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## The hit of the novel coronavirus outbreak to China's economy

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## ABSTRACT

Broke out at the end of 2019, the novel coronavirus pneumonia (COVID-19) has been spreading throughout the world, leading to more than 87 million confirmed infections and 1.88 million fatalities. Motivated by this, we evaluate the economic impacts of COVID-19 outbreak on both national and industrial levels by employing quarterly computable general equilibrium (CGE) model. Our results reveal that the epidemic may lower China's economic growth in 2020 by 3.5%, versus 4.4% for final consumption (relative to baseline). The service industry suffers the most from the outbreak, and the Accommodation-Food-Beverage service, Wholesale-Retail Trade, and Transport-Storage-Post are identified as the most vulnerable sectors, with the negative impact on output reaching as high as 14.6%. When moving to 2021, the hit to economy shrinks to 2% (1.2–2.7%), with industry estimated to be the most affected sector instead. This study indicates that implementing effective measures for preventing and controlling the epidemic and policies for post-disease economic recovery play critical role in curbing the potential economic damage.

## 1. Introduction

A novel coronavirus pneumonia known as COVID-19 broke out in Wuhan, China, in December 2019, and it has widely spread around the globe. As of April 8, 2020, more than 81,000 people have been infected and over 3300 people have been killed by the virus in China (slowly increased to 97,218 and 4795, respectively by Jan, 2021). Among all, the Hubei province has accounted for 84% and 96% of overall Chinese infections and death tolls, respectively; Wuhan, which is the epicenter of the outbreak in Hubei, has contributed to 74% of the province's cumulative confirmed cases and 80% of fatalities (Fig. 1). On January 30, the World Health Organization (WHO) declared the outbreak a public health emergency of international concern (PHEIC), and it has been upgraded as a global pandemic on March 11. A number of countries, such as the United States and Australia, have since implemented travel control measures such as suspending flights and restricting Chinese entry within a specific period of time, which marks an escalation of the impact of the outbreak. Meanwhile, the number of infections and deaths outside of China has increased rapidly from 504 cases and 2 cases on February 14 to more than 87 million cases and 1.88 million cases respectively, on January 7, 2021 (Fig. 1), implying that the coronavirus has entered a dangerous new phase (Callaway, 2020; JHU, 2020). Although confirmed cases of the virus have been

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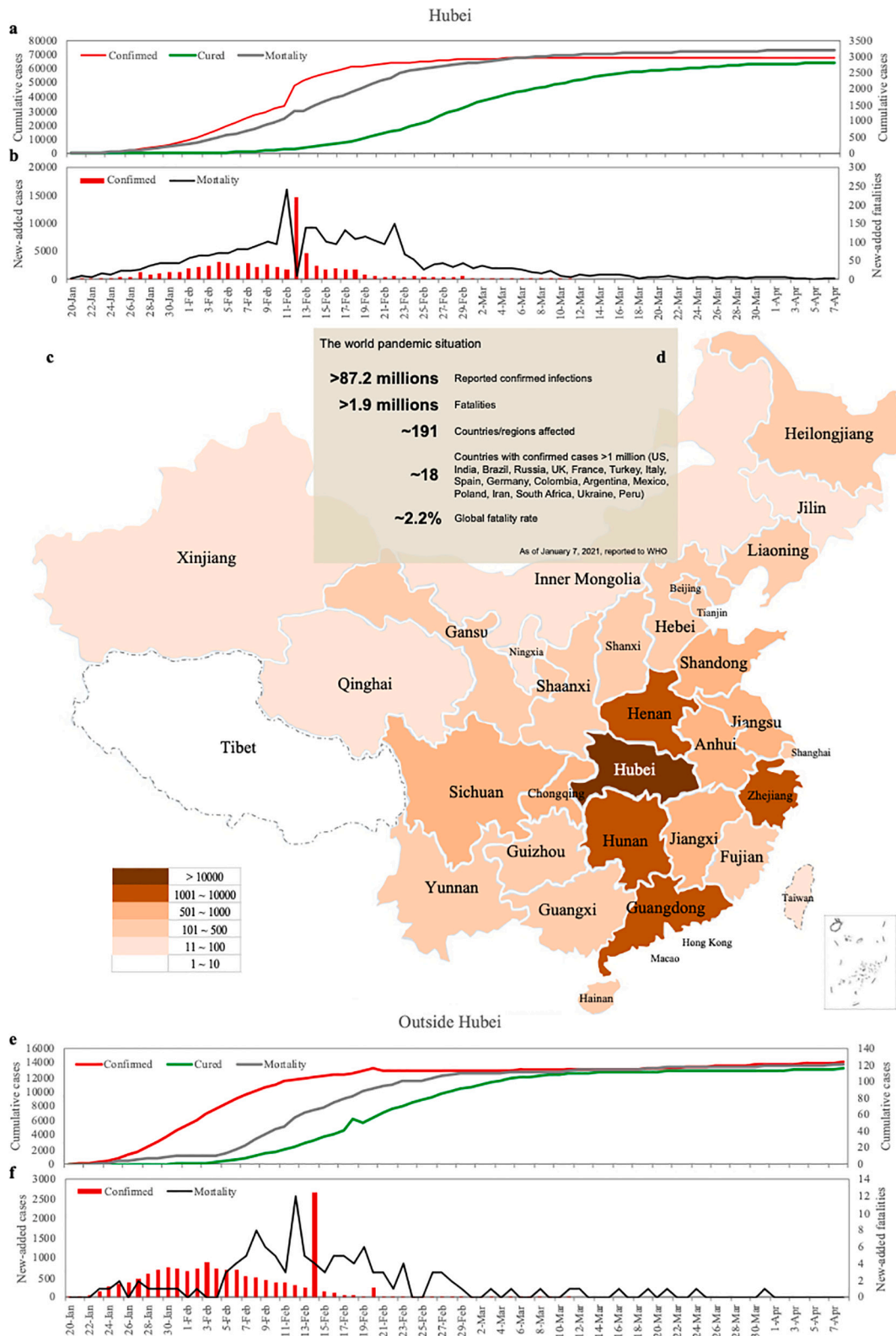
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**Fig. 1.** Distributions of confirmed cases of COVID-19 outbreak. a. Trends of cumulative confirmed, cured cases and mortality in Hubei province; b. Trends of new-added confirmed cases and mortality; c. Cross-provincial distribution of cumulative confirmed cases in China; d. Epidemic situation around the world, by January 7, 2021; e. Trends of cumulative confirmed, cured cases and mortality outside Hubei province in China; f. New-added confirmed cases and mortality outside Hubei province. China's statistics are up to midnight April 8, 2020 (Beijing time), at which time the lockdown of Wuhan city is cancelled, indicating a closed loop of China's public policy. Data is available mainly from the National Health Commission of China (NHC, 2020) and the CSSE at Johns Hopkins University (JHU).

reported in several Southeast Asian countries, the numbers may be much lower than expected; and there exist further worsening and increasing risks for the epidemic-vulnerable Africa countries, such as Nigeria, since the unreported and undetected cases might be rapidly overwhelmed by some local epidemics (Mallapaty, 2020). If this is the case, the global impact of the outbreak could be largely underestimated (Ataguba, 2020).

At the present, the risk of viral infection is still high, and the possibility of cases imported from abroad is also increasing in China. Further, the great uncertainties about the transmission mechanism of the virus, reliable treatment scheme as well as the development of vaccines has made it difficult to accurately predict when the outbreak will be over (Kupferschmidt & Cohen, 2020). As a result, it is particularly challenging to evaluate the economic risks and impacts of the epidemic (McKee & Stuckler, 2020). However, the post-disaster economic recovery not only has a significant impact on China's sustainable economic development, but also on the global economy (Di Marco, Baker, Daszak, et al., 2020).

