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The Hubei lockdown and its global impacts via supply chains

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Abstract

This article argues that the lockdown of Hubei province in China due to the Coronavirus outbreak provides a natural experiment to study the importance of China's role in global value chains. Since the lockdown started during the Lunar New Year, Hubei's migrant workers who went home could not return to workplaces in other provinces, resulting in a massive labor supply shock. I feed the supply shock through a Ricardian model with intermediate goods and sectoral linkages to study trade and welfare effects across several economies. While welfare in China is the most negatively affected, the shock also has sizeable negative implications for the US and the UK.

KEYWORDS

COVID-19, global supply chains, labor supply shock, productivity, welfare

JEL CLASSIFICATION

F10, F11, F14, F17, F41

1 | INTRODUCTION

Global supply chains have changed the pattern of trade by allowing international production fragmentation. While countries benefit from access to cheaper intermediate goods and a wider variety, they also face more risks. Both theoretical and empirical studies have shown the importance of global supply chains in propagating shocks across borders and amplifying aggregate fluctuations.[1] Nevertheless, being a developing country and the largest exporter in the world, China has not received much attention in this regard. This article argues that Hubei's lockdown provides a natural experiment to study the influence of a labor supply disruption in China on international trade and welfare through global supply chains.

The lockdown of Hubei province started in January and ended in late March 2020. When the lockdown began in late January, it was the Chinese New Year. Millions of migrant workers returned home to celebrate the festival. Due to the lockdown, Hubei's migrants were unable to travel outside the province and thus could not go back to work. This resulted in a massive and unanticipated labor supply shock in Hubei and other provinces. The supply shock was then propagated and amplified via regional and global supply chains, in which Hubei is deeply involved due to its central location in China. According to Zheng et al. (2020), 34% of the communication equipment, computer and other electronic equipment produced by Hubei was used as intermediate inputs by other Chinese provinces in 2015. Moreover, as one of Hubei's pillar industries, electrical machinery equipment accounted for 27% of China's total exports in 2019. Given the importance of Hubei in supply-chain trade, the lockdown provides a unique window to understand the impact of labor supply disruptions on global value chains. A key feature of Hubei's lockdown that enables me to focus on the labor supply shock in China is the timing. When Hubei entered the lockdown in January, other economies worldwide were still relatively untouched. Only in late March did some other countries start quarantines. This fact limited the impact of other foreign countries' lockdown on international trade.[2] Besides, although China has experienced structural upgrades, the main export-oriented sectors are still relatively labor-intensive (Lin & Wang, 2018). Given the fact that labor mobility is highly restricted over the period, a labor supply shock, even if it cannot fully capture the effect, should at least be one of the largest contributors to the first-order effect.[3] Furthermore, this article does not claim the labor supply shock is the only source of the changes in international trade and welfare, but rather shows that it matters even when other factors are not considered.

I build a Ricardian model with labor-augmenting technology, sectoral linkages, firm heterogeneity and trade in intermediate goods to analyze the effects of the labor supply disruption. To be more precise, I use the labor productivity shock to measure the labor supply disruption. This is a common practice in the literature (see, e.g., Carvalho et al., 2021; Luo & Tsang, 2020).[4] The productivity shock is calculated from the labor loss in Hubei. The reasons that I use productivity shocks to replace labor supply shocks are that the two shocks are statistically equivalent with a labor-augmenting Cobb–Douglas type production function and it gives a clearer functional form in equilibrium. The model allows me to study the total welfare changes and to further decompose the welfare changes into terms of trade effect and what I introduce as the "productivity effect." Caliendo and Parro (2015) use terms of trade effect, which is a multi-lateral weighted change in exporter prices relative to the change in importer prices, to measure the welfare changes from NAFTA's tariff reductions. Here I borrow the name to study the welfare changes caused by Hubei's lockdown. The productivity effect demonstrates the pure impact of a labor productivity shock on aggregate welfare in an economy. The decomposition displays each source's importance in transmitting and amplifying the original labor supply shock through global supply chains.

To feed the sectoral supply shocks through the model, I need to identify their magnitude. I adopt an approach from Luo and Tsang (2020) to measure the shocks. They estimate the sectoral supply shocks in each province by calculating the proportions of Hubei's migrants working in that province. As mentioned before, the lockdown limited migrant workers from traveling back to the provinces they worked in before the lockdown. Therefore, the share of Hubei's workers in each industry offered a good approximation for the sectoral shock magnitude in other provinces. How about the losses in Hubei? I consider two different ranges of losses: minor losses (case one) and full losses (case two). While the former assumes the loss in output is proportional to the labor share in production, the latter assumes a full stoppage of Hubei's production. The real situation should lie somewhere in between.

By treating December 2019 as the starting point, I calibrate the model using data from the World Input and Output Database (WIOD) and the OECD Structural Analysis (STAN) Database. I obtain the monthly trade flows from the International Trade Centre (ITC), which is part of the UN Comtrade database. However, one drawback of this database is that the data could not be collected at an aggregate level that is only one bilateral trade flow can be downloaded each time. To provide a timely estimation subject to the data limitation, I consider six other economies: Japan, the Republic of Korea (Korea hereafter), the European Union (27 countries, EU hereafter), the UK, the US, and the rest of the world (the ROW hereafter). Although the number of selected economies (except for the ROW) is relatively small, they are highly representative and account for approximately 50% of China's total exports in 2019. Moreover, the overall effects should not be significantly influenced by the number of economies. Since commodities are defined by the Harmonized Commodity Description and Coding System (HS) 2017 at the 6-digit level, I use the United Nations concordance table to concord them into 2-digit International Standard Industrial Classification of All Economic Activities (ISIC) Revision 4 divisions. I get 19 sectors after clustering, which contain agricultural, mining, all manufacturing sectors in ISIC Rev 4 and an aggregated service sector.

Using real income to measure welfare, the estimated welfare reductions in China are 7.61% and 18.28% under the assumptions of minor and full losses in Hubei. Whereas the UK, the US, and the ROW are hit severely, the European Union's real income increases in both cases. After decomposing the welfare effects into terms of trade effects and productivity effects, I find they have comparable magnitude for the same economy. However, there is significant heterogeneity across different economies. As the shock happens in China, it has a huge direct effect on China's welfare, but a relatively limited indirect impact on the other economies. In case one, the productivity effect in China is −7.55%, while for the other economies the effects are generally above −0.1%. Interestingly, the terms of trade effects are positive in four out of seven economies. The intuition behind the higher terms of trade is that the price increases in China are relatively small, which benefits the foreign firms using the intermediate goods from China. Regarding the magnitude, the overall effect depends on the relative increases in multi-lateral and multi-sector weighted export and import prices. Korea's terms of trade increase by 0.09% and 0.32% in both cases, respectively, which are the highest among all.

To further understand the sources of the aggregate welfare changes, I study the sectoral contributions. There is a large amount of heterogeneity across sectors. Nevertheless, a handful of sectors can explain the major parts of the welfare changes. For China, the 19th sector explains 64% of the productivity effect, given this sector is a sum of all non-manufacture sectors except for agriculture and mining. The main contributors in other economies are computer, textiles, and other manufacturing sectors as expected because those sectors are the hardest hit and are export-oriented in China. Thus higher prices and lower output in those sectors have a significant impact on the world economy. For instance, the computer and the textiles sectors contribute 27.11% and 16.48% to Korea's productivity effect, as well as 19.97% and 15.88% to the US's terms of trade effect in case one. Except for those sectors, the mining sector plays an important role in enhancing terms of trade in the US and the ROW.

World output decreases by 0.32% in case one and 0.97% in case two. The impacts are impressive given the short period under study and the ignorance of second-order effects such as the contagion through supply chains. The minerals sector and the basic metals sector are the most affected. The former's output falls by 1.78% and the latter by 1.43%.

In the extension, I relax the restriction that services are non-tradable. I find the welfare reductions are reinforced in most of the economies. Then I conduct a counterfactual exercise by assuming the same shocks happen in another economy and quantify the welfare changes. Comparison across countries reassures that China is playing a crucial role in global value chains. In Appendix C, I implement several exercises to examine the robustness of the baseline results. I find the results are invariant to changes in trade elasticises.

