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International cargo charter operations and preighter performances in the context of COVID-19: a case of China

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1. Introduction

Air transport services are commonly classified as either scheduled or non-scheduled. ICAO (2022) classifies non-scheduled (revenue) cargo flights as cargo charter and defines them as "cargo charter flights, including those chartered for resale by freight forwarders, consolidators, shippers' associations, express/small-package/courier services, and similar charterers, as well as those operated for the charterer's own use rather than for resale". Cargo charters have long played a critical role in transporting urgent, specialized, high-value, or outsized shipments on international routes (Morrell and Klein, 2018), accounting for 6–7% of global air cargo traffic during the 2010s (Boeing, 2022). During the COVID-19 pandemic, the share of nonscheduled cargo increased to 14% in 2020 and 15% in 2021 (Boeing, 2024), driven by several factors especially the suspension of scheduled passenger flights (and the associated loss of belly capacity), a sharp increase in urgent shipments, and the operation of "preighters" (all-cargo operations using aircraft normally designed for passenger transport) (ICAO, 2022). By 2023, the non-scheduled share remained elevated at 13% (Boeing, 2024), reflecting the importance of charter operations in the post-COVID period. Yet scholarly understanding of this segment remains limited. To the best of the authors' knowledge, no academic study has yet examined international cargo charter operations.

China represents an ideal case for examining the formation and transformation processes of a large-scale international cargo charter market, particularly within a comparatively less regulated, market-oriented policy environment, and in the context of the COVID-19 pandemic. Cargo charter markets are unevenly distributed across countries. For example, in 2019, charter service accounted for 16% of all air freight to and from the United States,[1] whereas its share in China's international cargo market was below 1%.[2] The Civil Aviation Administration of China (CAAC) had imposed strict limits on international non-scheduled services to protect scheduled flights (Wu et al., 2018) and emphasized equal treatment in approving charter permits for foreign carriers (CAAC, 2006). Following the outbreak of COVID-19, the CAAC strictly enforced the "Five-One" policy to limit international passenger flights but issued a series of notices and flexible policy measures to facilitate international air cargo transport (ICAO, 2021). In particular, on April 3, 2020, it launched the Notice on Launching a Review and Approval of the "Green Channel" for International Air Cargo Transport During the Period of Epidemic Prevention and Control (CAAC, 2020) to promote the smooth and efficient review and approval of the international cargo flight plan. With respect to non-scheduled cargo flights, CAAC (2020) adopted a set of deregulation policies and relaxation measures, conditionally allowing Chinese and foreign airlines to operate non-scheduled cargo flights on routes already served by scheduled services (scheduled routes), relaxing documentation requirements for foreign airlines in applying for flight operating permits, and supporting qualified third-country carriers to operate international cargo charters to China. Against the background of widespread suspension of scheduled passenger services, and in the context of other policy support and market demand, the non-scheduled international cargo flights to and from

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[1] In terms of freight ton, according to the U.S. International Air Passenger and Freight Statistics Reports (T-100 segment data).

[2] In terms of flight movements, estimated by the authors. The number of cargo charter flights is based on the lists of CAAC approvals for international non-scheduled flights, which classify non-scheduled flights into temporary extra flights and charter flights. Following ICAO (2022) and CAAC (2019), this study regards all non-scheduled cargo flights as cargo charter flights. In 2019, Chinese airports handled a total of 996,000 international flight movements, including both passenger and cargo flights as well as scheduled and non-scheduled services. In China's international air cargo market, belly-hold cargo accounted for 48.6% of total freight volume, while dedicated freighters accounted for 51.4%. These figures indicate that the market share of cargo charter services was well below 1%.

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China surged from about 6000 in 2019 to more than 80,000 in 2021,[3] accounting for over 30% of all international cargo flights operated between China and rest of world in that year.[4]

In addition, roughly three-quarters of the charters operated by Chinese flag carrier used preighter aircraft, and the CAAC publicly released relevant data, creating a rare empirical opportunity and a strong rationale for evaluating preighter performance on international routes. Preighters, also referred to as passenger-to-cargo (P2C) or temporary passenger-to-freighter (P2F) aircraft, accounted for approximately 10% of global international available cargo tonne-kilometres (ACTKs) in 2020 and 15% in 2021 (IATA, 2025). In the spring of 2020, when COVID-19 led to a global suspension of passenger flights, many airlines converted passenger aircraft to carry cargo, and aviation authorities issued temporary regulatory exemptions to enable preighter operations. Although preighters have attracted increasing attention in recent years, empirical evidence on their performance remains limited, highlighting a notable gap in the literature, particularly in the context of China. On routes between China and the rest of the world, the share of preighters was substantially higher than the global average, reaching 33% of international cargo flights in 2021,[5] whereas dedicated full-cargo flight (freighter) accounted for 67%. Therefore, evaluating the efficiency of preighter operations in China is particularly important.