In this circumstance, we initiate this study and contribute to the extant literature at least in two aspects. First, we examined the possible macro-economic shock of the COVID-19 outbreak to China, given the relative stable epidemic situation, by employing quarterly macroeconomic forecast model and computable general equilibrium model; we also explored the propagation of China's economic shock to the world and typical economies. It is common sense that the coronavirus epidemic damages the economy, especially for the African countries, in which the pandemic should be viewed as a 'war' to be won to cope with the increasing economic spending (Ataguba, 2020). Given the epidemic has spread from local outbreak to widespread contagion phase, the economic shock of COVID-19 to China may expand to  $-3.6\%$  relative to the no outbreak case; and if the world's situation increasingly worsens, China will keep suffering from the pandemic in 2021, with a negative economic impact up to  $-2.7\%$ . Moreover, China's GDP in the first quarter may encounter a  $-11\%$  cut (relative to the baseline forecast), and it rebounds significantly in the subsequent quarters, despite some delay resulting from the slumping activities in the rest of world (May, 2020). Second, we further estimated the potential impact of the COVID-19 outbreak on final demand and output across various sectors, and as far as we know, this should be the first paper to systematically evaluate the economic influence of the outbreak on multi-industrial scale, although there are few works discussed the possible impacts on supply chains and tourism (Ivanov, 2020; Yang, Zhang, & Chen, 2020). Actually, the development of economic models and influence analysis at the industrial level can generate more realistic estimates, even if the extent of economic losses of the pandemic is still unknown (Yu & Aviso, 2020). Industrial-level analysis could also help us to get a clear picture of the damage mechanism and the possible preventative policy responses, which in turn benefits the examination of the shape of economic shock and the understanding of potential economic damage associated with the novel coronavirus (Carlsson-Szlezak & Swartz, 2020). Furthermore, we show the effective measures that China has adopted and potential policy gaps to fill in the future, which could be valuable lessons for the other countries to contain the coming waves of epidemic and hedge against the associated economic risk.

The rest of this paper is organized as follows. Some pre-analysis based on the experience from SARS is presented in Section 2 and Section 3 is devoted to introducing models and methodologies for assessing economic damage in China due to the outbreak of COVID-19. The detailed analysis results are reported in Section 4. Finally, some further discussions and concluding remarks conclude Section 5.

## 2. Pre-analysis based on experience from SARS

Looking back at the outbreak of SARS in 2003, the outbreak did have a significant negative impact on the economy (Wilder-Smith et al., 2020). Take the tourism industry, which was affected the most, as an example, the tourism demand reduced by 175 to 1742 persons for each additional infection; as for Asia, the epicenter of the outbreak, the tourism demand was averagely reduced by about 403 arrivals for an extra person probably infected by SARS (Chen, Tseng, Ju, & Huang, 2008). Overall, the epidemic had longer and larger negative effect on the tertiary industry; take May of 2003 as an example, the total retail sales of consumer goods fell by 5% year-on-year, and the impact on the annual GDP growth may have reached 0.5–1% (Hai, Zhao, Wang, & Hou, 2004). Compared with SARS, the negative economic shock of the COVID-19 outbreak could be much severer. First, the virus itself is even more infectious, even in its long incubation period, and may have a mortality rate as high as 3–15% (Huang, Wang, Li, et al., 2020). Second, the outbreak has developed rapidly due to the impact of large-scale population movement in the Spring Festival, and the number of infected cases for the COVID-19 outbreak has reached more than ten times of that for SARS. Third, the COVID-19 has been spreading throughout the world over one year, and the cumulative confirmed cases and fatalities are not at the same magnitude with SARS, as for which the contagious situation was contained within half a year before the summer ended. Fourth, the negative effects of SARS were mainly on the demand side, and the outbreak did not deliver a supply-side shock (Siu & Wong, 2004), which determined the short-term of the economic impacts. Lastly, China only accounted for 4.2% of the world GDP at the time of SARS, while now, this number has increased to over 16%, and China's contribution to the world's economic growth has reached 39%. This intensive economic relations between China and the globe may enlarge the hit of pandemic to both China's and world's economy, specifically, the outbreak is estimated to reduce the global GDP by up to 4.4% (World Bank, 2020).

Despite the short-term risk of economic losses, the long-term economic impact of the current coronavirus outbreak could be relatively limited (Duan, Wang, & Yang, 2020). Since the SARS outbreak in 2003, China has made considerable progress in information transparency, emergency response time and international cooperation (Goldizen, 2016), which are all conducive to controlling the development of the outbreak and limiting potential negative economic damage. In fact, the cumulative infections in China has been stabilized since March (Fig. 1), given the world's worsening pandemic situation, which also contributes to projecting the limited long-term economic damage (Normile, 2020). Actually, according to the latest statistics, China's GDP have achieved a 4.9% of year-on-year growth in the third quarter, and the rebound effect will help the Chinese economy to expand up to 7.9% in 2021 (Behraves and Johnson, 2020; World Bank, 2020).

### 3. Models and methodologies

Taking into account the duration of the outbreak as well as policy response strength, we evaluate the impact of the COVID-19 outbreak on China's macroeconomy and its ripple effect on the global economy using China's quarterly macroeconomic model in Section 3.1, the quarterly computable general equilibrium model in Section 3.2, and the method for scenario design in Section 3.3, as well as the global economic impact transmission in Section 4.4.

#### 3.1. China's quarterly macroeconomic forecast model

In order to estimate the economic losses caused by the outbreak, we need to predict the quarterly economic development of China in 2020 under the reference scenario in which no outbreak occurs (Fig. 2a). This is achieved through the China Quarterly Macroeconomic Forecast Model (CqMEM), which is developed by the Center for Forecasting, Science Chinese Academy of Sciences (see Appendix Fig. A1 for the skeleton of the model). It is comprised of four modules, namely the demand module, the supply module, the fiscal module and the financial module. The model consists of 111 equations, of which 38 are estimating equations and 83 are defining equations. Our validation practices on the model indicate a wonderful performance in terms of the prediction accuracy. The out-of-sample prediction accuracy for the three major industries is -0.97%, 1.03% and -0.2%, respectively; and that for the four-quarter GDP in 2019 reaches 0.69%, 0.02%, 0.28% and 0.03%, respectively. According to the historical data from the first quarter of 2000 to the fourth quarter of 2019, we estimated and calibrated the critical parameters of the CqMEM and obtained the economic

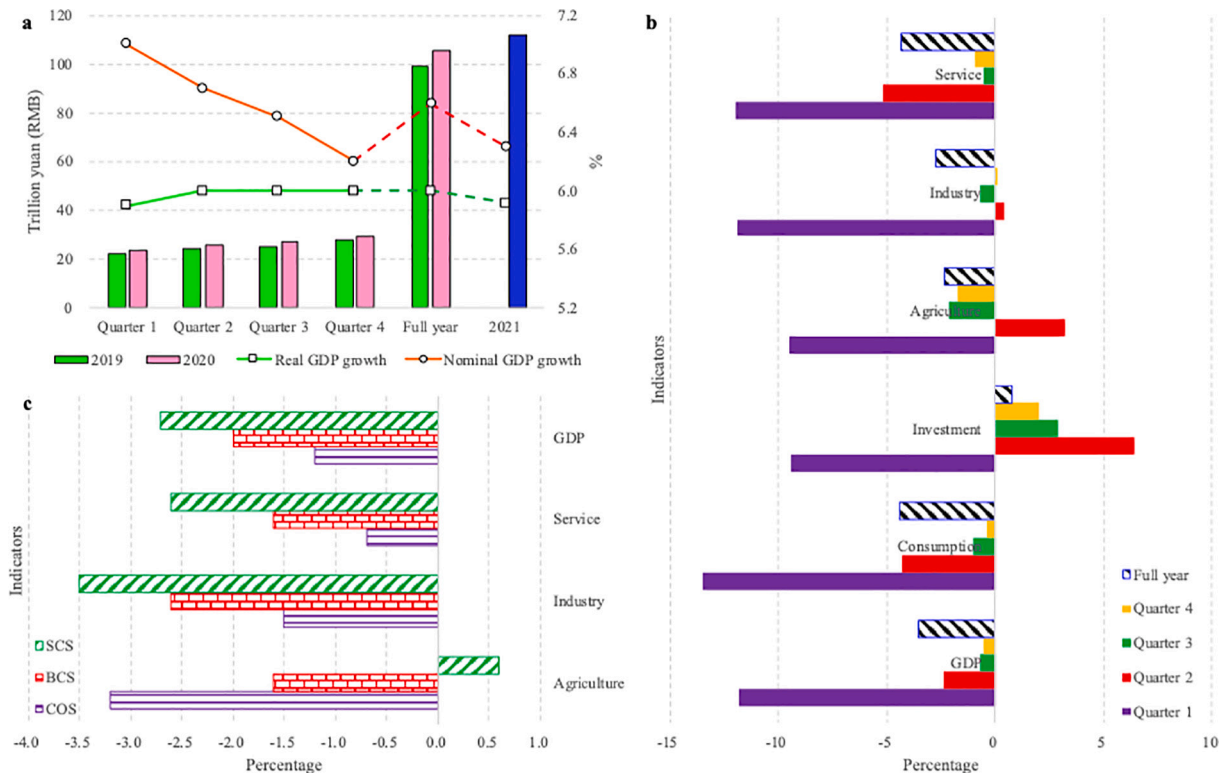


Fig. 2. Projected influence of COVID-19 on China's economy. a. Projected GDP in 2019, 2020 and 2021 as well as the projected real and nominal GDP growth rates; b. Economic impacts of COVID-19 outbreak on China's main industries and the whole country in terms of typical indicators in 2020, and the impacts are shown as the percentage changes to the basic projections in the absence of outbreak shocks; c. Influence of the COVID-19 outbreak on China's economy and the agriculture, industry and service sectors in 2021.

projections for 2020 (Fig. 2a).

