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Recovery of Chinese low-cost carriers after the outbreak of COVID-19 pandemic

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ABSTRACT
This study conducts a detailed analysis of the response of China’s low-cost carriers (LCCs) to the threats posed by the pandemic from a route network perspective, aiming to explore the resilience of LCCs and Chinese airlines. Using geographic visualization and network analysis, we evaluate and compare the network connectivity of each Chinese LCC to see the change patterns, then elaborate on the network connection of Spring Airlines. The major results are: the LCC sector has not recovered, but some of them exceed the pre-pandemic levels in a less deregulated environment; different LCCs show different recovery patterns; Spring Airlines outperforms the other four LCCs in terms of network connectivity. The recovery process is supported by various external factors, such as the reduction of new confirmed COVID-19 local cases and international flights, the re-open of inter-provincial tour groups and tourism demand, the nationwide rebound activities promoted by the central government, and the supporting policies, especially new slot allocation processes issued by CAAC. The case study further indicates the effects of high-speed rail (HSR) and regional subsidy measures on the tactical actions of Springs in route planning. This paper serves as a referential case for the LCCs worldwide and has good application for the recovery of other LCCs in other countries. Moreover, the study conducted in this time window offers a chance to assess the development of Chinese airlines in a not fully deregulated aviation environment. It contributes to the debate on the theory of air network resilience.

1. Introduction
Since early 2020, COVID-19 pandemic has put the aviation industry into unprecedented challenges. A lot of academic literature has investigated the impacts of the COVID-19 pandemic on airlines (Naboush and Alnimer, 2020; Kao et al., 2020; Abate et al., 2020; Macilree and Duval, 2020) and the strategic reactions (Albers and Rundshagen, 2020; Akbar and Kisilowski, 2020; Amankwah-Amoah, 2020) or operation updates of airlines (Bauer et al., 2020; Schultz et al., 2020; Salari et al., 2020; Brown and Kline, 2020) in this historical crisis. However, to the best of our knowledge, few academic papers have directly explored the recovery patterns of airlines after the pandemic. Meanwhile, related studies all focused on full-service carriers (FSCs) except Bombelli (2020) studied the integrators FedEx, UPS, and DHL and Li (2020) investigated cargo carriers. There has little detailed analysis been done to date on the COVID-19 effect on low-cost carriers (LCCs).

Researchers have different opinions on the recovery of LCCs. For example, Suau-Sanchez et al. (2020) argued that the outbreak of COVID-19 brings LCCs chances to entry hub airports, enabling them to compete with existing network carriers to get quick recovery. In contrast, Abate et al. (2020) predicated that LCCs would be the underdog in the recovering processes because most government capital was poured into the national carriers. Empirical evidence supporting by accurate data is therefore needed to make sound argument on the LCCs’ network change patterns during the pandemic.

To fulfil these research gaps, this paper aims to explore the performance of China’s LCCs after the outbreak of the COVID-19 pandemic. As the first market hit hard by coronavirus, China has entered a domestic air transportation recovery period since April 2020. It is estimated that Chinese domestic aviation market recovered to about 80% of the pre-crisis level by July 2020, and the number of domestic air passengers reached 90% year-on-year (yoy) in April 2021 (Czerny et al., 2020). China has also emerged as a country that welcomed LCCs to some extent (Dobruszkes and Wang, 2019) but various regulations and barriers of route entry make Chinese LCC sector remains underdeveloped (e.g., Jiang et al., 2017; Fu et al., 2019). Civil Aviation Administration of
China (CAAC) issued a series of policies in March 2020 to promote stable development of the civil aviation industry, and those policies brought Chinese airlines with a less regulated environment in route planning and supported domestic aviation recovery effectively (Czerny et al., 2020). Thus, a focus of Chinese domestic sector could help relevant operators and LCCs in other similar countries to develop long-term route network planning in post pandemic business environment, as well as contribute to the studies related to the effect of aviation deregulation on Chinese aviation market.

Air route network is particularly susceptible to disruption events, such as natural disasters, strike action, terrorist threats, or extremely bad weather (Dunn and Wilkinson, 2016). The resilience of air transport network is considered as the ability of airlines to neutralize the impacts of the disruptive events. A few of academic literature have made efforts to quantify the resilience of indivisual airlines’ networks and approved that the ‘point-to-point’ network structure is much more resilient than the ‘hub-and-spoke’ structure adopted by network carriers, thus LCCs’ networks seem more robust than the hub-concentrated networks adopted by FSCs (Wuehner et al., 2015; Jordan et al., 2016; Wong et al., 2020). Bombelli (2020) investigated the early effect of COVID-19 on the global logistics networks and revealed that the integrators (FedEx, UPS, and DHL) have escaped the early months of the pandemic due to the resilience of their point-to-point networks. Inspired by the study of Bombelli (2020), this paper assesses and compares the resilience of LCCs before and after the outbreak of the COVID-19 pandemic.

Overall, this study has two main purposes. (1) To measure those changes in network connectivity and performance of Chinese LCCs since the recovery period. (2) To emphasize the resilience of LCCs against the uncertain crisis. Following Wu et al. (2020), this paper takes Spring Airlines (9C), West Air (PN), China United Airlines (KN), and Jiuyuan Airlines (AQ), and Lucky Air (8L) as Chinese LCCs. Primarily, this paper estimates those changes of nodes (navigable cities) and edges (flight routes); and develops an integrated metric to quantify the network connectivity of the whole LCC sector and indivisual LCC before and after the COVID-19 outbreak. Then, conducts a case study on Spring Airlines. Four datasets obtained from CAAC timetables (summer & winter seasons of 2019 and 2020) are used for calculation, geographic visualization, and comparison. This paper serves as a referential case for the LCCs worldwide and has good application for the recovery of other LCCs in other countries. Moreover, the study conducted in this time window offers a chance to assess the development of Chinese airlines in a not fully deregulated aviation environment. It contributes to the debate on the theory of air network resilience.

2. Literature review

There are many definitions and concepts of resilience. According to the phases of system response, the resilience of transport systems includes two capacities: coping capacity (the innate ability of the system to absorb externally induced changes) and adaptive capacity (the adaptive actions that can be taken to preserve or restore performance post-event) (Zhang et al., 2015). From the perspective of air traffic management, resilience includes three types of capacities: absorptive capacity (network can withstand disruption), adaptive capacity (the flows through the network can be reaccommodated), and restorative capacity (the recovery enabled within time and cost constraints) (Francis and Bekera, 2014; Cook et al., 2016). The absorptive capacity only focuses on strategic actions, while adaptive and restorative capacities are tactical actions that result in a reduction of the magnitude of the disruption from a given disturbance (Cook et al., 2016). Combined with the study of Zhang et al. (2015), airlines’ adaptive and restorative abilities are aligned with their tactical actions that can be taken to recover performance in the post-event period. This paper focuses on the tactical route actions adopted by Chinese LCCs in the COVID-19 scenario. Especially, the paper assesses the changes in route network and connection efficiency indicators to highlight the resilience of LCCs, from the very beginning of the coronavirus outbreak to the early recovery of Chinese domestic market. Given the long-term strategic measures and their effect on reducing disturbance are out of the scope of the paper, we employ adaptive and restorative abilities but exclude coping or absorptive capacity.

