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How does COVID-19 affect the implementation of CORSIA?

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ABSTRACT

This paper investigates the impacts of COVID-19 on the implementation of Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). By using the Automatic Dependent Surveillance-Broadcast (ADS-B) aviation data, the forecast methods of Gompertz and Logistic curves and four COVID-19 scenarios, we find the following results. First, the international aviation activities of developing countries are on the track of rapid growth, while the trends of developed countries are relatively slow or even close to saturation. Second, our results provide retrospective support for the decision of the ICAO Council to revise the implementation baseline of CORSIA. The adjustment of the baseline has saved countries considerable purchasing offsetting costs, especially for China, the United States, the United Arab Emirates, and the United Kingdom. Third, although the adjustment of the baseline can lower the economic pressure of the global aviation industry, CORSIA will still bring considerable financial burden to international aviation enterprises.

1. Introduction

Given the significant environmental impacts brought by international aviation (Lee et al., 2010; Grewe et al., 2017; IATA, 2017), and the estimation that the emission level in 2050 will be 4 to 6 times higher than that in 2010 if emission restriction policies are not implemented (Cui and Li, 2017), in order to mitigate the greenhouse gas emissions from the international aviation activities, the International Civil Aviation Organization (ICAO) initiated the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) in 2016 (ICAO, 2016a). As of July 2020, 88 ICAO contracting states have announced their voluntary participation in the pilot phase of CORSIA (ICAO, 2020a). Most important “aviation countries”, such as the United States, the European Union, Canada, South Korea, Japan, the United Arab Emirates, and Qatar, have decided to participate from 2021. In contrast, countries such as China, Russia, India, and Brazil have not yet indicated their participation. Before the introduction of CORSIA, the European Union planned to include all flights passing through the EU into European Union Emission Trading Scheme (EU ETS), but this unilateral resolution has been stopped under the opposition of the United States, China and other countries (Larson et al., 2019). Then, CORSIA became the first industry emission reduction mechanism that broke through the national boundary, and also the first step of global aviation industry to reduce greenhouse gas emissions. In addition, the introduction of CORSIA seems to be timely, as people begin to have the awareness of emission reduction (Sharma et al., 2021).

With the introduction of CORSIA, airlines need to seriously consider how to reduce emissions, so as to operate in a more environmentally friendly way. Many scholars focus on CORSIA, mainly centering on economic impacts, environmental benefits and evaluation. In terms of economic impacts, according to ICAO (2016b), after the implementation of CORSIA, the carbon offsetting costs of global aviation industry will be between 5.3 and 23.9 billion US dollars in 2035, accounting for 0.5%–1.4% of the total revenue of international aviation, but this result does not take into account the pandemic. Maertens et al. (2019) pointed out that the implementation of CORSIA would cause great economic pressure on the development of aviation industry. Iacus et al. (2020) estimated that GDP losses of EU27 could reach 1.66%–1.98% by the end of 2020. In terms of environmental benefits, Scheelhaase et al. (2018) found that CORSIA would offset about 8% of the global aviation industry’s carbon emissions. Schep et al. (2016) found that an average of 81.5% of international air transport growth during 2021–2035 would be subject to the offset requirements of CORSIA. On the evaluation aspect, some scholars have questioned the fairness of CORSIA. On the one hand, it is difficult to balance the interests of all countries due to its imperfect supervision mechanism (Abeyratne, 2020). On the other hand, that the...
allocation follows the grandfather mechanism violates the principle of “common but differentiated responsibilities” (Zhao et al., 2014). However, it may still be the most suitable solution to deal with international aviation emissions (Efthymiou and Papatheodorou, 2019).

In the context of calling for aviation emission reduction, the rapid spread of COVID-19 has brought a huge negative shock to the international aviation and reduced the international flights significantly. At the beginning, the baseline level of carbon emissions in CORSIA is the average emissions of 2019 and 2020. However, due to the shrinking aviation activities in 2020, this baseline level has been reduced to a large extent, resulting in significantly higher offsetting requirements costs for carriers in future. If the baseline is maintained, the targets of CORSIA will be quite difficult to achieve. In March 2020, the International Air Transport Association (IATA) called on the Council of the ICAO to adjust the carbon emission baseline stipulated in CORSIA in time, so as to avoid the inappropriate economic burden on international aviation and ensure the sustainable development of the sector. In view of this, ICAO made a decision to change the baseline in the summer of 2020. Instead of taking the 2019–2020 average of CO2 emissions from international aviation, the new baseline is now simply the 2019 value, which would ensure the connectivity of international air transport system and contain further impact of the COVID-19 pandemic on air carriers to some extent. Even with the huge impact of COVID-19, the implementation time of CORSIA has not been postponed, and global airlines will make joint efforts to achieve the carbon neutral growth target.