### 3.2. China quarterly CGE model (CqCGEM)

Since the novel coronavirus outbreak is a typical short-term event, the analysis of its economic influence is therefore highly contingent on the development of quarterly models and methodologies (Baldwin and di Mauro, 2020). Our impact analysis conducted in this paper is mainly achieved through the China Quarterly Computable General Equilibrium model (CqCGEM), which is developed by the Center for Forecasting, Science Chinese Academy of Sciences (Bao, Tang, Zhang, & Wang, 2013) based on the general equilibrium theory. The model is comprised of five modules, namely production, foreign trade, investment, income and expenditure, as well as equilibrium and closures (See Appendix Fig. A2). The model consists of two elements of production (labor and capital), four kinds of economic agents (household, enterprises, government and rest of the world), as well as 153 major sectors. In order to better simulate the short-term impact of the outbreak on the current Chinese economy, the model uses the data from the input-output table and flows-of-funds table (non-financial transactions) in 2018 as the benchmark to calibrate important parameters associated with production, input, factor distribution, demand distribution and transfer payment. The values for the economic indicators in 2020 predicted using the CqMFM are used as initial values to calibrate the CqCGEM so that the simulated benchmark value of the model is consistent with the prediction under the no-outbreak scenario. By designing specific scenarios for the spreading of the epidemic, we solve for the economic equilibrium before and after the epidemic shock, then the economic impact could be figured out by comparing the typical indicators under the target scenarios with those under the reference case. The main modules of the model are as follows:

#### 3.2.1. Production module

In part A of the first layer, the value-added ( $VA_i$ ) of industry  $i$  is composed of capital ( $CAP_i$ ) and labor ( $LAB_i$ ) based on a constant elasticity of substitution (CES) function. The optimal production strategies are derived from the minimization of the production costs as follows:

$$\begin{aligned} \min &: R_i \cdot CAP_i + W_i \cdot LAB_i \\ \text{s.t. } VA_i &= A_{kl_i} (\alpha_{cap_i} CAP_i^{\rho_{va_i}} + (1 - \alpha_{cap_i}) LAB_i^{\rho_{va_i}})^{1/\rho_{va_i}} \end{aligned}$$

where  $A_{kl_i}$  denotes the production technology parameter (The impact on production technology under a pessimistic scenario is achieved by adjusting this parameter),  $\alpha_{cap_i}$  and  $\rho_{va_i}$  denote share and substitution parameter, respectively.

In part B of the first layer, the total intermediate inputs ( $TINT_j$ ) is composed of individual immediate input ( $INT_{i,j}$ ) using a Leontief function described as below:

$$INT_{i,j} = \alpha_{int,i,j} \cdot TINT_j$$

In the second layer, the output ( $X_i$ ) is composed of value-added ( $VA_i$ ) and the total intermediate inputs ( $TINT_i$ ) based on a CES function. The optimal production strategies are derived from the minimization of the production costs as follows:

$$\begin{aligned} \min &: PVA_i \cdot VA_i + PTINT_i \cdot TINT_i \\ \text{s.t. } X_i &= A_{x_i} (\alpha_{va_i} VA_i^{\rho_{x_i}} + (1 - \alpha_{va_i}) TINT_i^{\rho_{x_i}})^{1/\rho_{x_i}} \end{aligned}$$

According to the zero-profit condition, we could obtain the following in the production module, i.e.,

$$R_i \cdot CAP_i + W_i \cdot LAB_i = PVA_i \cdot VA_i$$

$$PQ_{i,j} = \alpha_{int,i,j} \cdot PTINT_j$$

$$PVA_i \cdot VA_i + PTINT_i \cdot TINT_i = PP_i \cdot X_i$$

$$PP_i \cdot (1 + indtaxrate_i) = PX_i$$

where  $R_i$  denotes the return on capital.  $W_i$  denotes the wage.  $PVA_i$  is the price of value-added.  $PTINT_i$  is the price of total intermediate inputs.  $PP_i$  represents the price of production,  $indtaxrate_i$  represents the tax rate of production tax and  $PX_i$  is the price of output.

#### 3.2.2. International trade module

An Armington assumption is used in the model such that the domestic goods and foreign goods are treated as imperfect substitutes for each other (Xie et al., 2014; Antoszewski, 2019). The total domestic demand ( $Q_i$ ) of industry  $i$  is composed of domestic sales ( $D_i$ ) and imports ( $M_i$ ) using a CES function. The optimal importing strategy is derived by minimizing the costs  $D_i \cdot PD_i + M_i \cdot PM_i$  as follows:

$$\begin{aligned} \min &: D_i \cdot PD_i + M_i \cdot PM_i \\ \text{s.t. } Q_i &= A_{q_i} (\alpha_{dm_i} D_i^{\rho_{m_i}} + (1 - \alpha_{dm_i}) M_i^{\rho_{m_i}})^{1/\rho_{m_i}} \end{aligned}$$

Similarly, the total domestic output ( $X_i$ ) is composed of the domestic sales ( $D_i$ ) and exports ( $E_i$ ) using a constant elasticity of transformation (CET) function. The optimal exporting strategy is derived by maximizing the sales  $D_i \cdot PD_i + E_i \cdot PE_i$  as below:

$$\begin{aligned} \max &: D_i \cdot PD_i + E_i \cdot PE_i \\ \text{s.t. } X_i &= A_{-X_i} (\alpha_{-de_i} D_i^{\rho-e_i} + (1 - \alpha_{-de_i}) E_i^{\rho-e_i})^{1/\rho-e_i} \end{aligned}$$

### 3.2.3. Income expenditure and investment modules

Households gain their income from labor income, returns of capital and transfers by the government, enterprises and foreign countries. After paying for income tax, they gain disposable income (*HDIS*) which can be consumed (*HCD*) or saved (*HSAV*). Assuming the saving tendency is  $mps_h$  (Different levels of household consumption desire in the model can be achieved by adjusting this parameter), then we have:

$$HSAV = mps_h \cdot HDIS$$

$$HCD = (1 - mps_h) \cdot HDIS$$

Enterprises gain their income from returns of capital and government transfers. After paying income tax to the government and transferring some of the income to households, enterprises make their savings. Government gains income from various taxes, including indirect tax from production sectors, tariffs against imports and income taxes from enterprises and households. It expends this income through transfers and consumption or leaves it as savings. Rests of the world gain their income from capital investments in China and exports to China. Meanwhile, they have to pay for their imports from China. The net earnings after paying for transfers to China's households and government are their savings.

As for the investment module, we assume the total investment of the agents consists of fixed capital formation and inventory and is driven by savings. Further, we also assume investment is characterized by a linear system.

### 3.2.4. Equilibrium and closure module

In the commodity market, the total demand is equal to the total supply. In the factor market, the total supply of labor force is equal to the total demand of capital. Given that the expected short-term impact of the outbreak, the total capital stock within the epidemic period is unlikely to change. Assuming that the total capital of the economic system remains unchanged, the rate of return is determined endogenously, then the impact of the outbreak on the supply side is mainly realized by its impact on labor force where the wage is endogenously determined as well. We also assume that the foreign exchange rate remains unchanged, and the foreign savings is determined endogenously.

