Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
1. Introduction

By number of casualties and degree of socioeconomic loss, the COVID-19 pandemic has become one of the deadliest pandemics in modern world history (Sun et al., 2021). The transportation sector has inevitably suffered heavy losses, especially the civil aviation industry (Bulchand-Gidumal & Melián-González, 2021; Serrano & Kazda, 2020; Suau-Sanchez et al., 2020). Efficient air connectivity poses challenges to pandemic prevention and control (Sotomayor-Castillo et al., 2021). As air transport is a known COVID-19 vector, passengers worry about air travel (Lamb et al., 2020; Piccinelli et al., 2021; Sotomayor-Castillo et al., 2021), and this has driven some passengers to cancel their travel plans or switch to private cars (Lamb et al., 2021), and this has driven some passengers to cancel their travel plans or switch to private cars (Lamb et al., 2021). To prevent the pandemic’s spread, various countries and regions have closed borders, banned travel, and implemented a series of social distancing measures (Albers & Rundshagen, 2020; Budd et al., 2020; Daon et al., 2020). The pandemic and blockade measures have had a devastating impact on the global tourism industry (Lamb et al., 2021), leading to an unprecedented decrease in air passenger transport demand (Albers & Rundshagen, 2020; Andreana et al., 2021; Budd et al., 2020; Carter et al., 2021, p. 102047; Hou et al., 2021; Monmousseau et al., 2020; Sotomayor-Castillo et al., 2021), and many airlines have fallen into survival mode (Amankwah-Amoah, 2020; Amankwah-Amoah et al., 2021). Consequently, airlines grounded most fleets, changed flight businesses, reconfigured networks, reduced personnel (Budd et al., 2020), implemented job rotation (Suau-Sanchez et al., 2020), and sought government subsidies and support (Amankwah-Amoah, 2020; Hou et al., 2021). It remains to be seen when air transport will return to pre-epidemic levels and how long COVID-19 will continue to disrupt it (Hotle & Mumbower, 2021).

It appears, however, that China’s domestic passenger transport market is recovering. China’s air transport market was the first to be hit hard by COVID-19 (Czerny et al., 2021). Since China became the second-largest civil aviation market in 2005 worldwide, its air transport industry has developed rapidly, and many Chinese airports have become international hubs (Fu, Oum, et al., 2015; Wang et al., 2014). However, the progress of China’s air transport industry has not been smooth. The rapid development of high-speed railways has caused more frequent air-rail competition (Fu, Lei, et al., 2015; Zhang, Yang, et al., 2020), which has led, in turn, to a decline in civil aviation passenger traffic (Su et al., 2019a, 2020). In 2020, the pandemic caused Chinese airlines to turn from profitable operations to operating in the red. On January 23, 2020, Wuhan’s outgoing flights were grounded, and various regions
begin to issue restrictive regulations. Owing to strict case tracking and social distancing measures, COVID-19 has been under control since early March 2020. Then, as the government liberalised the domestic service of airport slots, the civil aviation market began to rebound (Hou et al., 2021) as the tourism industry also showed signs of recovery. During the 2021 May Day holiday, China’s tourism industry showed huge activity, with 230 million domestic tourists in only five days; it rose 119.7% year-over-year and recovered to 103.2% of the comparable data in the pre-epidemic period (Ministry of Culture and Tourism of China, 2021). In these five days, civil aviation was expected to transport 8.66 million passengers, a sharp increase of 173.9% over the same period in 2020, although a slight decrease of 0.8% over the same period in 2019 (China Civil Aviation Online, 2021).