This article is closely related to articles that examine the importance of production networks in national and international trade. Caliendo and Parro (2015) provide evidence of the significant role of sectoral linkages in international trade and welfare analysis. I use a similar model and the same trade elasticises from their paper. The main difference between my work and theirs is that I use an exogenous labor supply shock while they use a trade shock from tariff reductions. My work also complements theirs by showing that the model is able to isolate the influence of productivity changes on welfare. In a later work, Caliendo et al. (2018) study how the disaggregated productivity changes across US states are transmitted through the intersectoral and interregional trade linkages. They also treat productivity changes as exogenous to the model and investigate the influences of regional and sectoral productivity changes on welfare. I use a similar technique but focus on international trade and global welfare changes.

Another related set of papers study the role of supply chains in amplifying disruptions caused by natural disasters. For example, Carvalho et al. (2021) study the influence of the Great East Japan Earthquake of 2011 through the supply chains using a general equilibrium model with input–output linkages. They find the shock is propagated through both the downstream and upstream chains and has significant indirect effects. Similarly, Barrot and Sauvagnat (2016) and Boehm et al. (2019) examine the transmission of shocks via firm-level linkages in the US using country-level data and cross-country data separately. My work complements these studies with a quantitative exercise to show that the labor supply shock in China, caused by an unexpected disaster, has a large impact on the global economy from a macro perspective.

Finally, this article is also closely related to the rapidly increasing research about the pandemic's impact through global supply chains under various setups. Some of this research focuses on the influence of COVID-19 on a particular country, for example, Inoue and Todo (2020), Fadinger and Schymik (2020), Baqaee and Farhi (2020), and Pichler et al. (2020). Others focus on the different measures such as social distancing and quarantine taken in many countries around the world, for example Barrot et al. (2021), Mandel and Veetil (2020), and Bonadio et al. (2021). In a similar paper, Sforza and Steininger (2020) also build a Ricardian model to quantify the welfare effect of the COVID shock on the world economy. They construct a measure of shock intensity for each country using the number of official cases of COVID-19. Considering three different levels of quarantine, they compare the effects of the shock across several countries. While in their paper, each country is hit by a local shock and by a foreign shock through the input linkages, I focus on a more specific event that is Hubei's lockdown, and do not consider shocks anywhere else. Besides, they model the shock as an increase in production cost, and I model it as a labor productivity shock. Another interesting example is Ando and Hayakawa (2021), where they use monthly export data of final machinery products for 35 countries to investigate the supply-side effects of COVID-19 on global value chains. While they focus on supplier diversification, my results are partially consistent with their findings that the machinery sectors experienced a large decline at the beginning of the pandemic, and China has a significant impact in those sectors via the global value chains. The most relevant paper is a parallel but independent work by Eppinger et al. (2020). They use the Ricardian model extended by Antras and Chor (2018) to estimate the welfare effects of Hubei's lockdown. The main difference is that they back out the sectoral labor supply shocks by estimating the initial output drops in January and February in China. Using the data of 2017–2019, they first estimate the expected output in 2020 and then use the differences between the expected and the observed values to back out the shocks. Moreover, they take intermediate and final goods' prices to be fixed when estimating the shocks. My work differs from theirs in four dimensions: (i) I model the labor productivity shock directly by assuming a labor-augmenting production technology. (ii) I use the number of migrant workers from Hubei to other provinces to identify the labor supply shock. (iii) My event window is from January to March, while they only consider January and February. (iv) I further decompose the welfare effects and study the different contributors. The remainder of the article is organized as follows. I set up the Ricardian model and derived the welfare decomposition formula in Section 2. Section 3 describes the source of data and calibration techniques. The baseline results are displayed and discussed in Section 4. Section 5 makes further extensions and compares the results with the baseline. Section 6 concludes.

2 | MODEL

The model bases on Caliendo and Parro (2015) and Caliendo et al. (2018), and it is a supply-side model. Since the COVID-19 is commonly recognized as a first-order supply shock, the model serves the goal of this article well. I modify the model by adding in labor-augmenting technology, assuming the tariffs are zero and the productivity shocks are the only exogenous shocks. I derive the theoretical decomposition of the welfare effect into terms of trade effect and productivity effect.

2.1 | Households

There are N countries and J sectors. Labor is mobile across sectors, but immobile across countries. In each country $n \in N$, there are L_n households. Households maximize the following utility by consuming final goods C_n^j from each sector j:

$$u(C_n) = \prod_{j=1}^{J} \left(C_n^j\right)^{\alpha_n^j}, \sum_{j=1}^{J} \alpha_n^j = 1, \tag{1}$$

subject to the budget constraint

$$I_n = w_n L_n + D_n, \tag{2}$$

where I_n is income, w_n is the wage, L_n is the labor supply, and D_n is the trade deficit.

2.2 | Firms of intermediate goods

In each country n, firms in sector j produce a continuum of intermediate goods $\omega^j \in [0, 1]$ with labor l_n and composite intermediate goods $m_n^{k,j}\left(\omega^j\right)$. Firms have different overall efficiency levels

$z_n^j(\omega^j)$, which are drawn randomly from a Fréchet distribution with shape parameter θ^j and location parameter 1.[5] Besides, there is a deterministic labor-augmenting technology A_n^j for each firm and the production function is at constant returns to scale, given by

$$q_n^j(\omega^j) = z_n^j(\omega^j)\left[A_n^j l_n^j(\omega^j)\right]^{\gamma_n^j}\prod_{k=1}^{J}\left[m_n^{k,j}(\omega^j)\right]^{\gamma_n^{k,j}}, \tag{3}$$

where $\gamma_n^{k,j}$ is the share of the composite intermediate goods $m_n^{k,j}(\omega^j)$ from sector k for the production of ω^j. γ_n^j is the share of value-added and $1-\gamma_n^j = \sum_{k=1}^{j}\gamma_n^{k,j}$.

The price of the intermediate good ω^j is determined by the unit cost of the firms. Denote the price of the composite goods from sector k by P_n^k, the cost of an input bundle c_n^j is given by

$$c_n^j = B_n^j w_n^{\gamma_n^j}\prod_{k=1}^{J}\left(P_n^k\right)^{\gamma_n^{k,j}}, \tag{4}$$

where $B_n^j = \prod_{k=1}^{J}\left(\gamma_n^{k,j}\right)^{-\gamma_n^{k,j}}\left(\gamma_n^j\right)^{-\gamma_n^j}$ is a constant.

To solve for P_n^k, I need to consider the production of the composite intermediate goods.

2.3 | Firms of composite intermediate goods

The composite intermediate goods Q_n^j functions as both the final consumption goods and the input of the intermediate goods mentioned in Section 2.2.[6]

To produce Q_n^j, firms search for the suppliers with the lowest cost across all countries.[7] The production function of Q_n^j is

$$Q_n^j = \left[\int r_n^j(\omega^j)^{1-1/\sigma^j} d\omega^j\right]^{\sigma^j/(\sigma^j-1)}, \tag{5}$$

where $\sigma^j > 0$ is the elasticity of substitution across intermediate goods in sector j and $r_n^j(\omega^j)$ is the demand for ω^j.

To maximize profits, the demand for $r_n^j(\omega^j)$ is given by

$$r_n^j(\omega^j) = \left(\frac{p_n^j(\omega^j)}{P_n^j}\right)^{-\sigma^j} Q_n^j, \tag{6}$$

where p_n^j is the lowest unit price of ω^j and P_n^j is the unit price for the composite intermediate good

$$P_n^j = \left[\int p_n^j(\omega^j)^{1-\sigma^j} d\omega^j\right]^{\frac{1}{1-\sigma^j}}. \tag{7}$$

2.4 | International trade

Trade in goods from country n to country i in sector j incurs the standard "iceberg" costs Samuelson (1954), which means transferring one unit of good to country n requires producing $d_{ni}^j \geq 1$ units of such good in country i. d_{ii}^j is normalized to one and $d_{ni}^j d_{ik}^j \geq d_{nk}^j$.