Our work makes two main contributions to the literature. First, we are the first to quantify the impact of ICAO’s decision to adjust baseline on offsetting requirements, combined with actual emissions, forecast data and scenarios setting. Second, we are the first to estimate the offsetting costs over time as a consequence of the CORSIA rules, the adjusted baseline and COVID-influenced traffic volumes.

The rest of this paper is as follows. Section 2 calculates the actual aviation carbon emissions and forecast the emissions until 2035. Section 3 considers four scenarios in the context of COVID-19 and studies the impacts of baseline adjustment on offsetting requirements and offsetting costs. It also calculates the actual costs that the aviation industry of various countries needs to bear in CORSIA. The last section concludes and discusses policy implications. In order to make the framework of this paper easier to understand, a brief flow chart is made, as shown in Fig. 1.

2. International aviation carbon emissions forecast

2.1. Calculation of aviation carbon emissions

Aviation carbon emissions are defined as the total fuel carbon emissions of aircraft flying from one airport to another, including taxi-out, take-off, climb out, climb, cruise, descent, approach, landing, and taxi-in (see Fig. 2). These nine stages can be categorized as Take-off and Landing cycle (LTO) and Climb-Cruise-Descent cycle (CCD). The carbon emissions of the aircraft are calculated according to these two processes (Jardine, 2005), that is:

$$E_{\text{total}} = E_{\text{LTO}} + E_{\text{CCD}}.$$  
(1)

For the calculation of carbon emissions in LTO cycle, in the absence of specific flight data, the product of the number of LTO cycles and the carbon emission factors in each LTO cycle can represent the emission value (Rometo et al., 1999; EEA, 2010; Bo et al., 2019). We adopt a method with a high precision, which requires detailed aviation data to be available (ICAO, 2007; EEA, 2010; Liao et al., 2021), as follows:

$$E_j = \sum_k TIM_{jk} \times FE_{jk} \times EF_{jk} \times NE_{j},$$  
(2)

$$E_{\text{LTO}} = \sum_j E_j \times N_j,$$  
(3)

in which $E_j$ is the carbon emissions of aircraft type $j$ in a LTO cycle; $TIM_{jk}$ is the flight time (unit: s) of aircraft type $j$ in stage $k$; $FE_{jk}$ is the fuel efficiency (unit: kg/s) of the engine of aircraft type $j$ in stage $k$; $EF_{jk}$ is the emissions factor (unit: kg/km); that is, the amount of CO2 emitted by unit fuel; $NE_{j}$ is the number of engines of aircraft type $j$; and $N_j$ is the flight frequency of aircraft type $j$.

For the calculation of carbon emissions in a CCD cycle, we use the measured data of EEA. Taking the aircraft type B737-400 as an example, according to Table 1, when the cruise distance is 1500 nm, the fuel consumption in the CCD cycle is 8362 kg, while it is 11342 kg when the cruise distance is 2000 nm. We use interpolation method to calculate the fuel consumption of CCD cycle. For example, the fuel consumption of a B737-400 aircraft with a cruising distance of 1723 nm is calculated as follows:

$$8362 + ((11342 - 8362) \times (1723 - 1500) / (2000 - 1500)) = 9691 \text{ kg}.$$  

Note that the cruise distance of each flight is defined as the arc distance between the take-off and the landing airports. Then, using again the emissions factor, we can obtain the carbon emissions in the CCD cycle.

The emissions calculator of EEA can execute the calculation methods above for the LTO and the CCD cycles. In the calculation of carbon emissions of each country in 2018, we use the ADS-B aviation data in June 2018 provided by ICAO, the fuel consumption data of the LTO and the CCD cycles from EEA and the airport geographic location data in the Open Flight website. For the calculation of the total emissions in 2018, we convert the emissions from June to the whole year according to the annual share of aviation activities in June 8.83% (ICAO, 2019). In addition, around 5% of the ADS-B data is missing or wrong, and we replace them by the average values. The calculation results for actual carbon emissions are provided in the supplementary document. In order to avoid double counting, we define the ownership of a route as the country of the airline it operates. For example, if an international flight between the United States and Germany is operated by American Airlines, the carbon emissions of the flight belong to the United States.