More active study of the impact of COVID-19 on the civil aviation industry is necessary (Lamb et al., 2021). Although China’s social credit system and revised hukou system have unique characteristics affecting air travel as compared to global polities, studying the recovery model and policies of China’s civil aviation industry can still be an important reference for decision makers in other markets and can promote further debate (Czerny et al., 2021). After all, worldwide, nations have the same vision of controlling the spread of the pandemic and supporting the development of civil aviation. Therefore, in this study, we used the latest data, combined with the Moran index and econometric model, to analyse the spatial distribution characteristics of and factors influencing China’s pandemic and air passenger transport market. The important contributions of this paper are as follows: First, we use epidemiology statistics (e.g. COVID-19 confirmed cases, continuance days, and occurrence frequency) and socioeconomic development data (e.g. GDP, import and export value, tourism revenue), not used in existing studies, to gain insight into China’s current civil aviation passenger industry; second, we pay attention to the spatial distribution of the epidemic situation in China alongside civil aviation passenger throughput, to more intuitively explain the spatial changes and spatial correlation between the two; finally, this study analyses the impact of epidemic and socioeconomic factors on the civil aviation passenger transport market from a statistical perspective, including some influencing factors in the econometric model not considered in other literature.

2. Study area and data gathering

The study area is China’s mainland. To analyse the changes in civil aviation passenger traffic under the pandemic’s influence, we built a database including confirmed COVID-19 cases, continuance days, occurrence frequency, civil aviation passenger throughput, and local socioeconomic data (see below).

1. The data on civil aviation passenger throughput are from the ‘2020 Civil Aviation Airport Production Statistics Bulletin’, issued by the Civil Aviation Administration of China on April 9, 2021. The bulletin counted passengers throughput of 240 Chinese airports in 2020, given the passenger throughput of 238 airports in 2019. Taking city-level administrative divisions (including province-level municipalities) as statistical units, we integrated airport passenger throughput data.

2. COVID-19 confirmed cases, continuance days, and occurrence frequency were taken from provincial government and health commission websites. COVID-19 continuance days is the sum of the days with newly confirmed cases. COVID-19 occurrence frequency is the frequency and timing of COVID-19 outbreaks in various cities, in keeping with the epidemic prevention policy, which takes as a statistical cycle a continuous period of more than 21 days without newly diagnosed cases. We also take city-level administrative divisions as statistical units to integrate the cumulative confirmed cases. In all, 361 city-level data were obtained, of which 326 had confirmed cases.

3. Socioeconomic data came from the ‘Statistical Yearbooks’ published by various Chinese provinces, the ‘Statistical Bulletin of National Economic and Social Development’ for the past two years, and the Culture and Tourism Bureau websites. Because only some cities published a ‘Statistical Bulletin of National Economic and Social Development’ in 2020, the disclosure was not comprehensive; ultimately, through our best efforts, we collected 191 city-level GDP and 132 tourism income data.

Table 1 provides the descriptive statistics for civil aviation passenger throughput, GDP, import and export value, tourism revenue, COVID-19 confirmed cases, continuance days, and occurrence frequency, from which we find that China’s civil aviation passenger throughput and tourism revenue decreased significantly after the outbreak of the pandemic.

### Table 1: Descriptive statistics of relevant data

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|----------|-----|------|-----------|-----|-----|
| Passenger throughput in 2020 (10,000 passengers) | 201 | 426.370 | 918.132 | 0.379 | 6,164.217 |
| Passenger throughput in 2019 (10,000 passengers) | 201 | 672.417 | 1,565.769 | 2.096 | 12,179.134 |
| GDP in 2020 (RMB100 million) | 191 | 3,841.658 | 5,677.019 | 30.700 | 38,700.580 |
| GDP in 2019 (RMB100 million) | 191 | 3,735.790 | 554.438 | 28.558 | 38,053.680 |
| Tourism income in 2020 (RMB100 million) | 132 | 602.958 | 689.543 | 21.440 | 3,335.400 |
| Tourism income in 2019 (RMB100 million) | 132 | 945.030 | 1,069.619 | 30.786 | 6,226.496 |
| Import and export trade in 2020 (RMB100 million) | 129 | 2,276.428 | 8,535.714 | 0.300 | 87,463.100 |
| Import and export trade in 2019 (RMB100 million) | 129 | 2,223.544 | 8,379.153 | 0.120 | 84,261.172 |
| COVID-19 occurred (occurrences) | 326 | 1.089 | 0.361 | 1.000 | 4.000 |
| COVID-19 confirmed cases (people) | 326 | 253.571 | 2,800.425 | 1.000 | 142,000 |
| COVID-19 confirmed cases (days) | 326 | 45.488 | 17,624 | 22.000 | 142,000 |