Therefore, the price of one unit intermediate good ω^j in country n that is produced in country i is

$$p_{ni}^j = \frac{c_i^j d_{ni}^j}{z_i^j\left(\omega^j\right)\left(A_i^j\right)^{\gamma_n^j}}.$$

Since the firms are searching for the lowest cost supplier, the actual price paid is the minimum across all countries,

$$p_n^j = \min\left\{p_{ni}^j; i = 1, \ldots, N\right\}. \tag{8}$$

To get a simple expression for the distribution of prices, I follow Eaton and Kortum (2002) to assume the country n's efficiency distribution is Fréchet and is independent across countries, sectors and goods. The exact formula of price of the composite goods P_n^j is

$$P_n^j = \kappa^j\left[\Phi_n^j\right]^{-1/\theta^j}, \tag{9}$$

where $\Phi_n^j = \sum_{i=1}^N \left(A_i^j\right)^{\gamma_i^j\theta^j}\left(c_i^j d_{ni}^j\right)^{-\theta^j}$ and $\kappa^j = \left[\Gamma\left(\frac{\theta^j+1-\sigma^j}{\theta^j}\right)\right]^{1/(1-\sigma^j)}$. Γ is the Gamma function. I also assume that $\sigma^j < 1 + \theta^j$ to ensure a well-defined price index. Some sectors are non-tradable by assuming the local suppliers are providing goods with the lowest costs. For those sectors, $d_{ni}^j = \infty$ and $P_n^j = \kappa^j\left(A_n^j\right)^{-\gamma_n^j} c_n^j$. Note P_n^j is also the price for final consumption goods. The consumption price index is $P_n = \prod_{j=1}^J \left(P_n^j/\alpha_n^j\right)^{\alpha_n^j}$.

2.5 | Expenditure shares

To link the model with data, the fraction of country n's expenditure on goods of sector j from country i is necessary. Define X_{ni}^j as country n's expenditure of sector j goods from country i and X_n^j as country n's total spending on sector j goods, then the share of sector j goods from country i is[8]

$$\pi_{ni}^j = \frac{X_{ni}^j}{X_n^j} = \frac{A_i^{j^{\theta^j\gamma_i^j}}\left(c_i^j d_{ni}^j\right)^{-\theta^j}}{\Phi_n^j} = \frac{A_i^{j^{\theta^j\gamma_i^j}}\left(c_i^j d_{ni}^j\right)^{-\theta^j}}{\sum_{i=1}^N A_i^{j^{\theta^j\gamma_i^j}}\left(c_i^j d_{ni}^j\right)^{-\theta^j}}. \tag{10}$$

2.6 | Total expenditure and trade balance

Total expenditure of country n on sector j goods is calculated by adding the firms' spending and households' spending, given by

$$X_n^j = \sum_{k=1}^J \gamma_n^{j,k} \sum_{i=1}^N X_i^k \pi_{in}^j + \alpha_n^j I_n, \tag{11}$$

where $I_n = w_n L_n + D_n$.[9] The sectoral j's deficit is given by the difference between the country n's import from all other countries and its export to the world, $D_n^j = \sum_{i=1}^N X_{ni}^j - X_{in}^j$. The national deficit is the sum of all sectoral deficits, $D_n = \sum_{j=1}^J D_n^j$. D_n is exogenously given in the model, but the sectoral deficits are endogenous. The sum of all economies' deficits is zero, $\sum_{n=1}^N D_n = 0$.

Combining all the conditions, we get[10]

$$\sum_{j=1}^{J}\sum_{i=1}^{N} X_n^j \pi_{ni}^j - \sum_{j=1}^{J}\sum_{i=1}^{N} X_i^j \pi_{in}^j = D_n. \tag{12}$$

2.7 | Equilibrium

The equilibrium is written in relative changes.[11] This approach is introduced and used by Dekle et al. (2007, 2008). Using the changes from the original equilibrium reduces the data requirements as the invariant parameters are canceled out. This significantly simplifies the calibration task and makes the comparison straightforward. Besides, this approach does not require the assumption of bilateral symmetries, which is rejected by many empirical studies. I measure the sectoral labor supply shocks due to Hubei's lockdown by the changes in labor productivity as Luo and Tsang (2020). To be more specific, the changes in A_n^j.

Write the variables before and after the shock as x and x', and define $\hat{x} = x'/x$, we get (same as before)[12]

$$\hat{c}_n^j = \hat{w}_n \prod_{k=1}^{J} \left(\hat{P}_n^k\right)^{\gamma_n^{k,j}}, \tag{13}$$

$$\hat{P}_n^j = \left[\sum_{i=1}^{N} \pi_{ni}^j \hat{A}_i^{j\,\theta^j \gamma_i^j} \left(\hat{c}_i^j\right)^{-\theta^j}\right]^{-1/\theta^j}, \tag{14}$$

$$\hat{\pi}_{ni}^j = \hat{A}_i^{j\,\theta^j \gamma_i^j} \left(\frac{\hat{c}_i^j}{\hat{P}_n^j}\right)^{-\theta^j}, \tag{15}$$

$$X_n'^j = \sum_{k=1}^{J} \gamma_n^{j,k} \sum_{i=1}^{N} X_i'^k \pi_{in}'^j + \alpha_n^j \left(w_n L_n + D_n\right), \tag{16}$$

$$\sum_{j=1}^{J}\sum_{i=1}^{N} X_n'^j \pi_{ni}'^j - \sum_{j=1}^{J}\sum_{i=1}^{N} X_i'^k \pi_{in}'^j = D_n. \tag{17}$$

2.8 | Welfare

The welfare effects are crucial. I first derive the representation of the total welfare effect and then decompose it into terms of trade and productivity effects. The name "terms of trade effect" is borrowed from Caliendo and Parro (2015), which measures the multilateral weighted sectoral change in export and import prices. I use the name "productivity effect" to measure how the import-weighted sectoral labor productivity changes influence welfare. The welfare of country n

is measured by real income,

$$W_n = \frac{I_n}{P_n} = \frac{w_n L_n}{P_n} + \frac{D_n}{P_n}.$$

Since we are interested in the changes, we get the following by totally differentiating the above equation:

$$dlnW_n = \frac{w_n L_n}{I_n} d\ln w_n - d\ln P_n. \tag{18}$$

After simplification,[13] we get

$$d\ln W_n = \frac{1}{I_n}\left(\sum_{j=1}^{J}\sum_{i=1}^{N} E_{ni}^j d\ln c_n^j - M_{ni}^j d\ln c_i^j\right) + \frac{1}{I_n}\sum_{j=1}^{J}\sum_{i=1}^{N} M_{ni}^j \gamma_i^j d\ln A_i^j, \tag{19}$$

where E_{ni}^j is the sector j's exports from country n to country i and M_{ni}^j is the imports of country n from country i. The first term is known as multi-lateral and multi-sectoral terms of trade effect and the second term is the productivity effect, which measures the change welfare due to the productivity change. Notice that it is not sufficient to say an increase in the input costs in country n relative to country i contributes positively to country n's welfare, because it also depends on the relative values of exports and imports of country n. However, it is clear from the second part of (19) that a decrease in productivity in other countries (A_i^j) will reduce country n's welfare, certis paribas.[14] This is intuitive since lower productivity in country n indicates a higher price there. This hurts all countries as firms are always searching for suppliers with the lowest costs.

3 | CALIBRATION AND SIMULATION

To analyze the trade and welfare effects, I calibrate the model parameters using the data from the World Input Output Database and the OECD STAN Database. As the latest version of the World Input–Output Table (WIOT) is the 2014 Table, I assume the parameters did not change from 2014 to 2020. The underlying assumption is that the massive supply shocks are likely to swamp the small changes in the parameters. I also need the bilateral trade flows data in December 2019, which are collected from the ITC.

