion (EU10.4 billion)

	Fiscal Stimulus	EROD's Data	Liquidity Injections	EROD's Data
			$11.2 billion additional credit line for various purposes	
Mexico	$7.7 billion	same	(policy rate cut) $2.1 billion equivalent of reserve requirement reduction	same $10 billion non-deliverable forwards (NDF) $60 billion swap line with the Fed
Netherlands	$16.8 billion	$22.1 billion (EUR20 billion)	(systemic buffer requirement reduction to selected banks)	
Saudi Arabia	$18.6 billion private sector support package	same	(policy rate cut) $13.3 billion support for SME lending	same
Turkey	$15.5 billion	$15.4 (TL100 billion)	(policy rate cut)	
Switzerland	$44.2 billion	$43.9 billion (CHF42 billion)	(introduction of refinancing facility)	$3.6 billion liquidity injected via auctions $20.9 billion (CHF20 billion) foreign exchange market intervention
Poland	$18.1 billion		(policy rate cut) (reserve requirement reduction) $18.4 billion government credit guarantees	$34 billion (PLN141 billion) central bank purchases of treasury securities
Sweden	$32.1 billion	$68.9 billion (SEK668 billion)	$50.5 billion lending via banks	$50.1 billion (SEK500 billion)

	Fiscal Stimulus	EROD's Data	Liquidity Injections	EROD's Data
			$30.3 billion securities repurchase (capital buffer relaxation)	$30 billion (SEK300 billion) $60 billion swap facility with the US Fed $60 billion used as collateral for banks to borrow in US dollars

Appendix 4. 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	Multi-regional input-output trade model	Multi-regional, 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) • Sectoral input-output analysis can also incorporate supply shocks (e.g., production disruptions due to forced closures)	• 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 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 • Production/supply chain disruptions due to forced closures (decline in imports/exports) • Decline in tourism receipts (global) • Impact on employment & wage Income (millions) • Impact of fiscal stimulus and liquidity injections (% GDP) • Impact on medical expenditures (% GDP)
Scenario Settings:		
Consumption	**Shorter containment, smaller demand shocks (Base case):** Growth in domestic consumption in the PRC slows by 5 percentage points; growth in domestic	

	consumption in out-break-affected economies excluding PRC declines by 2 percentage points;	
	Longer containment, higher demand shocks (Worst case): Growth in domestic consumption in outbreak affected economies declines by 5 percentage points;	
Investment	**Shorter containment, smaller demand shocks (Base case):** Growth in domestic investment in the PRC declines by 6.25 percentage points; Growth in domestic investment in outbreak-affected economies excluding the PRC declines by 2 percentage points.	
	Longer containment, higher demand shocks (Worst case): Growth in domestic investment in outbreak-affected economies declines by 6.25 percentage points.	
Tourism	**Shorter containment, smaller demand shocks (Base case):**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. 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.	
	Longer containment, higher demand shocks (Worst case): 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; 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.	
Database	ADB Multi-Region Input-Output	The latest GTAP 10 database was used and calibrated using 2018 data from the IMF and the ADB Multi-Region Input-Output.
Employment:	N.A	GTAP database
Health:	N.A	Used SARS data on health expenditures
Fiscal Stimulus:	N.A	Based on recent government pronouncements; IMF policy Tracker
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. 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	

	World Tourism Organization. 2019. Guidelines for the Success in the Chinese Outbound Tourism Market. Madrid: UNWTO. https://doi.org/10.18111/9789284421138

PRC= People's Republic of China, ROK = Republic of Korea

Note: Outbreak-affected economies are Australia, Brazil, Canada, Turkey, the European Union (notably France, Germany, Spain, and Italy) , Iran, Japan, Norway, the People's Republic of China, the Republic of Korea, Switzerland, the United Kingdom, and the United States.