## 3.3. Scenario design

Considering that the infections in China has been continuously decreasing since late February (JHU, 2020; NHC, 2020), implying that the outbreak of the novel coronavirus has been effectively contained, we therefore introduced the policy shocks mainly in the first quarter and the economic activities for many other sectors may rebound from the second quarter. The impact of the outbreak on the economic system is mainly reflected in two aspects: in terms of supply, the prevention and control measures imposed by the government has limited the population and logistics flow, which shocks the production in many vulnerable sectors; in terms of demand, the outbreaks has significantly affected the consumption in some sectors, and may also trigger changes in people's consumption preferences. Based on this, we adjust the settings of our CqCGEM model to the followings. First, on the supply side, the labor market is negatively impacted, with the labor input in major service sectors and industry sectors decreased by 10%. In particular, the reduction in extremely vulnerable sectors, such as transportation, accommodation and food services are set to be 20%, and the degree of shock is halved in the second quarter and returns to pre-shock levels in the third and fourth quarters. Further, we allow a 5% rebound in labor force for the vulnerable sectors. Second, on the demand side, consumer demands in some sectors (household consumption and government consumption) are affected, and the policy shocks on each quarter is illustrated in Table. A1 in Appendix). Third, under the base-case scenario, we assume the household consumption desire in the first quarter is reduced by 90% due to the outbreak, and gradually recovers in the next two quarters.

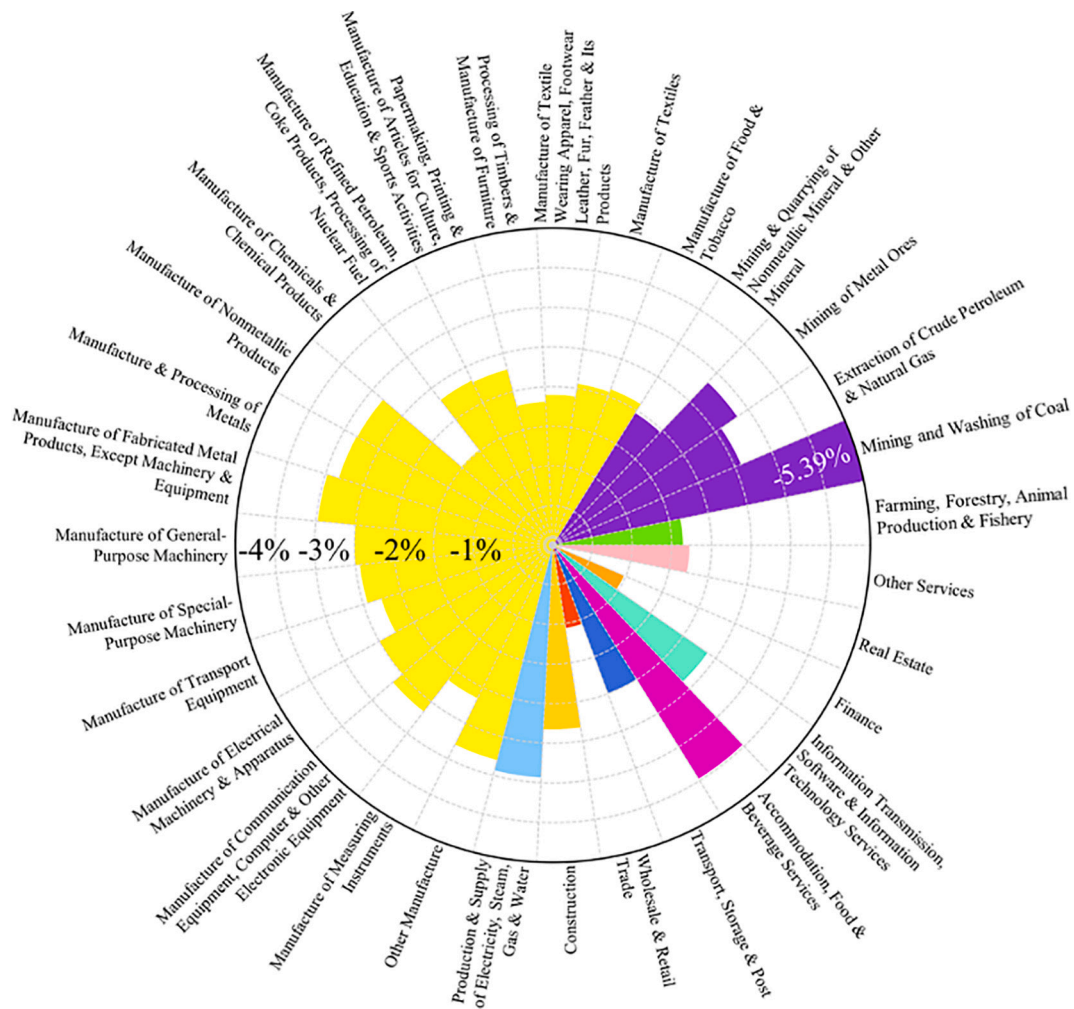
In addition, we also examined the economic impact of COVID-19 in 2021 by designing three typical scenarios, i.e., the conservative scenario (COS), the base-case scenario (BCS) and severely contagious scenario (SCS). As the spreading of COVID-19 has long been well contained in China, and it is of little probability to have a second wave of increased cases, the negative shocks to economy should therefore mainly come from the serious epidemic situation outside China. In the model, we use different price adjustments of world trade of goods to describe such external shocks for different scenarios. Specifically, we assume the world export price in 2021 decreases by -1%, -2% and -0.5% respectively under the BCS, COS and SCS cases, versus an increase of 0.5% for the world import price across all three scenarios.

## 4. Result analysis

### 4.1. Main results

Using the models and methodologies introduced in the previous section, based on the historical data from the first quarter of 2000 to the fourth quarter of 2019, we estimate and calibrate the parameters of the CqMFM and obtained the economic projections for 2020 and 2021; see Fig. 2a, which will serve as reference scenario values for estimating the impact of the outbreak. The results indicate that in the absence of the COVID-19 outbreak, China's GDP in 2020 will grow by 105.6 trillion Yuan (RMB, current price) from the previous





**Fig. 4.** Cross-sector impacts of COVID-19 on demand. As in Fig. 3, the 148 sectors in our quarterly CGE model have been merged into 31 typical sectors for convenience of display. The colored bands show the adverse impacts of the outbreak on real demand, while the bands with lined borders depict the relative positive impacts, full color-covered band means the impact is over 4% with the specific number marked.



year, versus 111.8 trillion Yuan in 2021. The nominal GDP growth rate in 2020 is expected to be 6.6% for the full year with the quarterly GDP growth rate falling from 7% in the first quarter to 6.2% in the fourth quarter. When moving to the real growth, China's GDP in 2020 and 2021 will grow by 6.0% and 5.9%, respectively.

In general, the outbreak will hit the economy from both supply and demand side. As for the former, the prevention and control actions of the disease largely hinder the flows of population and goods and limits the supply of labor, which shocks the production of many sensitive industries; as for the latter, the epidemic reduces the brisk demand and may change people's consumption behavior and preference. Besides, the outbreak also shocks some industries by sharply increase their demand, for example, the alcohol products, pharmaceutical products, and health care. On this basis, we introduced sectoral shocks in the CqCGEM for the four quarters of 2020 from both the supply side and the demand side to different degrees; by rebalancing the supply and demand of the whole economic system to reach the general equilibrium status, we obtain the optimum solution and evaluate the economic impacts accordingly. Given the stable epidemic situation in 2020, we believe the shocks in 2021 mainly come from outside China, and we therefore only consider the price change in the world trade goods when estimating the impact of COVID-19.

Our estimates suggest that the outbreak will have the greatest impact on China's economy in the first quarter at  $-11.8\%$ , which means the real GDP growth rate for this quarter will be below  $-6\%$ , and this influence will quickly fall back to  $-2.4\%$  in the second quarter (Fig. 2b) and fade in the second half of the year. The impact of the COVID-19 outbreak on the annual economic growth is expected to be  $-3.5\%$  relative to the baseline, which is more optimistic than the estimate given by the World Bank (World Bank, 2020), but much higher than the corresponding influence of the SARS outbreak (i.e.,  $-0.5\%$ ). Given the continuing epidemic waves of COVID-19 and the serious economic recession of the world, the negative shock of COVID-19 pandemic to China could still be  $2\%$  in 2021 (Fig. 2c). The disease will also have a greater impact on China's consumption and investment, particularly in the first quarter, the estimated decreases could be  $13.5\%$  and  $9.4\%$ , respectively. Considering the rebound effect, the hit to consumption shrinks to  $4.4\%$  for the full year, and investment gains a slightly positive growth by  $0.8\%$  (Fig. 2b), which means the economy could achieve year-on-year positive growth from the third quarter; and this could be largely attributed to the incentive effect of the outbreak to some industries. For example, the outbreak of COVID-19 has increased the need for automation in high-risk jobs, which in turn promotes the development of the AI industry such as AI-assisted diagnosis and treatment, intelligent disinfection, contactless remote treatment and unmanned logistics in the manufacturing and service industry. Most importantly, large-scale investment has been launched after the epidemic to promote economic recovery, which should be the origin of incentive effect.