3.1 | Data and calibration

I need to calibrate four parameters, $\gamma_n^j, \gamma_n^{j,k}, \alpha_n^j$, and θ^j to solve Equations (13)–(17). γ_n^j and $\gamma_n^{j,k}$ are calibrated using data from WIOT. γ_n^j is the share of value-added. It is calculated by sectoral value-added VA_n^j and gross production Y_n^j : $\gamma_n^j = \frac{VA_n^j}{Y_n^j}$. $\gamma_n^{j,k}$ is the share of sector k's spending on sector j's intermediate goods in country n, times $(1-\gamma_n^j)$. It measures the importance of sector j's intermediate goods in sector k's production. WIOT has detailed sectoral consumption of intermediate goods.

α_n^j is the final consumption share of sector j's goods in country n. I use the total expenditure minus the intermediate expenditure in sector j, divide by the total final absorption in country n

TABLE 1 Sectoral trade elasticity

Number	Sector	θ^j	Number	Sector	θ^j
1	Agriculture	9.11	11	Basic metals	3.28
2	Mining	13.53	12	Metal products	6.99
3	Food	2.62	13	Computer	8.53
4	Textiles	8.10	14	Electrical equipment	12.91
5	Wood	11.5	15	Machinery	1.45
6	Paper	16.52	16	Auto	1.84
7	Petroleum	64.85	17	Other transport	0.39
8	Chemicals	3.13	18	Other manufacturing	3.98
9	Rubber and plastic	1.67	19	Other activities	6

Note: The values are obtained from Caliendo and Parro (2015, Table 1), 99% sample. The value for the computer sector (No. 13) is the average of office, communication, and medical sectors in the original paper.

to estimate it. To calculate the total expenditure, I sum the sectoral imports of each country. The final absorption is calculated by value added plus the trade deficit in each sector. I collect the trade flows data for 2014 from the OECD STAN database. Note the parameters for the EU and the ROW are calculated using the average of all countries involved.

For the remaining parameters θ^j, I use Caliendo and Parro (2015)'s estimations with 99% sample. The elasticity for the service sector is not available, I choose 6, similar as Eppinger et al. (2020). The results do not change much when changing the elasticity. The parameters are displayed in Table 1.[15]

Finally, the sectoral bilateral trade flows are collected from the International Trade Centre's Trade Map Database.[16] Trade Map provides detailed monthly import and export data at Harmonized System 6 digits (HS6) level. I obtain the sectoral data for the seven economies in December 2019. I use the concordance table provided by the World Integrated Trade Solution (WITS) to convert trade flows into International Standard Industrial Classification Rev 4 divisions. After merging some sectors, I get 19 sectors in total, where the 19th sector is the aggregation of all non-manufacture sectors other than agricultural and mining (see Appendix Table A.1). Note the exports from the ROW to the world are the sum of other six economies' imports from the ROW. The gross production data is not available; thus, I back out the values for December 2019 by assuming the share of domestic consumption as a proportion of gross production in each economy remained the same between 2014 and 2019.

3.2 | Productivity shocks

One key question is how to get the productivity shocks ($\widehat{A}_i^j$) and map them into the model. I adopt the approach in Luo and Tsang (2020) to estimate the productivity shocks by measuring the sectoral labor losses due to the lockdown of Hubei province. The magnitude of shocks in each province is approximated using the proportion of Hubei's migrants working in that province and the provincial sectoral structure.[17] Since 80% of the migrants went home during the Lunar New Year, the lockdown prevented them from traveling back to work.

TABLE 2 Labor productivity shocks

Sector	Shocks (case one)	$\hat{A}^j$	Shocks (case two)	$\hat{A}^j$
Agriculture	−7.63%	0.92	−14.75%	0.85
Mining	−3.65%	0.96	−7.12%	0.93
Food	−9.17%	0.91	−30.83%	0.69
Textiles	−7.22%	0.93	−30.56%	0.69
Wood	−5.45%	0.95	−17.73%	0.82
Paper	−5.45%	0.95	−17.73%	0.82
Petroleum	−6.05%	0.94	−20.00%	0.80
Chemicals	−5.83%	0.94	−20.83%	0.79
Rubber and plastic	−6.05%	0.94	−20.00%	0.80
Minerals	−7.24%	0.93	−23.45%	0.77
Basic	−4.78%	0.95	−16.09%	0.84
Metal	−4.78%	0.95	−16.09%	0.84
Computer	−6.05%	0.94	−25.00%	0.75
Electrical	−6.05%	0.94	−25.00%	0.75
Machinery	−6.50%	0.94	−24.50%	0.76
Auto	−6.05%	0.94	−25.00%	0.75
Other transport	−6.05%	0.94	−25.00%	0.75
Other manufacturing	−7.72%	0.92	−14.56%	0.85
Other activities	−8.42%	0.92	−17.89%	0.82

In Luo and Tsang (2020), the production function for China is

$$q^j = \left(z^j l^j\right)^{\gamma^j} \prod_{k=1}^{J} \left[m^{k,j}\right]^{\gamma^{k,j}}, \tag{20}$$

where γ^j is the labor share and z^j is the labor-augmenting productivity. They log-linearize the model around the steady state to get the vector of sectoral labor productivity shocks $\mathbf{z} = \begin{bmatrix} \gamma^1 \tilde{z}^1 \\ \dots \\ \gamma^J \tilde{z}^J \end{bmatrix}$, where tilde indicate the percentage deviation from their steady state values. Then they use the sectoral labor loss to approximate $\tilde{z}^j$ and calculate $\mathbf{z}$.

Since the production function in my case is (drop subscript n for comparison)

$$q^j = z^j \left(A^j l^j\right)^{\gamma^j} \prod_{k=1}^{J} \left[m^{k,j}\right]^{\gamma^{k,j}}. \tag{21}$$

I can use the sectoral labor losses to approximate the labor productivity losses, that is, changes in A^j. As the equilibrium is in relative changes instead of the deviation from the steady state, I

TABLE 3 Welfare effects from the productivity shocks

	Welfare effect		Terms of trade effect		Productivity effect	
	Case one	Case two	Case one	Case two	Case one	Case two
China	−7.61%	−18.28%	−0.06%	−0.17%	−7.55%	−18.10%
Japan	−0.01%	0.03%	0.03%	0.15%	−0.04%	−0.12%
Korea	−0.02%	−0.07%	0.09%	0.32%	−0.11%	−0.39%
EU27	0.01%	0.02%	0.05%	0.17%	−0.04%	−0.15%
UK	−0.06%	−0.19%	−0.03%	−0.08%	−0.03%	−0.11%
US	−0.05%	−0.15%	−0.02%	−0.06%	−0.03%	−0.09%
ROW	−0.05%	−0.22%	0.01%	0.00%	−0.06%	−0.22%

recalculate the labor productivity shocks in Table 2. I further consider two cases for Hubei's lockdown, assuming minor losses and full losses of Hubei's production respectively.[18] However, not all of the sectoral productivity shocks are available in Luo and Tsang (2020). As six sectors are missing, I need to make further assumptions about the productivity shocks in those sectors.[19] I assume the productivity shocks are −6.05% in case one and −25% in case two for those sectors. −6.05% is the average shock level, while 25% is the magnitude of China's manufacturing value-added reduction during January and February.[20] The productivity shocks are displayed in Table 2.

4 | RESULTS AND DISCUSSION

4.1 | Welfare effects

The welfare changes for each economy due to the productivity shocks in China are displayed in Table 3. In the first case, when the sectoral shocks are mild and relatively uniform, the welfare decreases are smaller than in the second case for all economies except for Japan.[21] After decomposing the welfare changes into two parts, terms of trade (TOT) effect and productivity effect, I find large variations across economies. However, for the same country, the two effects have comparable magnitude.

For China, the productivity effects are high in both cases and are the main contributors to the welfare declines, indicating the labor supply shocks in Hubei have large implications. All other economies are affected moderately. Korea and the ROW are the most affected by the productivity effects, where the drops in welfare are 0.11% and 0.06% in the first case, and 0.39% and 0.22% in the second case.