In this paper, resilience refers to recovery ability from an external disruptive event such as natural disasters, strike action, terrorist threats, as well as the COVID-19 pandemic for several reasons. Firstly, resilience generally refers to the ability of an entity to recover from an external disruptive event, in the context of engineering systems (Henry and Ramirez-Marquez, 2012). Secondly, academic literature on air transport prefers to use the definition of resilience engineering (Cook et al., 2016) and the introduction of ‘resilience engineering’ paradigm has resulted in qualitative modeling of resilience in air traffic management (ATM) since 2009 (Francis and Bekera, 2014). Thirdly, the resilience is an ability of an air network to retain a certain level of the nominal performance facing crisis and fully recover relatively fast afterward, such as in the air transport control sector (Jaksic and Janic, 2020).

It is reasonable to assume that Chinese LCCs could take active route strategies to restart the market. As mentioned above, China has emerged as a country that welcomed LCCs to some extent and each LCC has developed its own route strategy (Wu et al., 2020). However, various regulations and barriers of route entry make Chinese LCC sector remains underdeveloped. In addition, CAAC has announced to implement flexible capacity introduction policies, including support airlines to flexibly adjust flight plans; prolong the implementation of flight plan for the 2019 winter season to May 2, 2020; suspend the assessment of airline’s flight plan completion factor, slot execution rate and flight irregularity; and waive the assessment of domestic flight slot execution rate in the summer season of 2020. These policies give airlines, even the LCCs, a relatively free environment to decide the flight plan for the following seasons. Therefore, it is hypothesized that Chinese LCCs could take restored strategies by taking the summer season of 2020 as the adaptive period and the following winter season as recover (restorative) period, accordingly.

The complex theory is a useful tool to assess the network resilience against major events. For example, Berche et al. (2009) investigated resilience of public transportation networks, using node degree, betweenness centrality, closeness centrality as key indicators. Wuelner et al. (2010) calculated the network resilience of the seven US airlines, using complex network metrics. They found that the Southwest Airlines – an LCC carrier adopting a typical point-to-point route network – was extremely resilient to both random and targeted failures. Wong et al. (2020) applied network theory to discuss trends in resilience among four US airlines; again, Southwest was approved to be the most resilient to targeted removals. In the COVID-19 scenario, Su et al. (2020) examined the spatial-temporal evolutionary dynamics of the global air transportation networks through complex network analysis; Bombelli (2020) used the complex network methods to investigate the COVID-19 effect on the global logistics networks.

The COVID-19 is such a disruptive crisis causing drastic change to the airlines’ network thus brings about the discussion on the network resilience (Bombelli, 2020). Following the previous studies (Berche et al., 2009; Bombelli, 2020), this paper estimates the values of nodes (navigable cities), edges (flight routes), and complex network indicators of individual LCCs, before and after the outbreak of COVID-19. Then, we assess the recovery level of each LCC through the difference between indexes in different periods. We calculate the differences between summer and winter seasons for two reasons. First, Chinese LCCs tend to use different route plans in different seasons (Wu et al., 2020). Second, route plan in the summer of 2020 presents the adapt ability of resilience.

As the first established and most successful LCC in China, Spring Airlines is the most studied Chinese LCC in relevant studies (Fu et al., 2015; Jiang et al., 2017; Liu and Oum, 2018; Dobruszkes and Wang, 2019). This paper also conducts a case study on Spring Airlines to grasp...
its adaptive actions and route network strategies/targets. We furtherly use geographic visualization and topological indicators to fully demonstrate its recovery pattern. Connectivity-based indices are widely used in resilience-related studies (Gu et al., 2020), and recent studies on air transport system resilience began to measure the robustness of the network in terms of the topology characteristics of air network. It is argued that the network topology influences network resilience at the aspect of resistance and recovery abilities (Zhang et al., 2015). Given the importance of setting a topological metric in the assessment of the air transport network’s robustness (Zhou et al., 2019) and the successfully use of topological indicators in the assessment of Spring Airlines in previous studies (Jiang et al., 2017; Wu et al., 2020), we adopt the connectivity measures and use topological indicators to evaluate the resilience of Spring Airline’s air route network in case studies.

3. Data and methods

3.1. Chinese LCCs

By the end of 2019, there are five Chinese airlines adopted the low-cost business model (Wu et al., 2020), Table 1 presents the profile of each LCC. Both Spring Airlines (9C) and Jiujuan Airlines (AQ) are private airlines. 9C was established as an independent LCC in 2005; AQ started commercial operation in 2015 as the LCC subsidiary of Juneyao Air. West Air (PN), China United Airlines (KN) and Lucky Air (8L) are used to be full-service airlines and declared as LCC in 2013, 2014 and 2016, respectively. In terms of annual revenue, the average increased rate of LCCs in 2021 (Table 1) is higher than that of all Chinese airlines (about 13.3%).

3.2. Data selection

To be specific, we screened the information of those airlines from four of China’s domestic air passenger timetables: 2019 summer & autumn timetable (effective from Mar. 31, 2019 to Oct. 28, 2019, hereafter summer 2019), 2019/2020 winter & spring timetable (effective from Oct. 29, 2019 to May 2, 2020, hereafter after winter 2019), 2020 summer & autumn timetable (effective from May 3, 2020 to Oct. 24, 2020, hereafter summer 2020), and 2020/2021 winter & spring timetable (effective from Oct. 25, 2020 to Mar. 27, 2021, hereafter winter 2020). Each piece of information contains the origin, the destination, weekly frequency, aircraft types.

3.3. Methods

Primarily, this paper compares LCCs’ network changes in nodes (navigable cites), edges (flight routes), and network connection efficiency indicators (average degree, average path length, and clustering coefficient) of each LCC to grasp the overall change pattern and recovery level. Taking individual airlines’ network as an undirected connectivity graph \( G = (V, E) \), where \( V = \{v_i : i = 1, 2, 3, \ldots, n\} \), \( n = |V| \) means the number of nodes, and \( E = \{e_a : i = 1, 2, 3, \ldots, m\} \), \( m = |E| \) means the number of edges. We define two directly-linked nodes \( e_{ij} = 1 \), otherwise \( e_{ij} = 0 \); besides, \( e_{ii} = 0 \); each indicator is then explained as follows.

- Average degree

Degree is defined as the number of edges that a node connects, that is, the degree of a node \( v_i = k_i \). The average degree of all nodes \( k \) represents the average degree of the whole network. This index reflects the general situation of city-pair links in the network, see Eq. (1).

\[
\langle k \rangle = \frac{1}{N} \sum_{i=1}^{N} k_i
\]

- Average path length

The node distance \( d_{ij} \) represents the number of edges that connects the shortest path between node \( i \) and \( j \). The average path length \( L \) represents the mean distance of any two nodes of a network. The larger the value is, the more transit hubs are needed to reach the destination. This index measures the connection efficiency of the LCC network, see Eq. (2).

\[
L = \frac{1}{N(N-1)} \sum_{i \neq j} d_{ij}
\]

- Clustering coefficient

The clustering coefficient \( C \) of a node \( i \) is the ratio of the connected edges \( E_i \) with all its neighbors to the maximum number of possible links. The clustering coefficient of a network \( C \) is the mean value of all the single nodes. The larger the value is, the easier for the navigable cities (nodes) to connect each other by short distance. This index indicates the closeness between navigable cities in the LCC network, see Eq. (3).

\[
C = \frac{1}{n} \sum_{i \neq j} \frac{E_i}{(k_i - 1)(k_i - 2)/2}
\]

Then, a case study of Spring Airlines is conducted, using geographic visualization and topological indicators. In this part, the topological analysis indicators are used to evaluate the overall network connectivity; and the complex network indicators are used to evaluate the network connection efficiency.