From the industrial level, the service sector suffers the most from the epidemic in 2020, followed by the industry, and the full-year impacts for the two sectors are estimated to be  $-4.3\%$  and  $-2.7\%$ , respectively. As for the tertiary sector, a reduction in household activities has caused a sharp drop in demand; while for the industry, the negative influence comes from the double effects of production stagnation resulting from the insufficient labor supply and decline in product demand. The situation changes when moving to 2021, with the industry suffering the most from the outbreak ( $-2.6\%$ ), followed by the service sector ( $-1.6\%$ ); this is because the shocks of

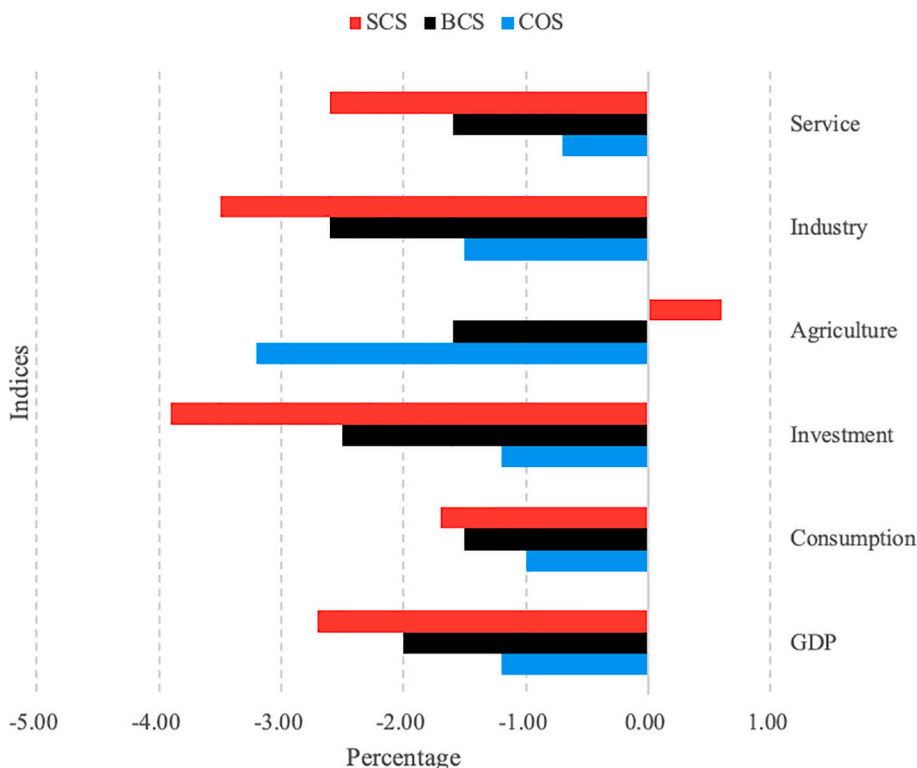


Fig. 5. The economic impact of COVID-19 on China and across typical sectors in 2021.

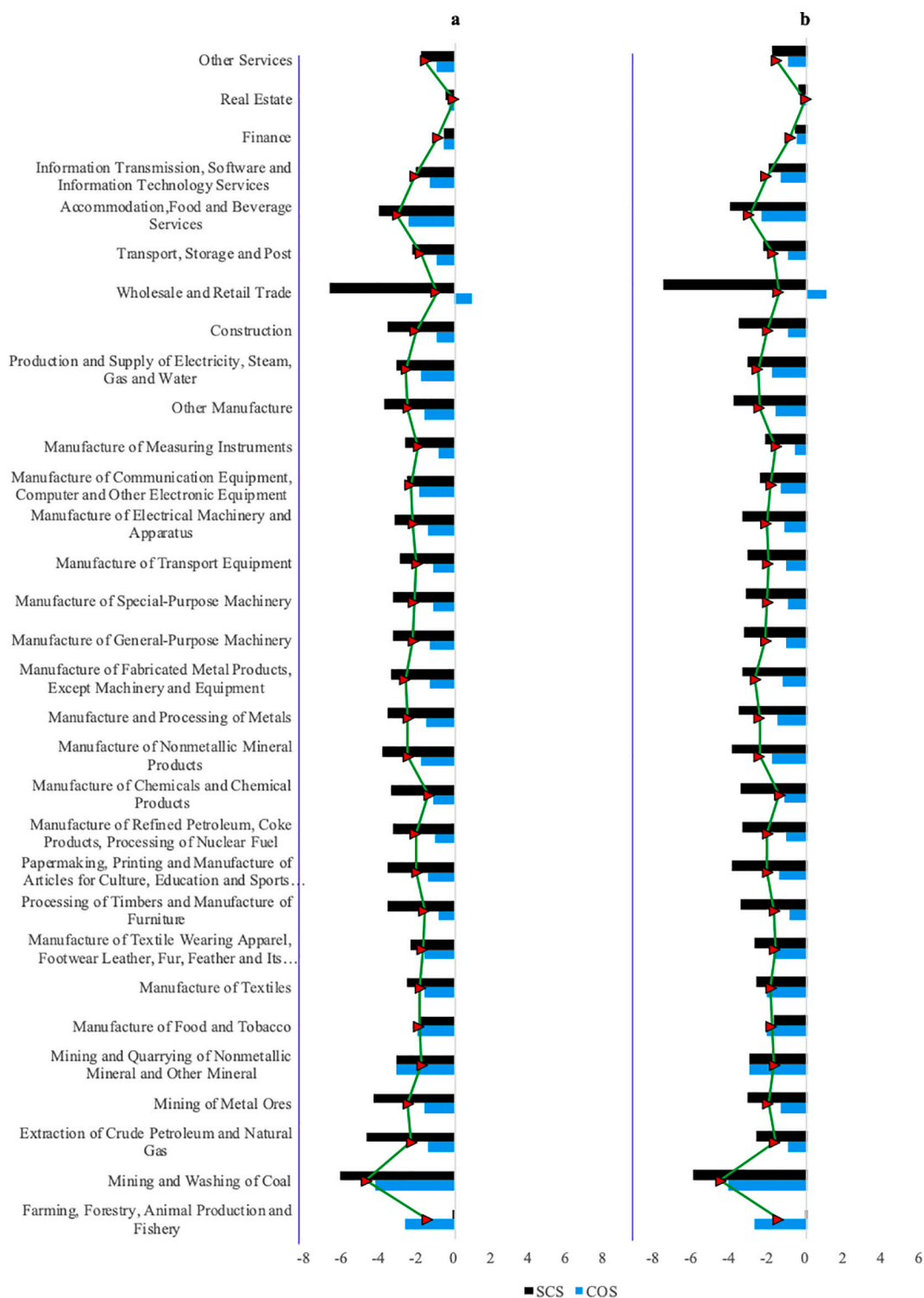


Fig. 6. Sensitivity of the cross-sector impact of COVID-19 outbreak to scenarios in 2021. a. Effects of the outbreak on output across sectors; b. Effects of the outbreak on gross demand across sectors; The red triangles give our main results, while the colored bars show the relative output and demand under the conservative scenario (COS) and the severe contagious scenario (BCS). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

COVID-19 in 2021 mainly come from the rest of world, while industry is more vulnerable to the world trade of goods (Fig. 2c). Overall, agriculture is relatively less affected by the disease. For one thing, the agricultural production management is relatively unconcentrated in the quarter when the COVID-19 virus broke out, and this period is hardly overlapped with the planting time of autumn grains and cash crops; for another, the low population density and infection rate in rural areas also serve to limit the impact of the outbreak during the spring farming period.

4.2. Cross-sector impact analysis

Overall, the outbreak has a negative impact on majority of sectors with the exception of few such as Health Care & Social Work Activities (Fig. 3). Among them, Accommodation, Food and Beverage Services, Wholesale & Retail Trade, Transportation & Storage and are the most affected sectors, with the corresponding negative impacts of the outbreak on output to be 14.6%, 12.4% and 10.3%, respectively (Fig. 3). In contrast, most sectors that benefit from the outbreak are related to the control of infectious diseases, which include directly related sectors such as Health Care & Social Work Activities, as well as indirectly driven sectors such as Information Transmission and Services to Households.