To better understand which sectors are the main driving forces of the productivity effects, I further consider the sectoral contributions. Figure 1 and Table 4 present the results in case one. From the subplot of China in Figure 1, the productivity effect mainly comes from the non-tradable sector (other activities).[22]

Because this sector sums all non-manufacture sectors except for agriculture and mining, it is reasonable to see a high contribution to the aggregate effect. The agriculture sector accounts for 12%. Since there is a large reduction in agricultural output in China, the higher price reduces welfare in China. For the other economies, the textiles sector, the computer sector and the other manufacturing sector play the most critical roles. The results are consistent with the fact that

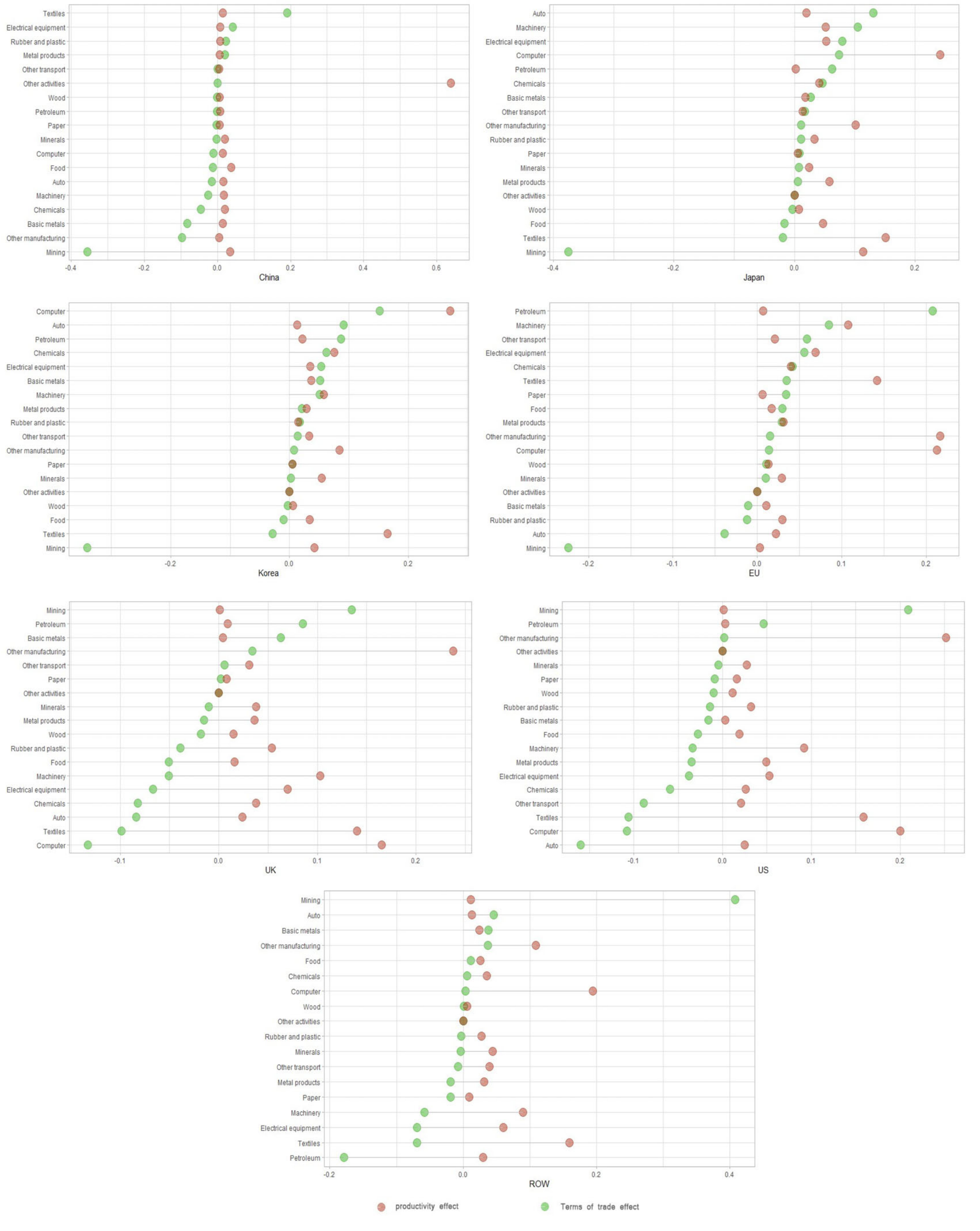

FIGURE 1 Sectoral contributions to the aggregate effects (case one). *Note*: The figure presents sectoral contributions to total welfare changes in each economy due to the productivity shock in China. The red points show the productivity effects, and the green points show the terms of trade effects. The unit of the x-axis is the percentage (%)

TABLE 4 Sectoral contributions to the aggregate effects (case one)

	China		Japan		Korea		EU27		UK		US		ROW	
Sectors	**TOT**	**Prod**	**TOT**	**Prod**	**TOT**	**Prod**	**TOT**	**Prod**	**TOT**	**Prod**	**TOT**	**Prod**	**TOT**	**Prod**
Agriculture	−7.04%	12.00%	0.31%	1.70%	0.27%	2.07%	8.43%	2.02%	−2.67%	1.12%	3.15%	1.14%	−2.14%	9.30%
Mining	−35.61%	3.51%	−37.54%	11.38%	−34.08%	4.15%	−22.36%	0.34%	13.54%	0.12%	20.90%	0.06%	40.77%	1.12%
Food	−1.32%	3.71%	−1.66%	4.72%	−1.05%	3.37%	3.00%	1.71%	−5.10%	1.59%	−2.82%	1.89%	1.13%	2.63%
Textiles	19.05%	1.42%	−1.89%	15.08%	−2.81%	16.48%	3.47%	14.16%	−9.87%	13.98%	−10.58%	15.88%	−6.89%	15.87%
Wood	−0.06%	0.64%	−0.29%	0.68%	−0.33%	0.63%	1.07%	1.27%	−1.83%	1.47%	−0.97%	1.14%	0.07%	0.57%
Paper	−0.16%	0.55%	0.83%	0.58%	0.52%	0.54%	3.43%	0.58%	0.24%	0.81%	−0.88%	1.56%	−1.94%	0.88%
Petroleum	−0.14%	0.85%	6.17%	0.22%	8.67%	2.20%	20.83%	0.69%	8.50%	0.88%	4.60%	0.30%	−17.86%	2.98%
Chemicals	−4.48%	2.04%	4.60%	4.12%	6.22%	7.55%	4.20%	3.97%	−8.21%	3.83%	−5.93%	2.59%	0.61%	3.51%
Rubber and plastic	2.35%	0.69%	1.07%	3.31%	1.66%	1.55%	−1.24%	2.98%	−3.89%	5.40%	−1.44%	3.19%	−0.32%	2.71%
Minerals	−0.33%	2.04%	0.69%	2.39%	0.15%	5.40%	1.01%	2.93%	−0.96%	3.82%	−0.49%	2.74%	−0.37%	4.36%
Basic metals	−8.27%	1.52%	2.67%	1.85%	5.23%	3.75%	−1.10%	1.12%	6.26%	0.38%	−1.63%	0.28%	3.80%	2.40%
Metal products	2.11%	0.61%	0.58%	5.79%	2.10%	2.94%	2.86%	3.12%	−1.51%	3.57%	−3.53%	4.89%	−1.90%	3.13%
Computer	−1.14%	1.41%	7.43%	24.21%	15.18%	27.11%	1.45%	21.31%	−13.25%	16.51%	−10.83%	19.97%	0.34%	19.40%
Electrical equipment	4.21%	0.83%	7.86%	5.28%	5.30%	3.51%	5.63%	6.90%	−6.65%	6.98%	−3.83%	5.31%	−6.88%	6.02%
Machinery	−2.59%	1.82%	10.52%	5.15%	5.12%	5.75%	8.52%	10.84%	−5.14%	10.29%	−3.36%	9.25%	−5.80%	8.96%
Auto	−1.50%	1.56%	13.06%	1.98%	9.07%	1.32%	−3.94%	2.23%	−8.40%	2.40%	−15.96%	2.53%	4.63%	1.33%
Other transport	0.00%	0.54%	1.73%	1.45%	1.39%	3.33%	5.91%	2.14%	0.61%	3.08%	−8.88%	2.08%	−0.83%	3.87%
Other manufacturing	−9.65%	0.37%	1.10%	10.10%	0.83%	8.36%	1.55%	21.69%	3.37%	23.79%	0.22%	25.19%	3.72%	10.94%
Other activities	0.00%	63.89%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