2.2. Forecast of international aviation carbon emissions

The aviation industries in most developed countries have been well developed and relatively stable, while such industries in many developing countries are still in the initial stage or the stage with rapid growth. Therefore, it is necessary to consider the growth trend of aviation in each country and the difference between developed and developing countries when we analyze the future carbon offsetting and reduction burden.

We use the data of international aviation turnover from ICAO and Civil Aviation Administration of China (CAAC) between 1970 and 2018 to simulate the trend of international aviation carbon emissions of each country. We adopt the Gompertz and Logistic curves to simulate the trend, both of which are growth curve models and have been widely used in the medium and short-term development forecast of transportation industry. For instance, Ogut (2004) used the Gompertz and Logistic curves to forecast Turkey’s car ownership from 2004 to 2020. Mazzanti (2007) used the Logistic curve to predict the fuel consumption of Iran’s transportation sector. Keshavarzian et al. (2012) used the Gompertz model to predict the oil demand of road transportation sector in 154 countries. Lu et al. (2017) used the Gompertz model to predict China’s car ownership before 2025. Therefore, our forecast methods are consistent with the relevant literature.

The Gompertz curve can be expressed as Equation (4):

$$E_j = E_{j0} \times \exp(-\exp(-\lambda_j \times (t_j - 2000))),$$  
(4)

where $E_{j0}$ is the initial carbon emissions of aircraft type $j$; $\lambda_j$ is the growth rate; $t_j$ is the time (unit: year) of aircraft type $j$.
\[ Y_t = K_G \times a^b \]  

where \( Y_t \) is the freight volume in time \( t \), and \( K_G, a \) and \( b \) are parameters to be estimated. The Logistic curve is shown in Equation (5):

\[ Y_t = \frac{K_L}{1 + ce^{-rt}} \]  

in which \( Y_t \) is the freight volume in time \( t \), and \( K_L, c \) and \( r \) are parameters to be estimated. The parameters of these two models are estimated by nonlinear least square method. The model with the least residual error will be selected as the forecast model for a country. Our forecast models achieve a high degree of fit, and the forecast results are provided in the supplementary document.

The forecast results are only the normal growth scenario of the aviation industry without pandemic. It is necessary for us to know the development trend of aviation industry in various countries under COVID-19. Although it is recognized that COVID-19 has caused a short-term recession in the global aviation industry (Iacus et al., 2020), it is not expected to cause a long-term structural interruption (Scheelhaase

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**Table 1**

| Fuel Consumption (kg) | Cruise Distance (nm) |
|-----------------------|----------------------|
| **Stage**             | Cycle 125 | 250 | 500 | 750 | 1000 | 1500 | 2000 |
| Taxi-out LTO          | 183       | 183 | 183 | 183 | 183 | 183 | 183 |
| Take-off LTO          | 86        | 86  | 86  | 86  | 86  | 86  | 86  |
| Climb-out LTO         | 225       | 225 | 225 | 225 | 225 | 225 | 225 |
| Climb/Cruise/Descent  | 777       | 1442| 2787| 4134| 5477| 8362| 11,342|
| Approach Landing      | 147       | 147 | 147 | 147 | 147 | 147 | 147 |
| Taxi-in LTO           | 183       | 183 | 183 | 183 | 183 | 183 | 183 |
| Total                 | 1603      | 2268| 3612| 4960| 6302| 9187| 12,167|

Note: 1 nm = 1.852 km.  
Source: Air Pollutant Emission Inventory Guidebook 2009 (EEA, 2010)
et al., 2021). Note that according to the estimates of IATA (2020), the international aviation industry may recover to the level of 2019 from 2023. Therefore, under the influence of the pandemic, we postpone the forecast values for 4 years on the original basis. In addition, according to ICAO (2020b), the international aviation activities in 2020 will decline by 38%–71% compared to 2019, and then we set two scenarios. Under the optimistic scenario, the amount of aviation turnover in 2020 will decrease by 38% compared to 2019, while under the pessimistic scenario the percentage is set to be 71%. Combining the actual emissions in 2018 with the trend of emissions forecasted, we can obtain the international aviation carbon emissions for each country between 2021 and 2035 under the above three scenarios.