Note: The social and economic data for 2019 are calculated on the real growth rate disclosed in 2020.

Economic and Social Development’ for the past two years, and the Culture and Tourism Bureau websites. Because only some cities published a ‘Statistical Bulletin of National Economic and Social Development’ in 2020, the disclosure was not comprehensive; ultimately, through our best efforts, we collected 191 city-level GDP and 132 tourism income data.

3. Methodology

3.1. Moran index

The Moran index (Moran, 1950, pp. 12–23) is one of the most popular methods for measuring spatial autocorrelation, or the presence of similar variable values in similar regions. If high values are clustered together, there is positive spatial autocorrelation; in contrast, if a high value is adjacent to a low value, there is negative spatial autocorrelation; and if the high and low values have a completely random distribution, there is no spatial autocorrelation. In this study, we used the Moran index to analyse the spatial correlation of confirmed COVID-19 cases. The value of the index is between -1 and 1, where a value greater than 0 indicates a positive correlation; that is, confirmed COVID-19 cases show a concentration tendency; in contrast, values less than 0 indicate a scattered distribution. The formula is as follows:

\[
I = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} (x_i - \bar{x}) (x_j - \bar{x})}{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}}
\]

where \(x_i\) and \(x_j\) are confirmed COVID-19 cases in cities \(i\) and \(j\), and \(n\) is

\(n\)
361 cities with or without confirmed cases; in addition, considering the epidemic’s spread from Wuhan to the surrounding cities, we use the adjacency matrix $\omega_{ij}$ to measure whether city $i$ is adjacent to city $j$ (if it is adjacent, $\omega_{ij} = 1$, and 0 otherwise).

3.2. Econometric model

As the COVID-19 was brought under control, the government liberalised the domestic service of airport slots, and the civil aviation market rebounded (Hou et al., 2021). For 2020, we find that the cities with more passenger throughput are indeed those with larger numbers of confirmed cases, and that hub airports still undertake the bulk of passenger transport. Therefore, we believe that even in cities with serious outbreaks and large numbers of confirmed cases, if the outbreak can be controlled quickly, rapid recovery of civil aviation passenger transport can occur. To test this idea, we constructed econometric Models (2) and (3).

$$\text{Passenger}_i = \alpha_0 + \alpha_1 \text{COVID-19}_i + \alpha_2 \text{GDP per capita}_i + \alpha_3 \text{Pop density}_i + \epsilon_i \quad (2)$$

$$\text{Passenger}_i = \alpha_0 + \alpha_1 \text{COVID-19}_i + \alpha_2 \text{Tourism}_i + \alpha_3 \text{Trade}_i + \alpha_4 \text{Pop density}_i + \epsilon_i \quad (3)$$

where Passenger$_i$ is the civil aviation passenger throughput of city $i$; Covid-19$_i$ is a variable related to COVID-19 in city $i$, including confirmed cases COVID-19$_{\text{cases},i}$, continuance days COVID-19$_{\text{days},i}$, and occurrence frequency COVID-19$_{\text{frequency},i}$. The socioeconomic factors of population and GDP are generally considered to be the main factors affecting transport services, widely used as explanatory variables in empirical studies (e.g. Chi & Baek, 2012; Zhang et al., 2017). China’s main domestic air routes are concentrated to the east of the ‘Hu line’, where there is a more developed economy and denser population. This provides evidence that economic development and population are important driving forces in the development of civil aviation (Su, Luan, Li, et al., 2019). Therefore, to eliminate multicollinearity, we use GDP per capita (GDP$_{\text{per}}$) and population density (Pop$_{\text{density}}$) as explanatory variables. At the same time, tourism and international trade play important roles in promoting cities’ development, and have an impact on the civil aviation industry. Combined with the correlation analysis results for existing data, we constructed Model (3) to analyse the impacts of tourism and international trade income on civil aviation passenger throughput.