The outbreak of COVID-19 coincided with the Chinese Spring Festival, which is usually the peak period for consumer demand; while due to the disease, most restaurants and shops had to close down, and travel, tourism and entertainment activities shrunk sharply as well. This sharp decline of retail demand experienced during the epidemic could be explained by the decline of direct consumer demand and factors such as labor shortage and difficulty in supply chain procurement. For transportation sectors, many cities are closed down while the logistics system is nearly paralyzed due to the strict control measures imposed during the outbreak. As a result, demands for air and railway transportation are greatly reduced. According to the data from the Ministry of Transportation, the total number of passengers carried by air, railway and road in the first quarter of 2020 decreased by about 45% compared with the same period of 2019. Meanwhile, the demand for tourism transportation has also dramatically declined: during the Spring Festival of 2019, the total number of tourists received in China was 415 million with the tourism revenue reaching 513.9 billion Yuan (RMB); and this number dropped by more than 80% in the same period of 2020. This economic impact is determined largely by the desire of people to reduce their public interactions such as travel, leisure and tourism during the COVID-19 outbreak (Keogh-Brown & Smith, 2008).

Drawing from the experience of the SARS outbreak, we expect there to be a sharp rebound in household consumption after the epidemic; despite the loss of specific sunk consumption during the Spring Festival, the average consumption level of various industries is still expected to grow significantly for the full year 2020 and 2021. In particular, the outbreak has stimulated the development of online economy to a certain extent, including online education, online shopping and other spin-off sectors, which will contribute to offsetting and limiting the possible adverse effect of the outbreak in the long run. Indeed, as shown in Fig. 4, the average sectoral impacts associated with COVID-19 are dramatically reduced in 2021, and the sectors suffer the most from the disease also change significantly with respect to 2020. First, industrial sectors would be most affected instead of service sectors. As depicted in Fig. 4, except for the Accommodation, Food and Beverage service, all the other sectors that suffer severely from the disease in 2021 are industrial sectors, such as the Mining and Washing of Coal, Manufacture of Fabricated Metal Products (Excluding Machinery and Equipment), Mining of Metal Ores, and the Other Manufacture, with the estimated contraction to be 5.39%, 2.97%, 2.83% and 2.8% respectively. Second, given the stable domestic epidemic situation, the hit of outbreak from the rest of the world to China's economy will be largely mitigated, as compared to -14.6% in 2020, the largest adverse impact is -5.39% in 2021.

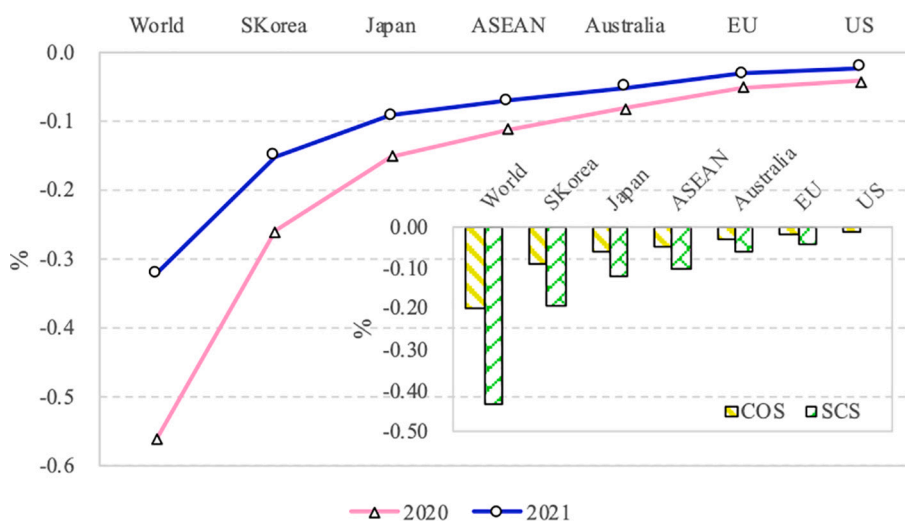


Fig. 7. The transmitted economic impact of COVID-19 on the world and main economies. The main chart gives the basic impact estimates of the outbreak in 2020 and in 2021 under the base-case scenario (BCS), and the embedded chart shows the relative estimates in 2021 under the other two scenarios.

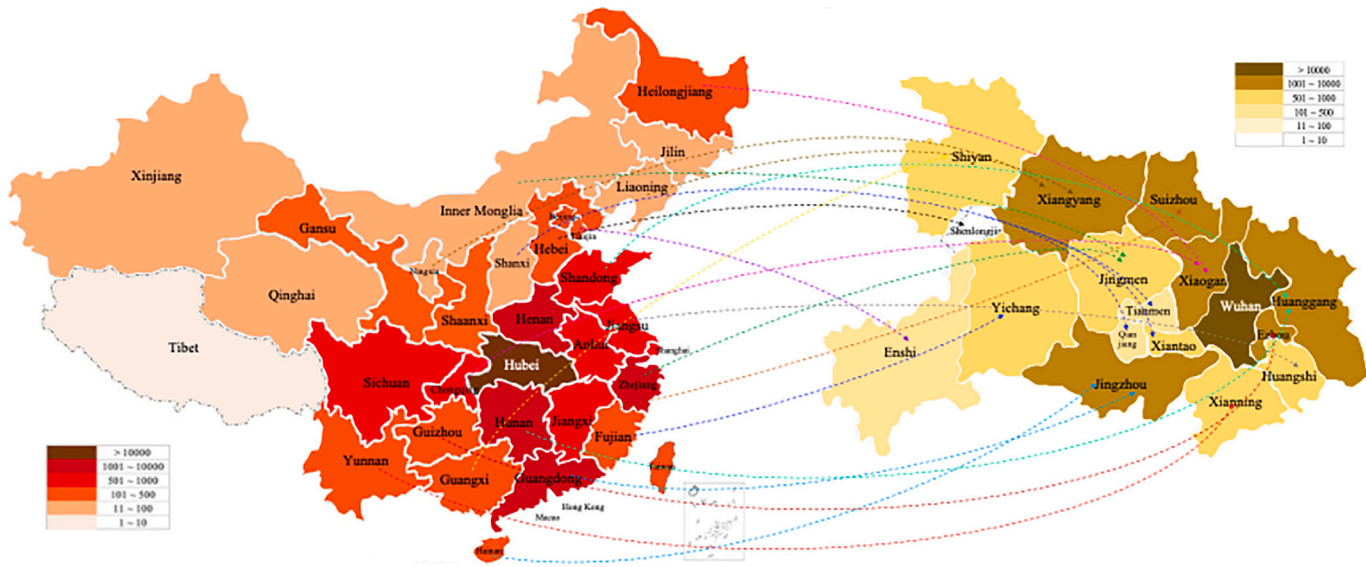


Fig. 8. China's many-to-one aid system to combating the novel virus outbreak.

### 4.3. Robustness checks

In order to verify the robustness of our results, we introduced conservative scenario (COS) and severely contagious scenario (SCS) for the estimates in 2021 in this extended analysis. As for the former, we assume that shock to the price of world trade of goods decreases by 50% compared to that under the base case, versus increases by 50% for the latter. The impact of the outbreak on the economy and the three major industries are shown in Fig. 5. For ease of comparison, we denote the main scenario as Base-case Scenario (BCS). As we can see in Fig. 5, the adverse shock of the outbreak to China in 2021 ranges from a low of 1.2% to a high of 2.7%. On one hand, given the well-contained situation, the hit of COVID-19 to China's economy in the coming years should be limited. On the other hand, if the outbreak situation stays worsening in other parts of the world and the risk of imported infections increases, China can lose up to 2.7% of its expected GDP. From the year-on-year perspective, China's economy could achieve a growth of up to 8.1% in 2021, which is consistent with the projections of the World Bank and IMF (World Bank, 2020). On the industrial level, the impacts of the outbreak on the industry and service sector are relatively robust; given a halved change in policy shock, the economic influence on these two sectors are also halved. However, the agricultural sector seems to be sensitive to the spreading situation of the outbreak (measured via different levels of price shock of trade goods), which may attribute to the relatively small share of its sectoral GDP in the whole economy.