We select ten representative countries, including the top five developed countries (the United States, the United Kingdom, Germany, South Korea, and France) and the top five developing countries (China, the United Arab Emirates, Qatar, Turkey, and Russia) in terms of international aviation carbon emissions in 2018. The classification standard of developed and developing countries comes from World Factbook. These ten countries cover nearly 60% of international aviation activities. Fig. 3 shows the international aviation carbon emissions for each of the ten countries between 2021 and 2035 under the three scenarios. Compared with the scenario without COVID-19, the international aviation industry of each of the ten countries presents a sharp drop in 2020–2023 in the scenario with pandemic. In addition, although the pandemic will lead to a temporary decline in international aviation, it will continue to grow after the recovery in 2023. Ultimately, we find that the international aviation of developing countries, such as China, the United Arab Emirates, Qatar, Turkey, and Russia, grow faster than the other countries, which may be due to that the aviation markets of developed countries are mature or saturated, while the aviation markets of developing countries are in the stage of rapid development.

3. Impact of COVID-19 on the implementation of CORSIA

3.1. CORSIA

In order to reduce the burden of carbon offsetting obligation on airlines as much as possible, CORSIA will be implemented in three phases, including the pilot phase (2021–2023), the first phase (2024–2026) and the second phase (2027–2035). In the pilot phase and the first phase, countries will participate voluntarily, and developed countries will take the lead. The second stage is the compulsory participation stage, in which the contracting countries whose revenue ton kilometers (RTKs) of international aviation activities reach 0.5% of the global total in 2018, or whose cumulative share in the list of states from the highest to the lowest amount of RTKs reaches 90% of total RTKs, must participate, except for the least developed countries (LDCs), small island developing states (SIDS) and landlocked developing countries (LLDCs) unless they join voluntarily.

CORSIA is based on the “grandfather principle”. Specifically, the international carbon emissions that an airline needs to offset in a specific year are:

\[\text{Offset obligations of an airline} = a_t \times e_t \times \frac{E_i - E_B}{E_t} + \beta_t \times e_t \times \frac{e_i - e_B}{e_t}\]

(6)

in which \(t\) denotes the year; \(a_t\) denotes the proportion of aviation industry in year \(t\); \(\beta_t\) denotes the proportion of individual airlines in year \(t\), with \(a_t + \beta_t = 1\); \(e_t\) denotes the international emissions of airline \(i\) in year \(t\); \(E_t\) denotes the total international emissions of all airlines in year \(t\); \(e_B\) is the average of international emissions of airline \(i\) in 2019; \(E_B\) is the average of international emissions of all airlines in 2019. According to CORSIA, the principle of offset gradually shifts from industry to individual airlines, that is, between 2021 and 2029, \(a_t = 100\%, \beta_t = 0\); between 2030 and 2032, \(a_t \leq 80\%, \beta_t \geq 20\%\); and between 2033 and 2035, \(a_t \leq 30\%, \beta_t \geq 70\%\). It is worth noting that the initial offset baseline of CORSIA is the average emissions in 2019 and 2020. Considering the impact of the pandemic, ICAO has changed the baseline to the emissions in 2019. This change has important implications for the number of offsets that have to be bought. In the following analysis, we will explore the impact of baseline change on offsets quantity, so as to provide retroactive support for the baseline decision to some extent.

In CORSIA, airlines have the liability to offset emissions. In this study, we aggregate the emissions and offsets of airlines to the national level, and focus the analysis on countries, instead of airlines.

3.2. Scenarios in the context of COVID-19

As mentioned in Section 2.2, due to the impact of the pandemic, the international aviation carbon emissions in 2020 will be at a very low level. We have added two boundary scenarios. Under the optimistic scenario, the amount of emissions in 2020 will decrease by 38% compared to 2019, while, under the pessimistic scenario, the percentage is set to be 71%. In order to study the impact of baseline changes on the offsetting requirements of each country, we use the initial baseline and the new baseline to calculate the offsetting amount, respectively. With the basic scenario of no pandemic (or a normal scenario), we have four scenarios in total as shown in Table 2.

The proportions of individual airlines and industry between 2021 and 2035 are set according to the boundary proportions, that is, between 2021 and 2029, \(a_t = 100\%, \beta_t = 0\); between 2030 and 2032, \(a_t = 80\%, \beta_t = 20\%\); and between 2033 and 2035, \(a_t = 30\%, \beta_t = 70\%\).