Air transportation is closely related to COVID-19 communication (Zhang, Zhang, & Wang, 2020). We believe that the civil aviation hub
airports that undertake the main passenger transport tasks will prove to have been hit the most by COVID-19, and thus their decline in passenger throughput will be more obvious than that in other airports. To further analyse the impact of COVID-19 and level of socioeconomic development on changes in civil aviation passenger throughput, we constructed Models (4), (5), and (6).

\[
\Delta \text{Passenger}_i = \alpha_0 + \alpha_1 \text{Covid}_{19i} + \alpha_2 \text{GDP per}_{i} + \alpha_3 \text{Pop density}_{i} + \epsilon_i
\]  
(4)

\[
\Delta \text{Passenger}_i = \alpha_0 + \alpha_1 \text{Covid}_{19i} + \alpha_2 \text{Tourism}_{i} + \alpha_3 \text{Trade}_{i} + \alpha_4 \text{Pop density}_{i} + \epsilon_i
\]  
(5)

\[
\Delta \text{Passenger}_i = \alpha_0 + \alpha_1 \text{Covid}_{19i} + \alpha_2 \Delta \text{Tourism}_{i} + \alpha_3 \Delta \text{Trade}_{i} + \alpha_4 \text{Pop density}_{i} + \epsilon_i
\]  
(6)

where \( \Delta \text{Passenger}_{i} \) is the change in civil aviation passenger throughput compared with the previous year in city \( i \); that is, passenger throughput in 2020 minus passenger throughput in 2019. Similarly, \( \Delta \text{Tourism}_{i} \) is the change in tourism income in city \( i \), and \( \Delta \text{Trade}_{i} \) is the change in international trade income in city \( i \). In all formulas, the estimation coefficients \( \alpha_1-\alpha_4 \) represent the marginal effect of independent variables on \( \text{Passenger}_{i} \) or \( \Delta \text{Passenger}_{i} \), and \( \epsilon_i \) is the error term.

4. Result analysis

4.1. Spatial distribution of COVID-19 confirmed cases and civil aviation passenger throughput

To intuitively visualise the spatial distribution of the COVID-19 epidemic and civil aviation passenger throughput, we created a spatial distribution map (as shown in Figs. 1–4), and calculated the Moran index of COVID-19 confirmed cases using Geoda software. The following phenomena can be observed.