Looking at the impact on output, the level of sensitivity to changes in policy shocks varies significantly from sector to sector. For example, sectors such as the Clothing and Textile industry, Finance, Transportation and Storage, Metal Mineral and Wood Processing, as well as the Real State are insensitive to changes in external prices (Fig. 6); on the contrary, the Chemical Production, Food and Tobacco, Whole Sale and Retail are more sensitive to the world's price shocks. Seen from the impacts, the Coal Product, Accommodation-Food-Beverage, Metal Product, Electricity, Gas and Water Supply Manufacture are suffering the most from the COVID-19 pandemic, with the estimated output losses range from 6.18%, 4.1%, 3.43% and 3.14% to 4.28%, 2.5%, 2.35% and 1.81%, respectively under SCS and COS cases. Looking at the influence on demand, the results from the sensitivity analysis for output still hold, but the magnitude in influence for majority of sectors are lower with respect to the demand. For example, the adverse impacts of COVID-19 on the Coal Product, Accommodation-Food-Beverage, Metal Product, Electricity, Gas and Water Supply Manufacture are 5.96%, 4%, 3.44% and 3.14%, respectively under the severely contagious scenario, versus 4.12%, 2.36%, 1.29% and 1.81, respectively under the conservative scenario (Fig. 6).

### 4.4. Impacts on global economy

Given the effective prevention and control measures in China, we believe it is of little probability to have a new wave of virus spreading in 2021. However, this is not the case for most of the other countries, and the epidemic even still do not peak till now in many countries. In this context, we expect that, in the coming future, China may suffer more from the epidemic in the rest of world, as compared to its impact on the other countries. Using the global input-output model, we estimated the impact of the outbreak on the global economy, particularly those regions that have close trade ties with China. Specifically, we adjusted the intermediate product import (export) and final product import (export) level based on the estimated changes of China's import and export caused by the outbreak. In this way, we were able to obtain the changes in the global economy as a result of changes in China's supply chains and demands. As shown in Fig. 7, the results indicate that the outbreak in China would negatively impact the global economy by 0.56% in 2020, and this impact will future shrink to 0.32% (0.43% in the severely contagious scenario).

On a regional level, South Korea and Japan, which have close business-ties with China, are the most negatively impacted countries, with the contractions to be 0.26% and 0.15% in 2020, versus 0.15%, and 0.09% in 2021, respectively. In addition, Australia, the European Union and the United States are also slightly affected. It is worth noting that the measured impact of the outbreak on the global economy only considers influence transmitted through the supply chain on a global level, which means that the economic losses caused by the spread of coronavirus within territories or countries such as the Eurozone, United States, Japan and Korea are not accounted for. If the latter is considered, the shock of the outbreak to the global and regional economy should be far more severe. According to the latest report by the World Bank, the pandemic will play an adverse role in the global economy by 4.3% in 2020, versus 4% in 2021 (World Bank, 2020), which is greatly in line with the estimate of IHS Markit (IHS Markit, 2020). The negative shocks to the EU are expected to weaken, with the estimated influences shrinks from -7.5% in 2020 to -3.5% in 2021, and this is also the case for the US (IHS Markit, 2020).

## 5. Conclusions and policy implications

### 5.1. Conclusions and discussions

In this paper, we estimate the hit of COVID-19 to China's economy by employing well-developed economic forecast and CGE models, and we find that the influences of the outbreak on economy is closely related to the intensity of people's public activities, including individual consumption activities as well as enterprise production and operation activities. We estimate that China encountered a contraction of 3.5% in 2020 (relative to the no COVID-19 case), and this negative impact could shrink to 2% in 2021, given the stable outbreak containment in mainland China and possible epidemic waves in the other countries. In 2020, the economic shocks of COVID-19 came from both demand side and supply side, and the textile industry, such as the Transportation, Accommodations-Food-Beverage service and Wholesale-Retail Trade sector suffer the most from the pandemic. When moving to 2021, the economic hit mainly results from the demand side, particularly demand from outside China, and the industry sector may suffer the most from the outbreak instead.

Despite this work, accurately assessing the economic impact associated with changes in these activities is relatively difficult. For one thing, it is largely dependent on the development of large-scale macroeconomic models (Xie et al., 2014); for another, there exist

uncertainties on the effect of response measures (Geoffard & Philipson, 1996; Keogh-Brown & Smith, 2008). For example, quarantine is a classic public health intervention, and a 50% or above of communal could effectively prevent the virus from spreading (Chinazzi, Davis, Ajelli, et al., 2020), despite the daunting economic costs (Pichler & Ziebarth, 2017). However, the specific economic response of quarantine is difficult to well capture in models (Fang, Wang, & Yang, 2020; Tian, Liu, Li, et al., 2020). The difficulties ahead should not overwhelm the great importance of estimating the economic impact of infectious diseases (Di Marco et al., 2020; Sands, Turabi, & VD., 2016). On one hand, the estimations can provide guidance in formulating policies to promote rapid post-disaster economic recovery and to mitigate potential risks; on the other hand, the analysis of economic impact of infectious diseases can help us strengthen the current public health capabilities and prepare for the future – after all, this will not be the last time that a highly transmittable disease emerges and spreads across the globe. As Gupta, Moyer, and Stern (2005) said after the SARS epidemic – “it is highly probable that the next pandemic will be more contagious and, perhaps, lethal than SARS”; indeed, the COVID-19 virus has proven it true, and it will remain true for the future.

## 5.2. The Chinese lessons and policy implications

Overall speaking, China’s efforts to control the COVID-19 outbreak have been effective, which supports our projection that the long-term economic damage of the outbreak is limited (Duan et al., 2020). First, in addition to the classic control measures such as travel restriction and quarantine, the Chinese government also constructed an innovative one-to-one or many-to-one aid system to combat the novel coronavirus (illustrated in Fig. 8), and this mode was broadly used in containing the latter small epidemic waves. Second, the SARS epidemic provided valuable experiences and lessons relevant in controlling outbreaks of emerging infectious diseases (Cao, Fang, & Xiao, 2019). The substantially improved infrastructures, surveillance systems, and capacity to response to health emergencies, as well as the establishment of a comprehensive nationwide internet-based disease reporting system all contributed to reduce the associated economic risk. Third, the government has implemented early policies to support economic and private sector recovery as the epidemic situation is gradually contained. On February 3, 2020, the People’s Bank of China injected 1.7 trillion Yuan worth of liquidity into the markets via reverse repo operations to ensure the liquidity remains reasonably ample, which also led to further decline of loan prime rate (LPR) and reduction of enterprise financing costs. At the same time, a special relending fund of 300 billion Yuan was established for financial institutions, supporting enterprises that supply goods and services for controlling the spreading of the novel coronavirus. Finally, across-the-board tax cuts that directly implement in local government and enterprises play a formidable role in China’s post-epidemic economic recovery; direct subsidies to small and medium-sized enterprises and epidemic-vulnerable sectors also perform to be more conducive than delayed payments on social security and rent credits. These fiscal measures greatly improve the policy effectiveness and practicality and avoid sinking limited budget and resources.

Despite the success, the policy system for the outbreak as well as the economic recovery work still have room for improvement. First, the government should find a better balance between early prevention and economic development, as well as between maintaining social stability and disclosing information, which seems to be a common challenge for the countries confronting the outbreak. Second, prevention and control actions for the epidemic should be implemented under the premise of normal economic development, especially in the latter phases of the disease. This means that we must take its cost into account, which will certainly help reduce the influence of the outbreak on the social and economic system. Third, the experiences we have gained from dealing with the past public health emergencies suggest that better targeted investments and more collaborative global effort is effective in containing the outbreak of COVID-19 (Hui, Azhar, Madani, Ntoumi, et al., 2020), and this should be sufficiently underscored in the government’s future work of public health services. On the economic policy side, different countries are much similar with respect to the fiscal and monetary instruments when confronting the pandemic, and the difference lies in the degrees of freedom and effectiveness in implementations (Cuzcano, 2020). The reality contradicted the advanced health system that the developed countries’ fiscal policy based, and policy effectiveness is greatly subordinated to the success of COVID-19 containment. It seems to be costly to strictly control the epidemic, but it is much more expensive to be devastated by the virus. In this regard, we believe China’s experience can be well generalized to the other countries which are struggling to hedging against the economic risk resulting from the pandemic waves (Normile, 2020).

## Declaration of competing interest

None.

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## Appendix A. The Appendix contains supplementary description of methods and scenarios design

### A.1. Model diagrams

The China Quarterly Macroeconomic Forecast Model (CqMFM) could be briefly described as the following diagram, and the China Quarterly CGE Model (CqCGEM) is portrayed as Fig. A2, given the five typical sub-modules and their dynamic linkages. Demand shocks of the basic scenario is shown in Table A1 in detail.