3.3. Results of offsetting requirements

Based on Section 3.2, we calculate the amount of carbon offsets that each country needs to purchase during 2021–2035 under the four scenarios. The results are shown in Fig. 4.

In general, in the four scenarios, the offsetting requirement of the pessimistic scenario under the initial baseline is the highest. As the baseline value in the pessimistic scenario is too low, it will make countries bear high offsets. Although the slowdown of aviation growth under the pandemic will reduce countries’ offset to some extent, the former is still dominant. Note that the offsetting amount of the optimistic scenario under the initial baseline is close to that of the basic scenario without COVID-19, which may result from that the negative effect can be balanced by the positive effect of the slowdown of aviation growth on offsetting amounts. However, there are differences between countries. Specifically, in the United States, the United Kingdom, Germany, France, South Korea, and the United Arab Emirates, the offsetting amounts in the optimistic scenario are slightly higher than those in the basic scenario. The opposite is true in China, Qatar, Turkey, and Russia.

More importantly, the offsetting amount of the COVID-19 scenario under the new baseline is much lower than the other three scenarios under the initial baseline. In this scenario, before 2024, the emissions are lower than the baseline, so there is no need to bear the offsetting responsibility, which is observed in all countries. The outbreak of the pandemic has caused a great impact on the aviation industry of all countries. If the baseline is not changed, the aviation enterprises of all countries will bear a high carbon offset responsibility while facing the economic contraction caused by the pandemic. The change of the baseline would greatly reduce the offsetting amount and the cost of purchasing carbon offsets, and lower the economic pressure of airlines.

3 World Factbook: https://www.cia.gov/library/publications/the-world-factbook/appendix/appendix-b.html.

4 Specifically, the amount of emissions in 2020 is obtained by using the actual emissions in 2018 and the trend of emissions forecasted. In the case of no pandemic, baseline is also calculated according to the initial.
making airlines in all countries have a higher possibility to survive under COVID-19. Therefore, our results support the ICAO’s decision to change the baseline.

As CORSIA increases the proportion of individual airlines in 2030 and 2033, there exist inflection points in both years in the growth curve of offsetting amount in each country. It can be seen that the increase in the proportion of individual airlines is more friendly to the United States, the United Kingdom, Germany, France, South Korea, and the United Arab Emirates. Their offsetting amounts decrease at these two inflection points. Nevertheless, the increase in individual airlines’ proportion leads to more offsetting amounts in other countries. In fact, the main reason for this phenomenon may be the rapid growth of international aviation in China, Qatar, Turkey, and Russia. Compared with the situation of joint emission reduction of the whole industry, they will bear a higher offset responsibility in the case of high individual airlines’ proportion.

### 3.4. Results of offsetting costs

Compared with the offsetting requirements, airlines and academia may concern more about the cost of purchasing qualified offset units. The prices of carbon dioxide in 2020, 2030 and 2035 are estimated according to the ICAO website.

5 Carbon price comes from: https://www.icao.int/environmental-protection/pages/a39_corsia_faq3.aspx.

It can be seen that under the new baseline, the total offsetting costs of these ten countries increase year by year. Under the low carbon price, they will reach 0.39, 2.00 and 5.24 billion US dollars in 2025, 2030 and 2035, respectively. Under the high carbon price, they will reach 0.90, 4.39 and 10.49 billion US dollars, respectively. If we calculate according to the proportion of these ten countries’ emissions in the world in 2018, under the scenario of high carbon price, the global aviation industry will even pay more than 18 billion US dollars of offsetting costs in 2035. Among the ten countries’ total offsetting costs, China’s contribution is the highest, and it increases year by year, reaching 17.72%, 28.00% and 45.46% in 2025, 2030 and 2035, respectively. In addition, the United States, the United Arab Emirates, Qatar, Turkey, and Russia will also pay a lot of offsetting costs. Although the national aviation industry does not need to purchase the offset requirements before 2024, when the aviation industry recovers, the offsetting costs paid by the global aviation industry are not a small amount.

After modifying the baseline, the global aviation enterprises will still pay a considerable purchasing cost in the future. We are curious about how much the cost will increase if the baseline is not changed. Specifically, we obtain the results in four scenarios: the optimistic scenario under low carbon price, the optimistic scenario under high carbon price, the pessimistic scenario under low carbon price, and the pessimistic scenario under low carbon price, as shown in Fig. 6.