The topological analysis metrics include four types of indicators (Jiang et al., 2017):

\[
\mu = m - n + g
\]

\[
\alpha = 2(m - n + g) / \lfloor(n - 1)(n - 2)\rfloor
\]

\[
\gamma = 2m / \lfloor n(n - 1) \rfloor
\]

\[
\beta = m/n
\]

where, \( m \) is the number of edges; \( n \) is the number of nodes, and \( g \) is the number of disconnected subgraphs which is usually set to 1. Generally, a larger value of \( \alpha, \gamma, \) or \( \beta \) indicates a better connectivity.

Furthermore, the paper calculates the changes in flight frequency (weekly flights). Flight frequency has important implications for connectivity and airline recovery in the Chinese domestic market (Wang et al., 2014). However, the frequency analysis could impose some data issues in this study because flight schedules are subject to change under the need for epidemic control; airlines could cancel/add the flights freely as CAAC suspended evaluating airlines regarding flight schedule execution rate for summer 2020. Therefore, this paper analyses recovery index

\[
\text{Index} = \frac{\text{Average daily flight utilization of 2021} - \text{Average daily flight utilization of 2020}}{\text{Average daily flight utilization of 2020}} \times 100\%
\]

This index reflects the recovery rate of flight schedules after the epidemic control. Table 2 presents a detailed profile of Chinese LCCs and their annual revenue (RMB billion) and flight frequency changes in 2020 and 2021.

Table 1

| Name       | Fleet size | Annual revenue (RMB billion) | 2020 | 2021 | Increased |
|------------|------------|-----------------------------|------|------|-----------|
| Spring 9C  | 102 (A320 series) | 9.16 | 10.90 | 18.57% |
| Lucky Air  | 51 (A320, A330, B737) | 3.93 | 4.33 | 10.02% |
| China United | 53 (B737 series) | 2.70 | 3.51 | 30.39% |
| West Air P | 37 (A319, A320, A321) | – | – | – |
| Jiujuan (AQ)| 20 (B737 series) | 1.88 | 2.26 | 20.36% |

Data source: Annual report of each carrier for 2020 and 2021.

\( ^{\text{a,b}} \): by the end of 2020.

\( ^{\text{c,d}} \): West Air did not issue annual reports for 2020 and 2021 due to a supervised reorganization. In March 2021, the number of flights served by West Air was 5% higher than in the same period of 2019; average daily aircraft utilization reached 9.3 h, 30% higher than the average rate of all airlines.
characteristics according to network efficiency and topological indicators, using frequency to highlight the recovery characteristics.

Finally, the recovery characteristics of China’s LCCs and Spring Airlines are interpreted in line with the COVID-19 pandemic situations and related policies. Given that the HSR network is a potential key factor that impacts Chinese domestic air services as well as LCCs (Wang et al., 2017, 2020; Su et al., 2020; Wu et al., 2020). This paper quantifies the changes in LCC destinations and routes connected with HSR stations to show the changes in the LCC-HSR relationship before and after the outbreak of the COVID-19 pandemic.

### 4. Recovery of China’s LCCs

#### 4.1. Nodes, edges and frequency

Table 2 shows the numbers of nodes (navigable cities), edges (flight routes), and frequency (weekly flights) provided by five LCCs show a general trend of increase. It seems that the performance of the LCC sector is better than that of FSCs, as the market share of all seats in mainland China flown by LCCs has grown from 10.1% in 2009 to 11.1% in 2020 (Spring Airlines, 2021). Therefore, we could conclude that the LCC sector in the Chinese domestic market has experienced a quick recovery and exceeded pre-epidemic levels, if only judged on the navigable cities, routes, and flights. Moreover, the mass increase in frequency reflected that the LCC sector has restored performance in winter 2020.

The above increases are in line with the reduction of new confirmed COVID-19 local cases in March of 2020, especially after no new local case was reported (IATA, 2020). It is also supported by the Notice of CAAC on Policies Supporting Active Response to COVID-19 Outbreak issued on March 9, 2020. The notice waived some requirements on slot allocation, such as exempting domestic flights from evaluating slot execution rate and allowing circulation of slots in slot pools for the 2020 allocation, such as exempting domestic flights from evaluating slot allocation or to claim historical slots. The submission deadline is 60 days before the operation, typically in January (March in 2020) and August. Consequently, the pandemic situation and aviation policies have encouraged LCCs to apply for more slots and serve more routes in

#### 4.2. Network connection efficiency

This paper uses the complex network metrics (average degree, average path length, and clustering coefficient) to illustrate the recovery level of network connection efficiency, in terms of different airlines. Table 3 lists the value of each metric in different seasons of 2020, with summer 2020. July and August are traditional peak seasons for domestic tourists. In 2020, domestic travel showed a “retaliatory rebound” in these two months. Again, the recovery of the domestic market in July and August has encouraged the LCCs to apply more routes for winter 2020.

It is acknowledged that the presented change rates differ from the actual ones. For example, the number of domestic routes flown by Springs by the end of 2020 is 210, 9% lower than the timetable (231). However, the performances of the LCCs in winter 2020 should be better than those in winter 2019. In winter 2019 (including January, February, March and April of 2020), the volume of domestic air passengers declined by more than 85% year-on-year (YOY) in February, 69% YOY in March, and 67% YOY in April, according to revenue passenger kilometers (RPKs) (IATA, 2020). From January 24 to February 16, 2020, the average flight cancellation rate of 9C, PN, KN, AQ, and 8L was 50.7%, 60.3%, 41.0%, 54.6%, and 68.3%, respectively. The number of domestic flights reached the lowest in the week of February 16, 2020. In this week, the flight cancellation rate of LCCs was 71.9%, 72.2%, 70.7%, 80.1%, and 84.0%, accordingly.

It is worth noting that the performance of 9C and AQ in winter 2020 is extremely better than those in summer 2020. The possible explanations are: (1) they are private airlines that could adopt more flexible tactics in a less deregulated environment. (2) They have more extra aircraft due to the suspension of international services. In order to rectually contain the increasing risks of imported COVID-19 cases, CAAC released the “Notice on Further Reducing International Passenger Flights during the Epidemic Prevention and Control Period” and officially implemented the “Five One” policy in March; furtherly reduced the total number of international passenger flights in June and December 2020, respectively. Under this background, 9C and AQ moved aircraft from the international to the domestic market. (3) They are both based in economically developed eastern cities (Shanghai and Guangzhou), owning the historical priority of slot in the busiest airports (Shanghai Hongqiao, Shanghai Pudong, or Guangzhou Baiyun).

### Table 2

Changes in five LCCs’ nodes, edges and frequency.

### Table 3

The results of complex network metrics.

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*The arrows indicate the increase (↑) or decrease (↓) in 2020 compared to the same period of 2019.

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1 Calculated by authors according to the data provided by Travel sky.
arrows indicating the increase (↑) or decrease (↓) compared to the same period of 2019. To demonstrate how the value of metrics evolve, Fig. 1 depicts the change curves of each LCC.