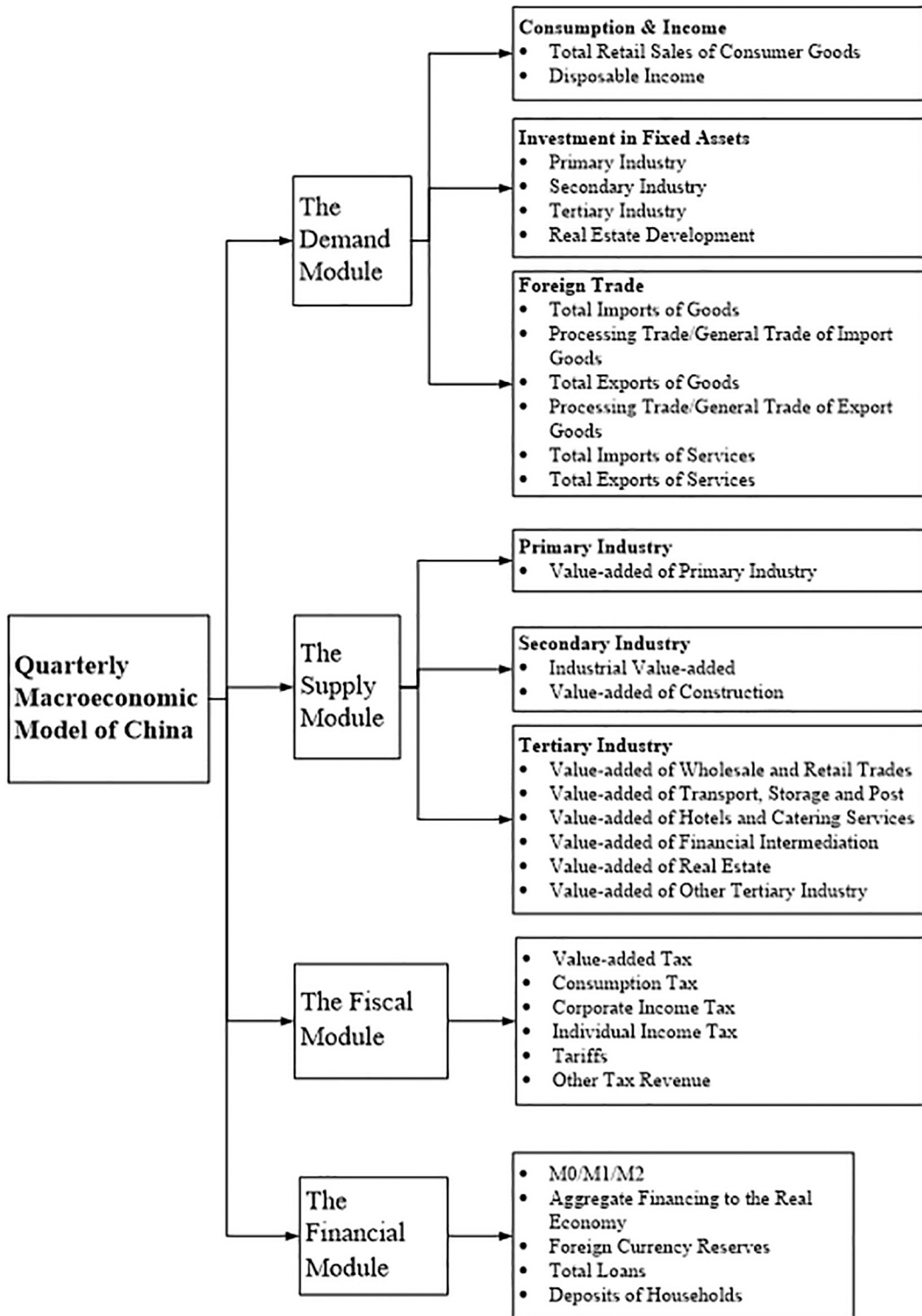


Fig. A1. The skeleton of China Quarterly Macroeconomic Forecast Model (CqMFM).

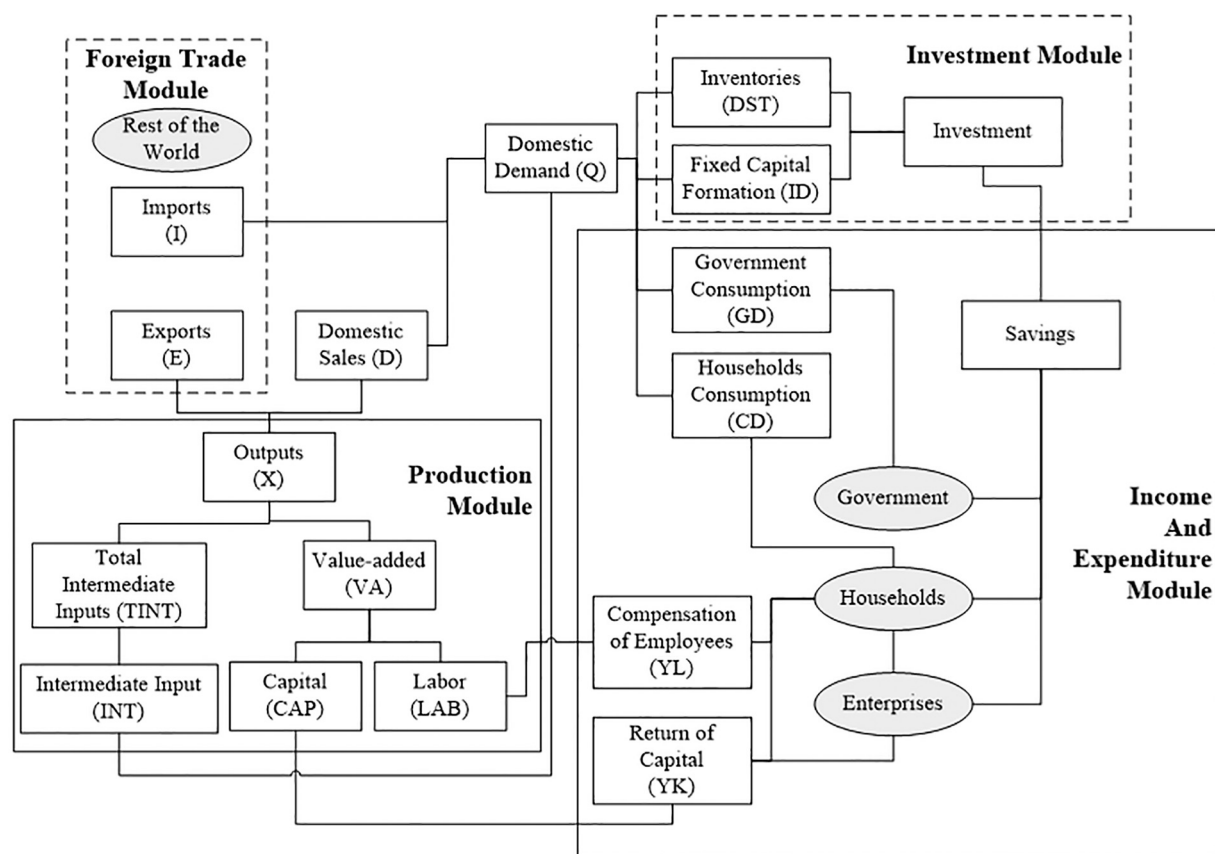


Fig. A2. The skeleton of China Quarterly CGE Model (CqCGEM).

Table A1

Policy shocks of COVID-19 outbreak to consumer demand across sectors (%).

	Q1	Q2	Q3	Q4
Manufacture of Alcohol and Alcoholic Beverages	12	6	3	1.5
Pharmaceutical products	-10	-2	2	2
Wholesale	-14	-2.8	2.8	2.8
Retail	-10	-5	0	0
Railway passenger transport	-8	-2	0	0
Freight Transport via Railway and Transport Ancillary Activities	-10	-5	0	0
Urban Public Transport and Highway Passenger Transport	-8	-2	0	0
Freight Transport and Transport Ancillary Activities	-8	-4	0	0
Passenger Transport by Sea	-8	-2	0	0
Freight Transport by Sea and Transport Ancillary Activities	-10	-5	0	0
Passenger Transport by Air	-5	-1.25	0	0
Freight Transport by Air and Transport Ancillary Activities	-18	-4.5	2.25	2.25
Accommodation	-18	-4.5	2.25	2.25
Food and Beverage Services	1	1	1	1
Research and Experimental Development	5	2.5	1.25	0.625
Services to Households	13	6.5	3.25	1.625
Health Care	-38	-20	5	5
Amusement and Recreation Activities	2	2	2	2
Social Security	1.5	1.5	1.5	1.5
Public Management and Social Organization	12	6	3	1.5



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