TABLE 5 Changes in sectoral costs (case one)

	China	Japan	Korea	EU	UK	US	ROW
Agriculture	−1.95%	0.93%	0.88%	0.91%	0.87%	0.89%	0.81%
Mining	−1.41%	0.86%	0.87%	0.91%	0.86%	0.88%	0.80%
Food	0.96%	0.94%	0.91%	0.91%	0.87%	0.89%	0.83%
Textiles	0.90%	1.03%	1.04%	0.96%	0.91%	0.96%	0.93%
Wood	0.33%	0.93%	0.90%	0.91%	0.89%	0.90%	0.83%
Paper	0.29%	0.93%	0.89%	0.91%	0.88%	0.90%	0.84%
Petroleum	0.10%	0.85%	0.84%	0.87%	0.86%	0.88%	0.81%
Chemicals	0.60%	0.92%	0.89%	0.92%	0.87%	0.89%	0.83%
Rubber and plastic	0.59%	0.94%	0.91%	0.91%	0.88%	0.90%	0.86%
Minerals	0.04%	0.91%	0.90%	0.91%	0.88%	0.90%	0.82%
Basic metals	0.34%	0.89%	0.87%	0.89%	0.87%	0.89%	0.82%
Metal products	0.34%	0.92%	0.89%	0.91%	0.86%	0.89%	0.83%
Computer	0.58%	0.96%	0.96%	0.94%	0.90%	0.89%	0.91%
Electrical equipment	0.60%	0.95%	0.91%	0.92%	0.89%	0.90%	0.86%
Machinery	0.23%	0.94%	0.91%	0.92%	0.89%	0.90%	0.86%
Auto	0.55%	0.94%	0.91%	0.91%	0.89%	0.91%	0.85%
Other transport	0.26%	0.93%	0.92%	0.92%	0.88%	0.91%	0.88%
Other manufacturing	−0.86%	0.95%	0.96%	0.92%	0.89%	0.91%	0.86%
Other activities	−1.00%	0.93%	0.87%	0.91%	0.86%	0.88%	0.81%

these sectors comprise a large part of China's total exports. According to Figure 1, the computer sector is the largest contributor to the productivity effect for Japan, Korea, and the ROW, while the other manufacturing sector has the largest effect on the EU, the US, and the UK. The computer and the textile sectors contribute 27.11% and 16.48% to Korea's welfare reduction in case one and 31.16% and 19.40% in case two (see Appendix). For the ROW, the computer sector also explains more than 19% of the productivity effect in both cases.

The terms of trade effects display some interesting features. Although China is hit seriously by the productivity shocks, the terms of trade only drop by 0.06% in case one and 0.17% in case two. TOT in the UK and the US drop by around half of the changes in China's TOT. Japan, Korea, the EU, and the ROW all have higher TOT. To understand the reason, we need to look at the changes in input costs in Table 5, as the export price is increasing in $\hat{c}$.[23] From Equation (19), the terms of trade effect is determined by the differences between the multilateral-weighted changes in export and import prices. According to Table 5, every sector in the other economies has a higher price after the shock, but the magnitude of the increase varies. Thus, the overall effect will depend on the relative increases in export-weighted and import-weighted prices.

The textiles sector contributes a significant proportion to China's improved TOT, following by the electrical equipment. The price index for textiles increases by 0.9% in China, which is the lowest among all economies. Because this is a leading export sector in China, the cheaper price has a positive effect on the overall terms of trade (see Figure 1). On the contrary, China is a net importer

TABLE 6 Output changes in case one

	China	Japan	Korea	EU27	UK	US	ROW	Sectoral total
Agriculture	−5.89%	1.04%	1.11%	0.77%	0.98%	1.04%	1.43%	−1.25%
Mining	−2.80%	−0.19%	−0.12%	−0.48%	0.21%	0.54%	−0.28%	−0.62%
Food	−5.61%	0.99%	1.07%	0.85%	0.91%	0.89%	0.98%	−0.76%
Textiles	−6.67%	3.64%	3.89%	3.65%	3.43%	3.85%	4.02%	−1.09%
Wood	−5.19%	1.15%	1.72%	0.99%	1.62%	1.33%	1.65%	−1.33%
Paper	−5.94%	1.07%	1.35%	0.96%	1.26%	1.28%	2.21%	−0.71%
Petroleum	−4.67%	1.03%	1.31%	0.59%	1.24%	0.57%	4.10%	−0.79%
Chemicals	−4.96%	0.59%	0.47%	0.81%	0.92%	0.92%	1.00%	−0.94%
Rubber and plastic	−4.23%	0.80%	0.69%	1.02%	1.04%	1.02%	1.14%	−0.77%
Minerals	−4.77%	0.89%	1.07%	0.93%	0.99%	1.04%	1.03%	−1.78%
Basic metals	−4.57%	0.54%	0.54%	0.73%	0.04%	0.95%	0.53%	−1.43%
Metal products	−4.16%	0.94%	0.98%	0.87%	1.09%	1.16%	1.34%	−0.48%
Computer	−4.76%	1.11%	0.85%	1.59%	1.79%	1.64%	1.13%	−0.85%
Electrical equipment	−5.88%	1.50%	1.87%	1.73%	2.29%	2.11%	2.35%	−0.90%
Machinery	−4.08%	0.16%	0.30%	0.69%	0.84%	0.82%	0.87%	−0.77%
Auto	−4.90%	0.42%	0.74%	0.62%	0.64%	0.80%	0.88%	−0.78%
Other transport	−3.81%	0.87%	0.75%	0.60%	0.78%	0.86%	0.85%	−0.49%
Other manufacturing	−4.41%	1.57%	1.86%	1.66%	1.79%	1.66%	1.89%	0.34%
Other activities	−5.10%	0.93%	0.86%	0.91%	0.83%	0.86%	0.82%	0.03%
Country total	−4.97%	0.91%	0.87%	0.91%	0.86%	0.89%	0.85%	−0.32%

in the automotive industry. Since the EU and Japan, the two largest auto exporters to China, both have significant rises in their prices, the auto sector contributes −1.50% to China's TOT. Price increases in Korea and Japan and the sectoral contributions are relatively similar. However, the largest contributors to the increased TOT of Japan and Korea are the auto sector and the computer sector, respectively.

The UK and the US experience the highest TOT losses. Twelve out of 19 sectors in the UK contribute negatively to the TOT, leading by the computer sector (16.51%) and the textiles sector (13.98%). Similarly, the computer sector and the auto sector contribute −10.83% and −15.96% to the US's TOT. The US is a net importer in those two sectors. China and the ROW account for 80% of the US's imports of computers, thus the higher import prices swamp the increased export prices in the US.

The ROW also has lower welfare, resulting from the productivity effect. But its TOT improves by 0.01% in case one and is unchanged in case two. The largest contributor to the positive TOT effect is the mining sector. From Table 4, the mining sector contributes 40.77% to the ROW's TOT. Figure A.6 in the Appendix shows the mining sector's trade flows. It is evident that the ROW's mining sector is so important that it could easily dominate the welfare change.

4.2 | Changes in output and exports

Regarding the output changes, world output drops by 0.32% in case one and 0.97% in case two. The impacts are impressive given the short period under study and the ignorance of second-order effects such as the contagion through the supply chains. I display the changes in the world sectoral output in Table 6 for case one. According to Table 6, every sector, except for the last two, has a lower output in the new equilibrium. The other manufacturing sector's production increases because of the lower export price of China. The other activities sector is assumed to be non-tradable, so the impact is indirect. The higher production indicates the labor is shifting from other sectors to the service sector. The biggest falls are the output of minerals (1.78%) and basic metals (1.43%) respectively. One interesting finding is that the other economies are producing more in almost all sectors, indicating they are substituting domestic goods for some imports from China.