In general, the average degree of individual airlines’ network is related to the size of the airline, that is, a larger size means a higher capacity that more city hubs could be connected. For this reason, 9C has the highest average degree (over 4), followed by 8L and PN (between 3 and 4); AQ and KN have the lowest average degree (between 2 and 3). In practice, the average degree is impacted by route configuration and capacity allocation tactics adopted by each LCC. Fig. 1 (a) shows that 8L surpasses KN in terms of k value, suggesting that the tactic adopted by 8L has some advantages than that of PN. In fact, 8L can connect more tourist destinations due to the base in a leading tourism province (Yunnan Province), especially after the relaxation of travel ban in the domestic market. Similarly, KN has some advantages than that of AQ. However, more importantly, it is a key and reliable index to measure the recovery ability of air transport networks from a disruptive perspective: higher average degree values (k-value) can guarantee a competitive advantage in route coordination or rapid transit when disruptive event such as flight cancellations happened. Improving the average degree of air route networks may have become a common target for LCC route planners after the COVID-19 pandemic, for the k-value of each LCC in winter 2020 all surpasses those in winter 2019.

The average path length (L) represents the mean distance of any two nodes within individual LCC’s air routes network. The longer the value is, the more transit hubs are needed to reach the destination, or vice versa. In other words, a decline of the values indicates an improvement of network connection efficiency. The index values of three LCCs (9C, 8L, and AQ) all increase in summer 2020, then decline in the next season, while those values of PN show a reverse trend; KN sees constant increase during both periods. As a result, the difference among those the LCCs is not obvious in winter 2020 (Fig. 1(b)). Meanwhile, AQ has the longest average path length among all five LCCs, which suggests a sparser network layout. Furthermore, the flight distance is an essential factor in airlines’ operating costs. Provided that other conditions are invariant, the costs will decrease as the distance increases due to a fixed fuel consumption cost of aircraft take-off and landing. In fact, 9C has adopted long-haul routes strategy during the recovery phase partly because of this reason, which will be discussed in section 5.

From a practical point of view, clustering coefficient (C) reflects how tight air route network is organized and how closely the navigable cities are connected. These five LCCs are divided into two groups as there exist two types of trends: (1) decrease in the summer season then increase in the winter season (9C, 8L and KN); (2) increase in the summer season then decrease in the winter season (PN and AQ). In the first group, the network structure of these three LCCs are relatively compact than the other two LCCs, possessing more navigable cities and flight routes. They also follow similar recovery strategies by expanding their network after the summer transition, which increase the clustering coefficient values. In the second group, PN shows more variation than AQ. In summer 2020, the value of PN reaches 0.534 (the highest value among the five LCCs over the studying periods), indicating that it is more likely to develop a small-world network configuration and has a stronger adaptive ability than other LCCs. However, the index value of PN decreases and drops to the third place in winter 2020, which may relate to the dispersion of major routes’ capacity. AQ has the lowest value on this index through the whole period as it has the most sparsely-configured network among all the LCCs. For airlines, a closely connected network is also helpful when dealing with customer complaints caused by flights diverted during the recovery period, for they can provide alternatives to reroute those passengers.

4.3. Network connectivity

Above results show the overall connectivity of the LCC sector in China’s domestic market has exceeded the pre-crisis level. Table 4 summarizes the performance of each LCC regarding to network connectivity. Among all the LCCs, 9C owns the best network connectivity and improves connection efficiency; AQ also improves the overall network efficiency but still lags behind other LCCs. 8L and PN are the subsidiaries of the HNA Group Co., Ltd., and they share many similarities such as adopting hub-and-spoke networks and basing in cities located in West China (Wu et al., 2020). However, after the coronavirus outbreak, 8L keeps growing on the connectivity and exceeds its
pre-epidemic level, while PN shows a downward trend and is more likely to develop a small-word network configuration. As the only state-owned LCC, KN fails to achieve a rapid recovery.

4.4. Effect of HSR on LCC recovery characteristics

Given that HSR is a potential key factor that impacts the route network of Chinese LCCs (Wang et al., 2017; Wu et al., 2020), this section quantifies the changes in HSR-LCC connection to reveal the effect of HSR. It could be observed from Appendix A and Fig. 2 that LCC and HSR are tightly connected because cities with HSR generally account for a large proportion of navigable cities among all LCCs, and most of their routes connect cities with HSR stations. Secondly, different carriers have different situations. For example, KN has the largest number of cities without HSR; AQ operates most of its flights between cities with HSR stations. Thirdly, it seems that LCC and HSR have become less connected, as the total number of navigable cities without HSR increased by 12%. For 9C, especially, the number of navigable cities without HSR stations increases by 44% and the Y–N routes increases by 35%.

5. Case study of Spring Airlines

5.1. Recovery pattern

Compared with 2019, the numbers of cities and routes served by Spring Airlines (hereafter Spring) increase by 38% and 56% in winter 2020, marking the highest growth rate among the LCCs (Table 2). From the network perspective, there are two reasons to explain why Spring can surpass all the other LCCs. (1) It seldom operates flights to Wuhan or airports in Hubei province, thus slightly affected by the COVID-19 pandemic in terms of the number of navigable cities. (2) Spring is the leading LCC in operating international flights in China (Wu et al., 2020). Thus, the suspending and groundings of international flights have brought Spring more capacity, enabling large-scale domestic route network expansion.

Given that Spring’s network connection efficiency in winter 2020 is better than that in summer 2020 (Table 3), we can see that the route planning tactics adopted by Spring in winter 2020 are more effective than those in summer 2020. Meanwhile, the recovery characteristics of Spring Airlines are different from other LCCs, as the international flights accounted for nearly 35% of the capacity in its route network in 2019. Under the international passenger flights reduction and control policies, the number of international routes served by Spring decreases from 67 (by the end of 2019) to 7 (by the end of 2020); while the number of regional routes (to Hong Kong, Marco, and Taiwan) decreases from 13 to 2. It seems that Spring has successfully moved aircraft from the international to the domestic market, as the number of domestic routes has increases by 82 routes during the same period.

5.2. Change pattern of navigable cities

To grasp the general change patterns over the studying periods, we rank all the cities according to the number of flights per season (see Appendix B). Table 5 shows the general change patterns. In terms of the seasonal and regional changes, firstly, we can see most newly appeared

Table 4

| Airlines | Highlights |
|----------|------------|
| 9C       | - The best network connectivity performer; seems to recover or even more develop after the transition period |
| 8L       | - A medium-high level of network connectivity; an improvement of network connectivity; massive tourism routes operation |
| KN       | - A decline of network connectivity performance; verage path length increased but recovered slowly |
| PN       | - A downward trend of network connectivity; deviation from general trend of winter recovery; a small-world network possibility |
| AQ       | - Better network connectivity than before; sparser network configuration than other LCCs |

Fig. 2. Distribution of LCCs’ navigable cities with and without HSR station in summer 2020 (orange color represents the cities with HSR; blue color represents cities without HSR; the height of the bar chart represents the number of flights departing from the city each week/frequency). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)
cities are concentrated in the East (e.g. Changzhou, Lianyungang, and Linyi) and the Northwest Regions such as Zhongwei, Yan’an, and Zhangye) in summer 2020. Northwest areas are not main concentration area of the pandemic, having less confirmed cases. Therefore, it is safer for Spring to operate new routes in these areas to go through the summer transition. Then, Spring expands its network to more cities located in the Northwest and Southeast Regions, like Yulin and the Southwest Region like Lijiang. Also, Spring suspends services to some cities, including Manzhouli and Baishan in the Northeast region, Wuhan and Zhongqiajie in the Central and Southern Region, and Jining and Jinjiang in East China Region.