4.2. Regression analysis of econometric model

To statistically analyse COVID-19’s impact on civil aviation passenger transport, we used OLS + robust standard error to regress the econometric models. Tables 2 and 3 show the impact of socioeconomic indicators on passenger throughput in 2020 and 2019, that is, the regression results of Models 2 and 3. As Table 2 shows, the fit of the models to the samples is relatively good. By using 191 observations regressions, Model 2’s goodness-of-fit (R-squared) was found to be between 0.417 and 0.496; Model 3 used 108 observations, and R-squared was between 0.755 and 0.760. From the regression results, we find that as of 2019 or 2020, the per capita GDP, population density, tourism income, and international trade income all have significant positive effects on civil aviation passenger throughput. This indicates that the higher the level of socioeconomic development, the greater the...
throughput of civil aviation passengers. Even when the pandemic was spreading in 2020, this situation still appeared, consistent with the situation shown in Fig. 3. The estimation coefficient of Covid_19\_day shows that passenger throughput average increased from 92,630 to 12,1500 passengers in a city where epidemic continuance days increased by 1 day. The estimated coefficient of Covid_19\_Frequency is also significantly positive, while the confirmed cases had no significant impact. This shows that COVID-19 has a higher probability of frequent occurrence and duration in cities with high passenger throughput. After the effective control of COVID-19 in various cities, the relevant restrictive policies were serially cancelled, resulting in effective amelioration of the civil aviation industry. Fig. 5 shows the monthly data for China’s domestic and international passenger traffic volume in 2019 and 2020. We can see that civil aviation volume decreased significantly in February 2020, but that due to timely and effective control, domestic passenger transport volume began to gradually recover in March 2020, and, recovered to the same level as in 2019 by September 2020. However, international passenger transport volume remained at a low level due to the continuous spread of the pandemic globally at a much higher rate than that within China. In terms of regions (as shown in Fig. 6), passenger throughput in eastern China decreased significantly but still maintained its top ranking. The throughput average across the regions gradually recovered to 84% of its corresponding level in 2019 by September 2020. Although the eastern region recovered significantly in terms of passenger quantity, the degree of recovery was not as good as that in the other three regions. In general, passenger throughput for regions with relatively long COVID-19 continuance days and higher frequency remained at a relatively high level.

To further analyse the change in passenger throughput in 2020 compared with that in 2019 and, thus, measure COVID-19’s impact, we conducted OLS + robust standard error regression on Models 4, 5, and 6. The results are shown in Tables 4 and 5. From the regression results, we see that COVID-19 continuance days, and occurrence frequency had a significant negative impact on the change in passenger throughput. This shows that in cities with high frequency or long duration of COVID-19 outbreaks, the decline in civil aviation passenger throughput is relatively large. Although the passenger traffic volume in these cities has remained relatively high, it is undeniable that it has suffered a heavy blow since February 2020. The epidemic’s spread has led to strict regional human flow control measures and aviation control policies, which erased any increase in civil aviation passenger volume. In China, if a city becomes high-risk for COVID-19, travel to and from it will be strictly controlled. This kind of policy has been supported and coordinated across the entire country, so that COVID-19 has been quickly controlled in China. Under COVID-19’s influence, cities with greater per capita GDP and population density, that is, higher social and economic development, saw a greater decline in passenger throughput. The results statistically verified the conclusion reflected in Figs. 2 and 6. Tourism income and international trade income also have significant negative impacts, which indicate that the main cities with high tourism and international trade income saw a significant decline in passenger throughput.
1. COVID-19 confirmed cases are concentrated in the central and eastern regions, with Wuhan as the centre and rates decreasing to the periphery, showing a clear positive spatial autocorrelation (as shown in Fig. 1). Wuhan was the region where COVID-19 was first discovered and the centre of its spread in China. The Moran index was 0.0703 and passed the 1% significance test, indicating that the spatial distribution of COVID-19 confirmed cases in China showed a concentration tendency. Overall, areas with high confirmed COVID-19 cases are mainly concentrated to the southeast of the Hu line, an area that features a high degree of social and economic development and includes the provincial capital cities that serve as regional transportation hubs.

2. Under COVID-19’s influence, regions with an obvious decline in passenger throughput are mainly around provincial capitals (as shown in Fig. 2). However, even under the influence of COVID-19, the hub airports still undertake the main task of passenger transport (as shown in Fig. 3). During the pandemic, passenger throughput decreased significantly, in some cities by as much as 65.5%. Thus, the pandemic had a huge impact on the civil aviation passenger transport industry in China.

3. The overall distribution of passenger throughput in 2019 and 2020 did not change significantly. From Figs. 3 and 4, we find that China’s civil aviation passenger throughput is mainly distributed to the southeast of the Hu line, and those provincial capitals and province-level municipalities bear the main passenger throughput. Even under the pandemic, there was no substantial change in distribution, which is attributed to China’s effective control of COVID-19.