One common feature across all economies is that the output of textiles changes significantly. Why? First, because this sector is hit by a higher-than-average productivity shock in China and the production cost increases a lot. Table 2 shows the sectoral shock is −7.22% in case one, which is huge. In case two, when the shock rises from 7.55% to 30.56%, output drops by 4.34% (see Appendix Table A.5). Second, the textiles sector is a relatively small sector compared with the others but accounts for 14% exports in China. Therefore, changes in China have a large impact on other economies. In general, sector produces less in China if it is hit harder, but the degree of reduction varies. With a 6.05% productivity shock, the auto sector's output declines by 4.9% while the electrical equipment sector by 5.88%. This partly indicates the importance of sector linkages. The electrical equipment sector relies heavily on other sectors, but the auto sector is relatively more independent. Another influential factor is the responses of the other economies. For example, the other manufacturing sector is also hit by a 6.05% shock in China, but it produces 0.34% more than before the shock. This is because all other economies are producing more when China's exports are cheaper in this sector. When the sectoral shock becomes −25% in case two, the world production increases more, showing China's importance in providing intermediate materials for world production.

Regarding the export shares, an interesting finding is that in each foreign economy, one to two sectors benefit significantly from the shocks in China. They are the electrical equipment sector in Japan, the Petroleum sector in Korea, the computer sector in the US, and the textiles sector in the EU, the UK, and the ROW (Table 7).

5 | FURTHER EXTENSIONS

To keep the main content concise, I present the model performance and the robustness check in Appendix C.

5.1 | Adding trade in services

Here I remove the restriction that services are non-tradable to check if this affects the results significantly. The trade in services data is collected from the World Bank and OECD International Trade in Service Statistics (ITSS) database. As only annual trade flows are available, I divide each series by 12 to get monthly flows.[24] Then I divide the bilateral exports by an economy's total

TABLE 7 Export shares by sector before and after the productivity shocks (case one)

	China		Japan		Korea		EU27		UK		US		ROW	
Sectors	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
Agriculture	1.74%	1.54%	0.63%	0.63%	0.45%	0.45%	5.01%	5.00%	1.08%	1.08%	5.33%	5.38%	2.40%	2.47%
Mining	1.12%	1.25%	0.16%	0.15%	0.94%	0.85%	8.08%	7.95%	19.25%	19.01%	25.76%	25.56%	30.29%	29.61%
Food	1.58%	1.55%	0.80%	0.80%	1.02%	1.02%	5.96%	5.95%	3.97%	3.98%	3.77%	3.77%	5.55%	5.60%
Textiles	14.50%	13.86%	1.31%	1.35%	2.23%	2.29%	5.34%	5.50%	2.82%	2.91%	1.07%	1.10%	3.55%	3.69%
Wood	0.88%	0.85%	0.07%	0.07%	0.02%	0.03%	1.09%	1.09%	0.15%	0.16%	0.36%	0.36%	0.84%	0.86%
Paper	0.96%	0.90%	1.15%	1.17%	0.89%	0.91%	2.09%	2.10%	1.34%	1.35%	0.96%	0.97%	0.76%	0.78%
Petroleum	3.30%	3.34%	8.53%	8.61%	11.79%	11.96%	9.34%	9.30%	7.42%	7.48%	7.92%	7.85%	0.64%	0.66%
Chemicals	4.65%	4.74%	9.68%	9.61%	12.37%	12.24%	12.20%	12.19%	10.59%	10.60%	10.84%	10.84%	9.50%	9.56%
Rubber and plastic	3.44%	3.55%	2.47%	2.46%	2.38%	2.37%	2.16%	2.16%	1.41%	1.41%	2.01%	2.01%	2.18%	2.20%
Minerals	2.79%	2.84%	1.17%	1.17%	0.61%	0.61%	1.21%	1.21%	0.56%	0.56%	0.78%	0.78%	0.82%	0.82%
Basic metals	3.31%	3.42%	6.81%	6.76%	8.36%	8.31%	4.18%	4.16%	11.88%	11.80%	3.68%	3.67%	6.97%	6.92%
Metal products	5.21%	5.29%	2.34%	2.34%	2.88%	2.89%	2.78%	2.78%	1.45%	1.46%	1.51%	1.51%	1.62%	1.64%
Computer	27.30%	27.52%	18.54%	18.56%	27.17%	27.12%	10.89%	10.97%	7.80%	7.88%	14.45%	14.60%	13.05%	13.12%
Electrical equipment	8.43%	8.14%	11.19%	11.31%	6.80%	6.90%	5.35%	5.39%	2.93%	2.97%	3.36%	3.40%	2.48%	2.54%
Machinery	8.53%	8.80%	13.53%	13.43%	8.33%	8.25%	9.24%	9.22%	5.79%	5.79%	8.12%	8.10%	5.14%	5.18%
Auto	2.13%	2.19%	17.12%	17.06%	10.36%	10.39%	7.54%	7.51%	8.89%	8.86%	5.62%	5.60%	8.30%	8.36%
Other transport	3.31%	3.44%	3.35%	3.36%	2.95%	2.95%	5.29%	5.27%	9.62%	9.63%	2.26%	2.27%	3.21%	3.23%
Other manufacturing	6.81%	6.78%	1.16%	1.17%	0.46%	0.46%	2.23%	2.25%	3.05%	3.08%	2.22%	2.24%	2.71%	2.76%
Other activities	1.74%	1.54%	0.63%	0.63%	0.45%	0.45%	5.01%	5.00%	1.08%	1.08%	5.33%	5.38%	2.40%	2.47%

TABLE 8 Adding trade in services

	Welfare effect		Terms of trade effect		Productivity effect	
	Baseline	With service	Baseline	With service	Baseline	With service
China	−7.61%	−7.85%	−0.06%	−0.21%	−7.55%	−7.63%
Japan	−0.01%	−0.01%	0.03%	0.06%	−0.04%	−0.05%
Korea	−0.02%	0.02%	0.09%	0.17%	−0.11%	−0.15%
EU27	0.01%	−0.02%	0.05%	0.03%	−0.04%	−0.06%
UK	−0.06%	−0.01%	−0.03%	0.03%	−0.03%	−0.04%
US	−0.05%	−0.04%	−0.02%	0.00%	−0.03%	−0.03%
ROW	−0.05%	−0.09%	0.01%	0.05%	−0.06%	−0.14%

TABLE 9 Counterfactual exercise: The same shocks happen in the other economies

	China	Japan	Korea	EU27	UK	US	ROW
China	−7.61%	0.01%	0.00%	0.06%	0.01%	0.07%	0.07%
Japan	−0.01%	−7.90%	0.00%	0.02%	0.00%	0.00%	0.03%
Korea	−0.02%	0.00%	−7.46%	0.05%	0.00%	0.03%	0.05%
EU27	0.01%	0.01%	0.00%	−7.74%	−0.01%	0.02%	−0.20%
UK	−0.06%	−0.02%	−0.01%	−0.14%	−7.52%	−0.07%	−0.12%
US	−0.05%	−0.02%	−0.01%	−0.06%	−0.01%	−7.65%	−0.13%
ROW	−0.05%	−0.01%	−0.01%	−0.12%	0.00%	−0.02%	−7.35%

exports to get proportions of trade with each partner. The proportions are assumed to be constant until December 2019 to construct the trade flows in that month. I incorporate trade in services and re-estimate the new equilibrium. Table 8 compares the baseline results with the new results. The welfare declines by 0.24% more in China. The welfare reductions are mitigated in Korea, the US, and the UK, but aggravated in the EU and the ROW. Although there is heterogeneity in the changes after considering trade in services, the impacts are generally larger.

The productivity effects are significantly bigger in Korea and the ROW, indicating their reliance on China's exports in producing services. When the production in the services sector is affected in China, the lower output impacts their production too through value chains. However, the terms of trade increase in all other economies except for the EU when considering trade in services. This is due to the fact that China is an importer in the services sector, and Chinese firms are substituting domestic services for foreign services.