Here, we interpret the change patterns according to the COVID-19 pandemic situations and related policies from a perspective of newly appeared airports. Twenty new cities appeared in summer 2020. Among them, Jinan, Nantong, Zhengzhou, Xuzhou, Kashgar, and Karamay are typical cities that serve Labor Charter flights (the charter flights that were operated by airlines to send migrant workers back to work during the Wuhan lockdown period) (Wu et al., 2022). Linyi, Ganzhou, Shangrao, Zhongwei, Jingjiang, and Yang’an (in order of traffic rank) are famous Long March revolutionary bases (old revolutionary base areas). Those cities located in remote areas or ethnic regions generally have received special airport subsidies from CAAC since the outbreak of COVID-19. In April, the Ministry of Finance and CAAC jointly issued a notice to revise Small and Medium-sized airports’ subsidy measures. The revised subsidy measures increase the support for airports located in deep poverty areas, areas of ethnic minorities, old revolutionary base areas, remote areas, and areas with poor ground transport. It means that the local governments of the above Long March revolutionary bases could have new budgets to subsidize airlines for introducing new routes.

In June 2020, the central government announced three batches of special government bonds for COVID-19 control. Some cities migrated COVID-19 Central Government Special Bonds to support air transportation. Such as Lijiang, as a famous tourist destination, migrated 60 million yuan of special government bonds to support the civil aviation industry and tourism enterprises; the government of Yulin spent 2.1 billion yuan on the local transport sector, including airport maintenance and expansion and flight route subsidies. Thus, more third- and fourth-tier airports appeared in winter 2020, including Lijiang, Yulin, Qionghai, Yichang, Nanyang, Songyuan, and Wenshan. In other words, Spring could obtain extra subsidies and more slots in first-tier airports by launching flights from airports located in the old revolutionary bases.

### 5.3. Change pattern of routes

Spring’s route change pattern shows difference in different seasons. In summer season, there are less changed routes with higher average frequency on major change ones, while winter season shows the opposite trend. The number of flight routes served by Spring keeps growing from 2019 to 2020, and each season of 2020 outperforms the same period of 2019 (Table 2). In winter 2020, it achieves a maximum quantity of 231. Fig. 3 visualizes the change patterns in both summer and winter seasons. In summer seasons (Fig. 3 (a)), there are 66 new routes and 32 cancelled routes, and most of new routes are confined in the middle and eastern parts of China, with cities located in Northeast getting reconnected. The cancelled routes mainly are connection between inland cities, especially the cities near the territorial border which face a higher risk of imported cases. The major changed routes centered on Shanghai and Shijiazhuang, two hub cities of Spring. In winter seasons (Fig. 3 (b)), there are 91 new routes but only 11 cancelled routes, and the new routes connects with remote areas such as Lanzhou, or tourist destinations such as Lijiang. Spring’s route change pattern demonstrate that it expands its network by opening niche routes during winter 2020, which is an important part of its recovery strategies.

Then, the routes are divided into three levels according to traffic volume: trunk lines (having more than 800 flights per season), branch lines (having less than 400 flights per season), and average lines (having less than 800 but higher than 400 flights per season). Fig. 4 (a) shows that the trunk lines of summer are mainly connected by two city hubs (Shijiazhuang and Shanghi), serving cities within a wide geographical range from west to east. Interestingly, after the coronavirus breakout, Spring begins to operate more flights in long-haul routes based on the Shijiazhuang hub (e.g., Shijiazhuang-Urumqi, Shijiazhuang-Harbin, Shijiazhuang-Shenzhen). During the summer season of 2019, most trunk lines connect eastern coastline cities, while the trunk lines of winter are centralized in the Shanghai hub, connecting eastern areas and several cities of middle region.

The branch lines experienced more conspicuous changes during the winter season. Fig. 4 (b) shows a surge of the branch lines. It could be observed that those routes expand to more wide and remote cities in the winter of 2020 than the same period in 2019. In fact, after the launching of new route Ningbo-Lanzhou-Karamay in June 2020, Spring keeps on opening long-haul and stop-over routes that connect cities in the eastern and middle area with cities located in Xinjiang or Northeast region. However, many tourists are still cautious about traveling during the post-pandemic period, and the traffic volume of these routes is relatively tiny.

As for the average lines (Fig. 4 (c)), most of them are operated during the summer season of 2019 across the entire eastern region, with some long-haul routes connecting northwestern cities. Nonetheless, this market shrinks to the eastern and middle areas during the summer of 2020; that is, many long-distance routes originated from eastern hubs like Shanghai and Ningbo are canceled, and the focus has been shifted to the short- and medium-haul routes. This situation is kept till the winter season, as the pivotal role of the Shijiazhuang hub becomes increasingly apparent. This means that the eastern area is the most stable source market for Spring. It would choose to maintain the stability of those routes when the COVID-19 pandemic hardly hit the whole domestic market.

Table 6 summarizes major change routes of summer and winter seasons, using the number of new/cancelled routes, proportion, route’s name, and flight amount. Combined with Fig. 4, the following tactics adopted by Spring under the impact of the COVID-19 pandemic could be observed. (1) Expanding the network of major bases such as Shanghai, Shijiazhuang, Shenyang, Yangzhou, or Xi’an to strengthen the network. (2) Obtaining new slots in major hubs, such as Chengdu, Hangzhou, and Guangzhou. (3) Enlarging destinations to the third or fourth tier airports.

### Table 5
Change patterns of navigable cities.

| City rankings | Highlights |
|---------------|------------|
| Tier 1 (Ranking 1–40) | - Major hubs (Shanghai, Shijiazhuang, and Shenyang) maintain dominance |
| - Cities in this tier remains substantially unchanged, except Kunming in winter 2020 |
| - Beihai, Yuncheng, Harbin have some changes in their summer rankings, recover in the winter; Nanchang and Hefei see big jump in the rankings |
| - Most declined: Changchun. |
| Tier 2 (Ranking 21–40) | - Cities in this tier remains somehow stable with fluctuation, except the appearances of Jinan (a city appeared in the recovery period) |
| - Zunyi and Urumqi significantly move up the rankings (over 10 spots) |
| - Rankings of Guiyang, Sanya, and Nanning decline more than 10 spots |
| Tier 3 (Ranking 41–60) | - Rankings show notable swings. |
| - Significant drop in the ranking: Weihai, Wenzhou, Zhubai, Shaoyang |
| - Zhengzhou and Hohhot climb 28 and 27 spots in winter 2020 |
| - More than 20 cities are new destination appeared in the recovery period |
| Tier 4 (Ranking over 60) | - The most significant drop in the ranking: Anhun (drops 37 spots), Chengde (drops 30 spots), Xinxiang (drops 20 spots) |
located in the old revolutionary regions or ethnic regions, probably for financial subsidies and chances of getting more slots in hub airports, especially Shanghai. (4) Launching services to deep poverty areas such as Wenshan to practice Corporate Social Responsibility (CSR).

5.4. Changes of the overall network connectivity

This part further analyzes Spring’s network performance through topological indicators. Table 7 shows the values of those indicators of four seasons. It could be observed that all the indicators in summer 2020 have the smallest values, which is in line with the value of complex network indictors (Table 3). This suggests that the network of Spring shows the worst connectivity in the summer of 2020. Given that this period (Oct. 29, 2019–Mar. 2, 2020) contains the early outbreak stage of the COVID-19 pandemic, we presume that the air traffic connection between some closely-connected city pairs had been suddenly cut off to prevent the widespread of the coronavirus. Then, the network connection efficiency improves and surpasses pre-crisis level in winter 2020. However, if judged from the topological metrics, the overall network connectivity has not fully recovered yet, as the values of indicators $\alpha$ and $\gamma$ in winter 2020 are still lower than those in 2019. It suggests that the COVID-19 pandemic has had a particular influence on Spring’s overall network connectivity, which takes more time to recover to its pre-epidemic vigor.