Table 2
Regression results of Models 1 and 2 using 2020 data.

| Passenger   | Model 1-1       | Model 1-2       | Model 1-3       | Model 2-1       | Model 2-2       | Model 2-3       |
|-------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Covid_19day | 12.125*** (3.60)| 9.263*** (2.92) | 9.263*** (2.92) | 0.853 (1.56)    | 0.853 (1.56)    | 0.853 (1.56)    |
| Covid_19Pos | 0.001 (0.12)    | 0.853 (1.56)    | 0.853 (1.56)    | 0.853 (1.56)    | 0.853 (1.56)    | 0.853 (1.56)    |
| GDP_per     | 36.702** (2.48) | 34.769*** (2.10)| 34.769*** (2.10)| 37.385** (2.21) | 37.385** (2.21) | 37.385** (2.21) |
| Pop_density | 0.573*** (3.30) | 0.787*** (3.53) | 0.787*** (3.53) | 0.692*** (3.32) | 0.692*** (3.32) | 0.692*** (3.32) |
| Tourism     | 0.721*** (4.92) | 0.752*** (4.68) | 0.752*** (4.68) | 0.721*** (4.92) | 0.721*** (4.92) | 0.721*** (4.92) |
| Trade       | 0.035*** (4.83) | 0.035*** (4.53) | 0.035*** (4.53) | 0.035*** (4.83) | 0.035*** (4.83) | 0.035*** (4.83) |
| Constant    | −597.779*** (−3.69)| −142.187 (−1.42)| −532.468*** (−3.72)| −473.769*** (−2.64)| −532.468*** (−3.72)| −532.468*** (−3.72)|
| R-squared   | 0.496           | 0.417           | 0.449           | 0.760           | 0.755           | 0.748           |
| Obs.        | 191             | 191             | 191             | 108             | 108             | 108             |

Note: ***significant at 1%; **at 5%; *at 10%; t-statistics in parentheses.
In China, as Fig. 7 shows, tourism has always been one of the main sources of civil aviation passenger transport. COVID-19’s impact on China’s tourism industry has resulted in a sharp drop in the number of domestic and international tourists, especially the latter (2.88 billion domestic tourists in 2020, a decrease of 52.1% over the previous year; domestic tourism revenue was RMB2228.6 billion, down 61.1%). The number of international tourists in most regions dropped by more than 90%). The negative impact of international trade also shows that, under the influence of COVID-19, the higher the degree of development and openness, the greater the decline in passenger throughput.

Table 5 shows the influence of variation in tourism and international trade income on changes in passenger throughput. Consistent with the results in Table 4, COVID-19 confirmed cases and duration days had a significant negative impact on passenger throughput. The regression result for tourism income variation is significantly positive, which indicates that cities with higher tourism growth had a greater increase in passenger throughput. In China, the area southeast of the Hu line has always been the most important passenger transport market of civil aviation, and COVID-19 has led to a major decline in socioeconomic indicators in this area, which has also led to a setback in the civil aviation passenger transport market.

5. Discussion

At a time when the epidemic is continuing to spread, it is necessary to enrich the studies of COVID-19’s impact on the aviation industry (Lamb et al., 2021). In the past two years, numerous relevant studies have emerged. This study focuses on the development of China’s civil aviation passenger transport industry under the influence of COVID-19. Using the latest data, the Moran index, and econometric models, it analyses the spatial distribution characteristics of COVID-19 and civil aviation passenger throughput.

It is worth mentioning that Wuhan, as the epicentre, faced a grave risk as well as immense responsibility. Its closure bought some time for China and the world to deal with the pandemic. Wuhan’s public health intervention measures not only played a decisive role in preventing the epidemic spread and deterioration but also provided essential information for public health authorities and policymakers in other countries and regions. No country can be isolated in an epidemic. As an important means of transportation for international and domestic travellers, civil aviation inevitably is a major medium for epidemic transmission.