5.2 | Comparison across economies

Another way to show China's importance in global value chains is to compare the welfare effects assuming the same sectoral shocks occur in another economy. For example, if the same supply shock happens in Japan, what will the welfare losses be in other economies? Will the impact be more severe or less? How about Korea? Table 9 shows the welfare changes in all economies (column) if the same shocks (in case one) happen in each economy in the row.

If the same shocks happen in Japan, Korea, or the UK, the welfare changes in other economies are limited to 0.02%. While if the EU is hit by the same shocks, then the UK and the ROW will suffer from higher welfare losses than the benchmark case. As the EU is the biggest economy in the world, the larger impacts are reasonable. The same reason applies to the ROW, which is an aggregate economy. While the US and China should be more comparable, shocks in the US have a higher welfare impact on the UK. Interestingly, China and Korea benefit from the productivity shocks in the US. The main reason is the substitution effect dominates.[25] Firms are switching their suppliers from the US to China and Korea, especially in the textiles sector and the computer sector. Overall, since the US has a higher reliance on imports, it generates a lower impact on world welfare. The comparison shows the importance of China in the global value chains as a world leading exporter.

6 | CONCLUSION

This article estimates the trade and welfare effects of Hubei's lockdown in China on several economies by a Ricardian model with sectoral linkages and trade in intermediate goods. I calibrate the model parameters using the data from STAN and WIOD. I study two ranges of productivity shocks, assuming a minor loss and a full loss in Hubei, according to the approach developed by Luo and Tsang (2020). China's welfare decreases by 7.61% in the first case and 18.28% in the second case. Korea, the UK, the US, and the ROW all have lower welfare levels in both cases. However, the EU's real income increases, where the other manufacturing sector and the computer sector are the largest contributors. Those sectors gain from substituting China's exports.

I derive a theoretical representation for welfare decomposition, and I introduce a new way to measure the influence of a productivity change on welfare. After decomposing the welfare effects into terms of trade effect and productivity effect, I find the magnitude of the two effects is comparable. Sectors vary a lot in their responses, depending on the sectoral linkages and the industrial sizes. Generally, export-oriented sectors in China contribute more to welfare changes given similar shock levels.

World output falls by 0.32% and 0.97% in two cases separately. The numbers are striking given the short period under consideration. China loses 4.97% output in case one. World sectoral output also responds differently. While most of the sectors' output fall, the other manufacturing sector's production increases by 0.34%. Similar results are found in case two, although the magnitude is higher.

In the extension, I find adding trade in services amplify the welfare effects. I also conduct a counterfactual exercise by assuming the same shocks happen in another economy and quantify the welfare changes. Comparison across countries reassures that China is playing a significant role in global value chains. I also check the robustness of the results by changing the trade elasticities. I find the results do not differ from the baseline significantly.

It is necessary to emphasize that this exercise only considers the lockdown of Hubei province without thinking about the further transmission of the virus. Thus the results only reflect a very small part of the influence of COVID shock on the world economy. Nevertheless, Hubei's lockdown provides a natural experiment to study the importance of China's role in global supply chains. Although the shock only happens in China, it affects countries worldwide rapidly and strongly. As the global trade pattern may change after the pandemic, how to optimize the supply chains in each country would be a useful and interesting future research direction.

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DATA AVAILABILITY STATEMENT

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials, and the code supporting the findings of this study are available within the supplementary materials.

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ENDNOTES

1 Carvalho and Tahbaz-Salehi (2019) provide an excellent summary of the recent development on this topic.

2 Although some countries in Europe took lockdown measures in late March, the drop in exports of the European Union only started to show up in April. See Eurostat News Release, https://trade.ec.europa.eu/doclib/docs/2013/december/tradoc_151969.pdf. Last accessed: November 17, 2020.

3 First-order effect here means the immediate impact on the supply-side. del Rio-Chanona et al. (2020) estimate the first-order effects in the US and find that impacts from the supply-side are much larger than from the demand side.

4 As Shimer (2005) stated, "A change in labor productivity is most easily interpreted as a technology or supply shock."

5 The number of the location parameter does not matter as it will be canceled out in equilibrium.

6 Denote the composite goods produced by firms in country n, sector j as Q_n^j. Then the market clear condition for Q_n^j is $Q_n^j = C_n^j + \sum_{k=1}^{J} \int m_n^{j,k}\left(\omega^k\right) d\omega^k$.

7 An important feature for this model is that the production of the composite intermediate goods Q_n^j requires the intermediate goods ω^j as inputs. Thus the productions of intermediate goods and composite intermediate goods are interrelated.

8 This is calculated by $X_{ni}^j = Pr\left[\frac{c_i^j d_{ni}^j}{z_i^j(\omega^j) A_i^{j\,\gamma_i^j}} \leq \min_{h \neq i} \frac{c_h^j d_{nh}^j}{z_h^j(\omega^j) A_h^{j\,\gamma_h^j}}\right] X_n^j$ and Equations (B.1) and (B.2).

9 I assume tariffs are zero here since the data are hard to get and complicate the collection process a lot. Besides, I am not interested in the tariff changes as in Caliendo and Parro (2015) since the time slot for my study is short.

10 The non-tradable sectors will not influence the result as they cancel out.

11 The original equilibrium is the following: Given L_n, D_n, A_n^j, and d_{ni}^j, an equilibrium is a wage vector $\mathbf{w} \in \boldsymbol{R}_{++}^{\boldsymbol{N}}$ and prices $\left\{P_n^j\right\}_{j=1,n=1}^{J,N}$ that satisfy equilibrium conditions (4) and (9)–(12).

12 Note the deficits remain the same after the shock because I want to make sure the only source of all changes in the model is $\widehat{A}_i^j$.

13 The derivations are in Appendix B.

14 Note that M_{ni}^j will not change due to the change in A_i^j since it is fixed at the pre-shock level.

15 In Caliendo and Parro (2015, footnote 42) states China is an outlier in the Chemicals sector. The value including China is −0.64. While the negative value seems strange, I use it as a robustness check in Section 5.1.

16 https://www.trademap.org. Last accessed: October 16, 2020.

[17] The steps for getting the values are: (1) calculate the share of Hubei's migrant workers in each province, (2) construct the sectoral production share in each province using the 2017 Industrial Production Yearbook and Statistics Yearbook of China. Then we can get the sectoral labor loss in each province by multiplying (1) and (2). More details can be found in Luo and Tsang (2020).

[18] I do not consider work from home (WFH) because most of the available studies focus on developed countries and WFH is much less common in developing countries. Saltiel (2020) finds around 23% work can be conducted from home in Yunan province in China. However, this is only for urban workers. Since I also take rural areas into account, the number would probably be even smaller and thus would have a very small impact on the results.

[19] These six sectors are petroleum, chemicals, rubber and plastic products, computer, electrical equipment, motor vehicles, and other transport equipment. According to the industrial value-added data from the National Bureau of Statistics of China, those sectors have similar losses.

[20] *Source*: National Bureau of Statistics of China, http://www.stats.gov.cn/tjsj/zxfb/202003/t20200316l732232.html. Last accessed: October 16, 2020.

[21] Although some numbers look small, the impact is, in fact, large. In Caliendo and Parro (2015), the welfare effects are also below 0.1% for Canada and Mexico due to the North American Free Trade Agreement (NAFTA).

[22] I also take the non-tradable sector into account, which is different from Caliendo and Parro (2015) since they are interested in the changes in tariffs, where the non-tradable sectors do not play any role.

[23] I only present the cost changes in case one here, as case two shows a similar pattern. Results for case two are shown in Appendix Table A.4.

[24] The latest available data is in the year 2019 for the US and the UK, in 2018 for Japan, Korea, and EU, and in 2016 for China.

[25] Although the period is short, changes of suppliers are still possible for some firms. In Ando and Hayakawa (2021), they show that countries generally have suppliers worldwide. When COVID had not yet become a pandemic before March 2020, the world production of machinery only dropped 10%.

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SUPPORTING INFORMATION

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