6. Discussion and conclusion

As the first market hit by the pandemic and reopened at the end of February 2020 (IATA, 2020), China’s domestic market would be a typical case to investigate the recovery patterns of LCCs after the outbreak of the COVID-19. Using geographic visualization and network analysis, this study investigated the recovery characteristics of five Chinese LCCs according to the changes in nodes, edges, frequency, and complex network metrics. In addition to the effects of COVID-19 pandemic situations, new aviation policies, as well as central and regional governments’ subsidies, the study also discusses the effect of HSR on LCCs’ recovery characteristics. Furthermore, a case study on Spring Airlines is conducted to explore its route network tactical actions and the effects of above factors.

By comparing Five LCCs’ network changes in four periods, we find that the whole LCC sector has experienced a recovery process and exceeded the pre-epidemic level in winter 2020. Of course, different

Fig. 3. Changes in the flight routes of summer and winter: 2019 vs 2020.
airlines show different recovery patterns. Specifically, Spring Airlines enjoys the best network connectivity. Although Lucky Air and West Air belongs to the same parent company, these two LCCs show different trends of network connectivity. The former has a medium-high level of season, the overall network connectivity has not recovered to its pre-
tom in summer 2020. Though it has been gradually improved in the next
performance is not good. Jiuyuan Airlines lags behind other LCCs in winter
which, Spring Airlines starts to operate
outperform other business models in the Post COVID-19 Era. In line with
model (Spring Airlines, 2020).

The main findings of the case study are three. (1) Spring Airlines reaches the peak in destinations and routes in winter 2020. The overall network connectivity and network connection efficiency reach the bottom in summer 2020. Though it has been gradually improved in the next season, the overall network connectivity has not recovered to its pre-
crisis level even in winter 2020. (2) Long-haul trunk lines emerge in summer 2020, and branch lines expand to wider areas with longer flying distances in winter 2020. (3) Its recovery tactics include maintaining base cities’ traffic volume, dispersing capacity to major hubs, expanding to small cities, and launching services to deep poverty areas. According to the value of complex network metrics, we can see that the route planning tactics adopted by Spring Airlines in winter 2020 are more effective than those in summer 2020. It is in line with the key feature of adaptive capability (network can withstand disruption) as well as that of restorative capability (recovery enabled within time constraints and may focus on dynamics/targets) (Cook et al., 2016).

Czerny et al. (2020) estimated that a series of deregulation and supporting policies issued by CAAC could support the recovery of the Chinese aviation industry and argued for conducting case studies from the perspective of airlines. Through a case study of Spring airlines, it is approved that the revised Small and Medium-sized airports subsidy measures and Special government bonds for COVID-19 control are two policies that impacted LCCs’ selection of new destinations. It is also approved that these two policies have supported airlines’ recovery as the increase rates of routes, frequencies and connection efficiency indicators in winter 2020 are significantly higher than those in summer 2020. It seems that Spring Airlines could obtain extra subsidies and more slots in the first-tier airports by launching flights from the old revolutionary base or deep poverty areas. In the whole year of 2020, Spring Airlines gained a profit of $20.7 million despite that the turnover volume reduced by 21.8%, demonstrating the resilience of the low-cost business model (Spring Airlines, 2020).

The findings of this paper also show some distinct patterns. One aspect is the long-haul flight tendency. A previous study by Bauer et al. (2020) argued that the Ultra Long Haul (ULH) operation would outperform other business models in the Post COVID-19 Era. In line with this tendency, this study discovers that Spring Airlines starts to operate

(a) Trunk lines (number of flights> 800)

(b) Branch lines (number of flights< 400)

(c) Average lines (400 ≤number of flights≤ 800)

Fig. 4. Route evolution of Spring Airlines from 2019 to 2020.

Table 6
Major change routes of summer and winter.

| Season | New routes | Cancelled routes |
|--------|------------|-----------------|
|        | No. (%)    | No. (%)         |
| Summer | 66 (36%)   | 32 (17%)        |
|        | 900 (Shanghai-Luoyang) | 2100 (Shanghai-Shenzhen) |
|        | 900 (Shanghai-Chengdu)  | 1080 (Shanghai-Harbin) |
|        | 700 (Shanghai-Jinjiang) | 840 (Shijiazhuang-Beijing) |
|        | 500 (Yancheng) | 250 (Mianyang) |
|        | 650 (Chengde-Dalian) | 350 (Shijiazhuang-Xiamen) |
| Winter | 91 (39%)   | 11 (5%)         |
|        | 924 (Shanghai-Quanzhou) | 616 (Shanghai-Jinjiang) |
|        | 500 (Lanzhou) | 616 (Lanzhou) |

*1: Proportion of the number of changed routes to the total number of routes in that season of 2020.
*2: The numbers in brackets indicate the frequency on that route in each season, here major change routes refer to routes with more than 500 flights.

Table 7
The results of topological analysis indicators of Spring Airlines from 2019 to 2020.

| Topological indicators | Summer 2019 | Winter 2019 | Summer 2020 | Winter 2020 |
|------------------------|-------------|-------------|-------------|-------------|
| µ                      | 82          | 88          | 99†         | 142†        |
| α                      | 0.038       | 0.044       | 0.028†      | 0.036†      |
| γ                      | 0.067       | 0.073       | 0.053†      | 0.058†      |
| β                      | 2.209       | 2.338       | 2.153†      | 2.567†      |

* The arrows indicate the increase (↑) or decrease (↓) in 2020 compared to the same period of 2019.
more flights on long-haul routes in the adaptive period and adopts the same route strategy in the restorative period. Another particular focus of our findings relates to the LCC-tourism relationship. When the international tourism market shrinks and the domestic market thrives, the relationship between LCC and tourism is meant to be mutually beneficial due to lower traveling costs. Therefore, relevant public sectors should reboot a sustainable pathway by prioritizing the intra-tourism promoted by LCC in the post-pandemic business environment (Ania and Joseph, 2021). This study also find that the number of navigable cities without HSR stations increased by 44% and the Y–N routes increased by 35%, confirming the pressure of HSR on LCC on the short-haul routes (Su et al., 2020). It is worth noting that our analysis is consistent with Wang et al. (2017), who suggested LCC is likely to squeeze the living space of HSR in less populated areas in China, especially in the central and western regions.

China has been pursuing a zero virus policy and reducing international passenger flights over the last two years, raising some practical implications for aviation stakeholders. For airlines, internal adjustment is required apart from government support. For LCCs, strategic network reconfiguration is needed against major crises. On the basis of maintaining major hubs connectivity, LCCs could expand their routes to connect remote places or tourism destinations to keep their market shares. For aviation authorities, it is vital to ally with companies and local governments, providing necessary support to guarantee the smooth transition from the COVID-19 pandemic. Overall, this historical crisis provides a special window time for the Chinese aviation industry to raise the awareness of supporting LCCs to enter international routes, maintaining infrastructure, optimizing network structure, and cultivating remote airports. The central government needs to provide more special bonds for the aviation industry for pandemic control. Air transport is approved to be an effective transport method as the risk of in-flight transmission is very low (Bhuvan et al., 2021). Addition to the rise in oil prices, the increase of new local confirmed cases have brought Chinese airlines great pressure and challenges in last two years. CAAC has injected three billion yuan into each of the three state-owned aviation groups (Air China, China Eastern, and China Southern). However, it is nowhere near enough.