Table 4
Regression results of Models 4 and 5.

| Passenger | Model 4-1 | Model 4-2 | Model 4-3 | Model 5-1 | Model 5-2 | Model 5-3 |
|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| \( \Delta \)COVID_{19}\_day | –11.855*** (–2.91) | –11.594* (–2.41) | | –0.903 (–1.59) | | –329.650* (–1.83) |
| COVID_{19}\_cases | | | –0.014*** (–2.68) | | | |
| COVID_{19}\_frequency | | | –364.118** (–2.17) | | | |
| GDP\_per | –27.069** (–2.50) | | | | | |
| GDP\_density | –0.292 (–1.48) | –0.495** (–2.06) | | | | |
| Tourism | | | –0.397** (–1.77) | 0.004 (0.03) | | |
| Trade | | | –28.029** (–2.12) | | | |
| Constant | 585** (3.05) | 136.888 (1.57) | 501.204** (2.37) | 514.294** (2.56) | 174.669** (2.42) | 436.337** (2.19) |
| R-squared | 0.450 | 0.322 | 0.386 | 0.810 | 0.786 | 0.787 |
| Obs. | 191 | 191 | 191 | 108 | 108 | 108 |

Note: ***significant at 1%; **at 5%; *at 10%; t-statistics in parentheses.
Therefore, while COVID-19 has not been effectively alleviated worldwide, civil aviation needs to continue to cooperate with and assist in epidemic prevention and control, taking social responsibility and ensuring the success of control policies.

Under the influence of COVID-19, both elastic and rigid demand decreased significantly. For example, the number of tourists dropped sharply, and online meetings replaced business travel (Fatmi et al., 2021). In 2020, the news that it was difficult to get a ticket to return to China attracted domestic attention. In addition, China implemented strict isolation measures for inbound passengers to protect public interest. In June 2020, CAAC put fuse-breaking and incentive measures in place for international flights to control the spread of the pandemic. Of course, this, in turn, provided a safe environment for the domestic civil aviation industry’s rapid and continuing recovery. However, this also led to a serious imbalance between supply and demand and a sharp rise in the number of unsold tickets for international flights. As self-financing organisations, it is understandable for airlines to make rational use of market rules to increase revenue. Ultimately, 2020 was a difficult winter for the civil aviation industry. Helping airlines survive the winter will be beneficial for all involved.

In the face of the social economy’s sustained recovery after COVID-19 subsides, airlines should see a market recovery, be able to formulate operational policies for their main passenger transport hubs, and strive to adjust ticket pricing and frequency to pre-epidemic rates. Today, the tourism industry is recovering steadily, and passenger traffic in various regions is increasing. In this regard, airlines should meet the changing needs of passengers in peak seasons and holidays and try to maximise profits. At the same time, it is necessary to deal with the possibility of ‘explosive’ travel growth after the epidemic.

Undeniably, China’s Social Credit System and Revised Hukou System have unique characteristics that help the government track patient trajectories and use health codes to collect personal information. However, as the visions of controlling the pandemic and supporting the civil aviation industry’s recovery are intertwined, studying the recovery model and aviation policy of China’s civil aviation industry can not only enrich existing studies and open the door for more in-depth analyses, but also provide an important reference for decision makers in other markets. As comprehensive data for national economic and social development of individual cities in 2020 have not yet been published, we could not research the impact on China’s civil aviation for all cities. However, our dataset covers most cities in China, and our data selection had a certain randomness due to the problem of disclosure. Therefore, our research has strong credibility and reference value for the analysis of the decline, recovery, and reconstruction of the civil aviation passenger transport industry during the COVID-19 pandemic.