The results show that the baseline change will greatly reduce the offsetting costs of airlines in various countries, especially for China, the United States, the United Arab Emirates, and the United Kingdom. In the optimistic scenario under low carbon price, the cost reduction is the lowest. Specifically, for China, the United States, the United Arab Emirates, and the United Kingdom, it will reduce total carbon offsetting costs by 23%, 45%, 39%, and 44%, respectively. In the pessimistic scenario under high carbon price, the cost reduction is the highest. Specifically, it will reduce total carbon offsetting costs by 36%, 60%, 54%, and 59%, respectively. The baseline adjustment will greatly reduce the offsetting costs of aviation enterprises and make the global aviation industry operate better under the pandemic. These results show the necessity for ICAO to make the adjustment of baseline year in the context of global pandemic.
4. Conclusions

This paper studies the effects of COVID-19 on the implementation of CORSIA. The calculation based on micro flight data can ensure the reliability of results. We come to several major conclusions.

The forecast of international aviation carbon emission shows that there is still a large room for the growth of global aviation industry. Therefore, international aviation industry is a key area of global emission reduction in the future. The trend of international aviation carbon emissions varies from country to country. In general, the international aviation activities of developing countries such as China, Qatar, Turkey, and Russia are on the track of rapid growth, while the growth trend of international aviation industry in developed countries such as the United States, the United Kingdom, Germany, South Korea, and France is relatively slow or even close to saturation. Therefore, CORSIA brings more offsetting requirements to developing countries. The
opposite situations between developed and developing countries are largely due to that the annual offsetting requirements only depend on the difference between a year’s emission value and the baseline value and has nothing to do with future trend or historical emissions. If ICAO adjusts CORSIA in the future, future trend or historical emission levels should be taken into account.

The results of various scenarios provide retroactive support for the decision by the ICAO council to revise the baseline. The offsetting requirements of COVID-19 scenario under the new baseline are much lower than those under the initial baseline. In terms of offsetting costs, the adjustment of the baseline makes various countries save considerable costs to purchase offsetting requirements, especially for China, the United States, the United Arab Emirates, the United Kingdom, and other countries with large international aviation traffic volumes. If we estimate the global reduction in offsetting costs, it would make the global aviation industry save 5.03, 6.26 and 7.59 billion US dollars in 2025, 2030 and 2035, respectively. Therefore, the adjustment of baseline standard reduces the offsetting costs greatly and provides larger buffer room for global aviation enterprises.

Finally, since the implementation of CORSIA has not been delayed, we calculate the offsetting costs that the aviation industry will pay. The results show that, the ten countries in this paper will pay a total of 0.39–0.90 billion US dollars, 2.00 to 4.39 billion US dollars and 5.24 to 10.49 billion US dollars in offsetting costs in 2025, 2030 and 2035, respectively, with China topped the contribution. At a high carbon price, the global aviation industry will even pay more than 18 billion US dollars in 2035. Although the adjustment of the baseline has slowed down the economic pressure of the global aviation industry, CORSIA will still bring considerable offsetting costs to international aviation enterprises, which will make carriers pay more attention to carbon emission reduction, so as to operate in a cleaner way in the future.

For future research, the effect of baseline adjustment on air quality
and accordingly people’s health loss is worth further investigating, as only offsetting costs are considered in this study. A second potential avenue for future research would be to include other emission reduction measures of ICAO’s basket of measures such as sustainable aviation fuels and technological and operational improvements into our analysis framework. Last but not least, it is worth noting reduction during COVID-19 has led to a shift in the global aviation network from the hub-and-spoke network to the point-to-point network (Bauer et al., 2020; Liao and Wang, 2021). Since fewer stops under the point-to-point network may imply lower emissions, the change in network structure would affect the implementation of CORSIA (Wang and Wang, 2019a, 2019b). In addition, this trend may also make the implementation of CORSIA easier as it removes some countries with international hubs from the negotiation table. Therefore, a further study incorporating the change in airline networks after COVID-19 is highly valuable.

Author statement

Weijun Liao: Investigation; Methodology; Writing – orginal draft; Writing – review & editing. Ying Fan: Conceptualization; Investigation; Methodology; Funding acquisition. Chunan Wang: Investigation; Methodology; Writing - orginal draft; Writing – review & editing; Funding acquisition.

Declaration of competing interest

None.

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Appendix A. Supplementary data

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