The COVID-19 pandemic has greatly challenged the aviation industry since the beginning of 2020. This study conducted in this time window offers a chance to assess the movement of Chinese airlines in a not fully deregulated aviation environment. Wu et al. (2022) explored how Chinese airlines started and were involved in labor charter operations during the Wuhan lockdown period, showing that labor charter operation was airlines’ response to rebound activities and private airlines played a leading role in the initial stages. Following Wu et al. (2022), this paper highlights the resilience of LCCs after the re-opening of the domestic market. However, it should be noted that this study only provides a geographic analysis of Chinese LCC networks. Besides, it fails to compile cancelled flight information due to data limitations, whereas flight cancellation is an important indicator for assessing the network resilience of LCCs (Wuellner et al., 2010; Wong et al., 2020).

Future studies could conduct in-depth investigations based on more indicators such as airlines’ performance, aircraft size, and flight cancellation rates. Due to the reduction of international services, Air China, China Southern, and China Eastern have kept expanding the domestic market: the total number of domestic passenger flights provided by those three state-owned FSCs has increased by nearly 30%, from 141 thousand in January 2021 to 182 thousand in January 2022. Thus, further studies should explore the FSC-LCC competition or the impact of FSC and HSR operations on the LCCs’ recovery in such a disruptive event.

Author contribution

Maozhu Liao: Methodology; Writing – original draft; Writing – review & editing, formal analysis, Chuntao Wu: Conceptualization, Writing - review & editing, Formal analysis, Supervision, Hongmeng Yan: Data curation; Software.

Declarations of conflict interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Summary of LCCs’ route choices against HSR presence during the summer seasons

| Airlines | No. of | In Summer of |
|----------|--------|--------------|
|          |        | 2019 | 2020 | Change rate |
| 9C       | Navigable cities with HSR station (Y) | 58 | 72 | 24% |
|          | Navigable cities without HSR station (N) | 9 | 13 | 44% |
|          | Y–Y routes | 130 | 159 | 22% |
|          | N–N routes | 1 | 1 | 0% |
|          | Y–N routes | 17 | 23 | 35% |
| BL       | Navigable cities with HSR station (Y) | 51 | 58 | 14% |
|          | Navigable cities without HSR station (N) | 11 | 12 | 9% |
|          | Y–Y routes | 76 | 92 | 21% |
|          | N-N routes | 3 | 5 | 67% |
|          | Y-N routes | 28 | 29 | 4% |
| KN       | Navigable cities with HSR station (Y) | 63 | 68 | 8% |
|          | Navigable cities without HSR station (N) | 14 | 14 | 0% |
|          | Y–Y routes | 76 | 78 | 3% |
|          | N-N routes | 1 | 1 | 0% |
|          | Y-N routes | 22 | 30 | 36% |
| PN       | Navigable cities with HSR station (Y) | 39 | 38 | -3% |
|          | Navigable cities without HSR station (N) | 7 | 7 | 0% |
(continued)

| Airlines No. of In Summer of Change rate |
|---|---|---|---|
| | | 2019 | 2020 | |
| Y–Y routes | 67 | 67 | 0% |
| N–N routes | 0 | 0 | 0% |
| Y–N routes | 13 | 12 | –8% |
| AQ | Navigable cities with HSR station (Y) | 31 | 33 | 6% |
| Navigable cities without HSR station (N) | 2 | 3 | 50% |
| Y–Y routes | 44 | 45 | 2% |
| N–N routes | 0 | 0 | 0% |
| Y–N routes | 3 | 4 | 33% |
| Overall | Navigable cities with HSR station (Y) | 242 | 269 | 11% |
| Navigable cities without HSR station (N) | 43 | 48 | 12% |
| Y–Y routes | 393 | 441 | 12% |
| N–N routes | 5 | 7 | 40% |
| Y–N routes | 83 | 98 | 18% |

*1 Shanghai Pudong and Shanghai Hongqiao are counted as one airport.
*2 The Y in the parentheses indicates cities with (at least one) HSR station(s), N indicates cities without HSR stations.
*3 The Y–Y indicates routes between any two cities with HSR stations; N–N indicates routes between any two cities without HSR stations; Y–N indicates routes connecting cities with HSR and cities without HSR stations.

Appendix B. Rank changes of cities served by Spring Airlines, by no. of flights

| No. | City | Rank in summer 2019 | Rank in summer 2020 | Rank in Winter 2019 | Rank in Winter 2020 | Rank change in summer | Rank change in winter |
|---|---|---|---|---|---|---|---|
| 1 | Shanghai | 1 | 1 | 1 | 1 | 0 | 0 |
| 2 | Shijiazhuang | 2 | 2 | 2 | 2 | 0 | 0 |
| 3 | Lanzhou | 3 | 3 | 3 | 3 | 0 | 0 |
| 4 | Ningbo | 6 | 8 | 4 | 4 | 2 | 0 |
| 5 | Shenyang | 5 | 7 | 6 | 5 | 2 | 1 |
| 6 | Shenzhen | 4 | 5 | 5 | 6 | 1 | 1 |
| 7 | Yangzhou | 20 | 6 | 9 | 7 | 14 | 1 |
| 8 | Jieyang | 8 | 4 | 11 | 7 | 14 | 3 |
| 9 | Shenyang | 17 | 17 | 8 | 9 | 0 | 1 |
| 10 | Xiamen | 6 | 8 | 4 | 4 | 2 | 1 |
| 11 | Guangzhou | 5 | 5 | 6 | 6 | 1 | 1 |
| 12 | Xi’an | 15 | 13 | 12 | 12 | 0 | 0 |
| 13 | Nan’nan | 3 | 3 | 3 | 3 | 0 | 0 |
| 14 | Harbin | 11 | 15 | 14 | 14 | 4 | 0 |
| 15 | Yancheng | 14 | 13 | 15 | 15 | 1 | 0 |
| 16 | Huzan | 10 | 12 | 15 | 16 | 2 | 1 |
| 17 | Changzhou | 24 | 19 | 12 | 17 | 1 | 5 |
| 18 | Hefei | 39 | 20 | 18 | 25 | 19 | 7 |
| 19 | Quanzhou | 21 | 21 | 28 | 21 | 0 | 0 |
| 20 | Beihai | 40 | 38 | 20 | 20 | 2 | 0 |
| 21 | Hangzhou | 21 | 25 | 28 | 21 | 3 | 7 |
| 22 | Kumming | 12 | 21 | 18 | 22 | 7 | 4 |
| 23 | Yinchen | 44 | 10 | 19 | 23 | 1(max)34 | 4 |
| 24 | Chengdu | 28 | 25 | 30 | 23 | 13 | 7 |
| 25 | Dalian | 17 | 16 | 30 | 25 | 1 | 5 |
| 26 | Sanya | 29 | 43 | 25 | 25 | 15 | 10 |
| 27 | Zhanjiang | 43 | 24 | 25 | 27 | 19 | 2 |
| 28 | Tianjin | 34 | 32 | 25 | 27 | 12 | 2 |
| 29 | Urunchi | 26 | 36 | 40 | 29 | 10 | 11 |
| 30 | Zhangjiakou | 45 | 40 | 30 | 29 | 5 | 1 |
| 31 | Zunyi | 23 | 36 | 40 | 31 | 13 | 11 |
| 32 | Nanjing | 28 | 23 | 48 | 32 | 15 | 18 |
| 33 | Changde | 17 | 31 | 23 | 32 | 14 | 9 |
| 34 | Fuzhou | 40 | 34 | 30 | 32 | 16 | 8 |
| 35 | Mianyang | 13 | 21 | 29 | 35 | 18 | 7 |
| 36 | Guiyang | 15 | 25 | 22 | 35 | 10 | 12 |
| 37 | Nanning | 49 | 58 | 24 | 37 | 19 | 14 |
| 38 | Luoyang | 34 | 34 | 30 | 38 | –0 | 8 |
| 39 | Jinan | 55 | 55 | 55 | 55 | 0 | 0 |
| 40 | Guilin | 34 | 29 | 42 | 40 | 5 | 2 |
| 41 | Weihai | 28 | 43 | 30 | 40 | 15 | 10 |
| 42 | Zhengzhou | 43 | 60 | 43 | 60 | 1(max)28 | 28 |
| 43 | Hohhot | 45 | 40 | 60 | 45 | 15 | 27 |
| 44 | Yulin | 43 | 43 | 43 | 43 | 0 | 0 |
| 45 | Guangyuan | 28 | 43 | 30 | 45 | 15 | 15 |
| 46 | Wenzhou | 34 | 38 | 30 | 46 | 4 | 16 |
| 47 | Qingdao | 27 | 40 | 43 | 46 | 13 | 3 |
| 48 | Changzill | 43 | 46 | 46 | 46 | 9 | 2 |
| 49 | Taiyuan | 49 | 58 | 48 | 46 | 9 | 2 |
| 50 | Yueyang | 58 | 46 | 46 | 46 | 9 | 2 |