### 6. Conclusions

We use COVID-19 confirmed cases, duration days, occurrence frequency, civil aviation passenger throughput, and cities’ socioeconomic data to analyse the impact of COVID-19 on China’s civil aviation passenger transport industry. At the same time, we focused on the spatial distribution of the epidemic situation and civil aviation passenger throughput as well as the spatial correlation between them. The following main conclusions can be drawn from the data analysis and measurement model.

1. China’s confirmed COVID-19 cases show a positive spatial correlation with Wuhan at the centre.
2. Due to China’s effective control of COVID-19, the domestic civil aviation industry has recovered rapidly. Even in areas with a large number of confirmed cases, COVID-19 has been quickly controlled, and the various restrictive measures have been subsequently cancelled, promoting the rapid recovery of the civil aviation passenger transport industry to the September 2020 level.

3. The international air passenger transport market continues to be depressed owing to continuous high COVID-19 prevalence internationally.

4. Relatively developed areas are still the main market for the civil aviation passenger transport industry, where the continuous spread and frequent occurrence of COVID-19 has led to especially large declines in passenger throughput. Although the eastern region’s recovery lags, the sharp rebound in passenger numbers has once again made it the main market for civil aviation, supporting its recovery.

5. Although the tourism industry has been significantly affected by the pandemic as well, it still makes a large contribution to the sustainable development of the civil aviation passenger transport industry in China.

CRediT authorship contribution statement

Min Su: Conceptualization, Methodology, Writing – original draft, preparation.
Baoyang Hu: Data curation, Visualization. Weixin Luan: Conceptualization, Writing – review & editing. Chuang Tian: Data curation, Software.

Acknowledgments

This work was supported by the Key Program of the National Natural Science Foundation of China (42030409).

References

Albers, S., & Rundhagen, V. (2020). European airlines’ strategic responses to the COVID-19 pandemic (January-May, 2020). Journal of Air Transport Management, 87, Article 101863. https://doi.org/10.1016/j.jairtraman.2020.101863
Amanwah-Amoah, J. (2020). Stepping up and stepping out of COVID-19: New challenges for environmental sustainability policies in the global airline industry. Journal of Cleaner Production, 271, Article 123000. https://doi.org/10.1016/j.jclepro.2020.123000
Amanwah-Amoah, J., Khan, Z., & Osabutey, E. L. C. (2020). COVID-19 and business renewal: Lessons and insights from the global airline industry. International Business Review, 30, Article 101447. https://doi.org/10.1016/j.ibusrev.2021.101447
Andreadis, G., Güralp, A., Martini, G., Porta, F., & Scotti, D. (2021). The disruptive impact of COVID-19 on air transportation: An ITS econometric analysis. Research in Transport Economics, 101042. https://doi.org/10.1016/j.retrec.2021.101042
Budhi, L., Isom, S., & Kenna, N. (2020). European airline response to the COVID-19 pandemic – contraction, consolidation and future considerations for airline business and management. Research in Transporta and Business Management, 37, Article 100578. https://doi.org/10.1016/j.rtbm.2020.100578
Bulchand-Gidumal, J., & Meli-Gualini, A., Martini, G., Porta, F., & Scotti, D. (2021). The disruptive impact of COVID-19 on air transportation: An ITS econometric analysis. Research in Transport Economics, 101042. https://doi.org/10.1016/j.retrec.2021.101042
Czerny, A. I., Fu, X., Lei, Z., & Oum, T. H. (2021). Post pandemic aviation market recovery: Effectiveness and lessons from China. Journal of Air Transport Management, 90, Article 101971. https://doi.org/10.1016/j.jairtraman.2021.101971
Deon, Y., Thompson, R. N., & Oboldt, U. (2020). Estimating COVID-19 outbreak risk through air travel. Journal of Travel Medicine, 27. https://doi.org/10.1093/jtm/taaa993
Fatmi, M. R., Thirkell, C., & Hossain, M. S. (2021). COVID-19 and travel: How our out-of-home travel activity, Home Activity, and Long-Distance Travel Have Changed.