(continued on next page)
### Table: City Ranking Change 2019 vs 2020

| No. | City       | Rank in summer 2019 | Rank in summer 2020 | Rank in Winter 2019 | Rank in Winter 2020 | Rank change in summer | Rank change in winter |
|-----|------------|---------------------|---------------------|---------------------|---------------------|-----------------------|-----------------------|
| 51  | Jinggangshan | 62                  | 50                  | 55                  | 51                  | ↓14                   | ↓13                   |
| 52  | Qingyang    | 62                  | 73                  | 55                  | 51                  | ↓11                  | ↓15                   |
| 53  | Dunhuang    | 49                  | 43                  | 48                  | 53                  | ↓16                  | ↓13                   |
| 54  | Zhoushan    | 54                  | None               | New                 | None               | New                   | None                  |
| 55  | Baotou      | 49                  | 43                  | 60                  | 55                  | ↓16                  | ↓15                   |
| 56  | Zhubai      | 42                  | 29                  | 45                  | 56                  | ↓13                  | ↓16                   |
| 57  | Handan      | 28                  | 33                  | 60                  | 57                  | ↓15                  | ↓13                   |
| 58  | Shaoyang    | 45                  | 55                  | 30                  | 57                  | ↑10                  | ↑27                   |
| 59  | Nantong     | 55                  | 46                  | 57                  | New                 | New                   | New                   |
| 60  | Changsha    | 62                  | 73                  | 46                  | 57                  | ↓11                  | ↓9                    |
| 61  | Sanming     | 57                  | None               | New                 | None               | New                   | None                  |
| 62  | Tongliao    | 57                  | None               | New                 | None               | New                   | None                  |
| 63  | Yantai      | 60                  | 53                  | 48                  | 63                  | ↑7                   | ↑15                   |
| 64  | Shiyang     | 45                  | 58                  | 43                  | 63                  | ↓13                  | ↓20                   |
| 65  | Dongying    | 49                  | 58                  | 48                  | 63                  | ↓11                  | ↓15                   |
| 66  | Enshi       | 62                  | 58                  | 65                  | 63                  | ↓4                   | ↓2                    |
| 67  | Ganzhou     | 58                  | New                | New                 | None               | New                   | None                  |
| 68  | Lianyungang | 58                  | 63                  | New                 | None               | New                   | None                  |
| 69  | Linyi       | 58                  | New                | New                 | None               | New                   | None                  |
| 70  | Xuzhou      | 79                  | 63                  | New                 | None               | New                   | None                  |
| 71  | Baishan     | 57                  | 48                  | 63                  | None               | Disappear            | ↑15                   |
| 72  | Lijiang     | 63                  | None               | New                 | None               | New                   | None                  |
| 73  | Qionghai    | 63                  | None               | New                 | None               | New                   | None                  |
| 74  | Weifang     | 63                  | None               | New                 | None               | New                   | None                  |
| 75  | Yichang     | 63                  | None               | New                 | None               | New                   | None                  |
| 76  | Nanyang     | 55                  | 50                  | 55                  | 76                  | ↓5                   | ↓21                   |
| 77  | Huaihua     | 55                  | 58                  | 55                  | 76                  | ↓5                   | ↓21                   |
| 78  | Qianjiang   | 57                  | 76                  | New                 | New                 | None                  | New                   |
| 79  | Songyuan    | 76                  | None               | None               | None               | None                  | None                  |
| 80  | Shangrao    | 58                  | 80                  | New                 | New                 | None                  | New                   |
| 81  | Xixuangbanna| 66                  | 79                  | 60                  | 80                  | ↑7                   | ↑12                   |
| 82  | Kashgar     | 85                  | 80                  | New                 | New                 | None                  | None                  |
| 83  | Jiayuguan   | 80                  | 80                  | None               | None               | None                  | None                  |
| 84  | Wenshan     | 80                  | None               | New                 | New                 | None                  | None                  |
| 85  | Chengde     | 38                  | 50                  | 55                  | 85                  | ↓12                  | ↓30                   |
| 86  | Anshun      | 57                  | 76                  | 48                  | 85                  | (max)20              | (max)37               |
| 87  | Karamay     | 79                  | 85                  | New                 | New                 | None                  | New                   |
| 88  | Mohe        | 79                  | 85                  | New                 | New                 | None                  | New                   |
| 89  | Zhongwei    | 79                  | 85                  | New                 | New                 | None                  | New                   |
| 90  | Shizhezi    | 85                  | None               | New                 | None               | New                   | None                  |
| 91  | Jining      | 25                  | 30                  | None               | New                 | New                   | New                   |
| 92  | Manzhouli   | 49                  | 53                  | None               | None               | None                  | None                  |
| 93  | Zhangjie    | 60                  | 58                  | None               | None               | None                  | None                  |
| 94  | Fuyang      | 58                  | None               | New                 | None               | New                   | None                  |
| 95  | Jining      | 58                  | None               | New                 | None               | New                   | None                  |
| 96  | Yan’an      | 58                  | None               | New                 | None               | New                   | None                  |
| 97  | Xilingol    | 73                  | None               | New                 | None               | New                   | None                  |
| 98  | Wuhan       | 76                  | None               | New                 | None               | New                   | None                  |
| 99  | Changbaishan| 76                  | None               | New                 | None               | New                   | None                  |
| 100 | Zhangye     | 66                  | 79                  | None               | None               | None                  | None                  |

*The arrows indicate the rise (↑) or fall (↓) of city ranking in 2020 compared to the same period of 2019; New represents the new navigable city appears of that season; None represents no connection of that season; Disappear represents the city vanishes in that season compared with the same period of 2019.*

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