Whilst cargo charter is still one of the untouched research area, passenger charters have attracted researchers' attention from various aspects. Over the last two decades, aviation deregulation always led to an increase in scheduled flights, particularly those provided by low-cost carriers (LCCs) and a decline in charter flights in many parts of the world (Dobruszkes et al., 2016). Accordingly, many researchers explored the extent to which LCCs could replace charter carriers (CCs), the substitution of charter flights by scheduled flights, the impacts of scheduled service availability on charter demand, or the effect of charter operation deregulation. However, global passenger charter traffic increased constantly in the 2010s, despite increased scheduled service availability and LCC expansion. It is assumed that the tourism elements, through the activities of charterers (tour operators), could maintain the stability of charter demand and therefore enhance the resilience of the air charter transport system (e.g., Castillo-Manzano et al., 2017; Wu et al., 2023). Nevertheless, these propositions have yet to be tested within a theoretical framework, leaving open the question of whether systematic patterns driven by charterers can be identified.

With the above in mind, this paper takes China as the study area to investigate the evolution and transformation of international cargo charter operations during 2020–2021, with a specific focus on preighter charters operated by Chinese carriers. The main datasets were extracted from CAAC approval lists for international non-scheduled flights, while additional information was collected through document analysis and personal communications. Descriptive statistics, geographic visualization, and route network analysis are the primary methods employed. In addition to real (actual) network analysis approaches, we tentatively selected complex network indicators to quantify the performance and reconfiguration trends of preighter charter networks. Furthermore, we reviewed CAAC's international charter policies and analyzed the changes in charter demand and route networks. We also examined the role of charterers (freight forwarders) in organizing charter flights and optimizing city-centered routes, aiming to identify the characteristics of the charter market and to reveal the mechanisms underlying the resilience of the air charter transport system.

This study makes four contributions to related literature. First, it advances the international air cargo research by analyzing the emergence and transformation of a large-scale cargo charter market under a less regulated and more market-oriented environment, while also evaluating the performance of preighter operations. Second, it contributes to the literature on charter services by providing empirical evidence from the cargo market. To the best of our knowledge, it is the first paper focused on international cargo charter services. Methodologically, we interpret the mechanisms underlying the resilience of air charter transport systems by linking operational flexibility to charterer activities. Third, we introduce methods used in previous research on integrators to assess the evolutionary patterns and efficiency of networks built by cargo charter flights. Like charter operations, operational flexibility is a defining characteristic of integrators, and the lack of comprehensive databases has constrained empirical research on integrators (e.g., Bowen, 2012; Malighetti et al., 2019). Thereby, we build a framework to investigate the evolutionary patterns and performance of charter flights. We also fill a research gap in the structural and dynamic analysis of highly flexible transport networks, such as those formed by integrators' flights and cargo charter flights. Fourth, this study contributes to the literature on China's air cargo transport from the perspective of both charter flights and preighter operations.

From a practical perspective, our findings enhance understanding of the resilience and recovery capacity of air cargo networks in response to external shocks such as the COVID-19 pandemic. The results provide guidance for airlines regarding fleet selection and acquisition strategies, and offer implications for aircraft manufacturers on design optimization, including the incorporation of convertible cargo capabilities in future aircraft. In addition, the study offers evidence-based insights for policymakers to support the development of targeted regulations that strengthen market resilience and crisis-response capacity. Given that China represents the largest air cargo market in Asia, these findings also carry important implications for air cargo policy and industry development across the broader region.

2. Related studies and methodologies

Three kinds of literature relate to our work: international air cargo transport, passenger charter operations, and integrators. Prior research on international air cargo transport can be grouped into four categories: (i) analyses of factors influencing airport choice from the perspective of airlines or freighters (e.g., Gardiner et al., 2005; Chu, 2014); (ii) evaluations of the performance of international cargo hubs or markets along with driving factors (e.g., Chakraborty et al., 2020; Alexander and Merkert, 2021); (iii) analyses of the evolutionary patterns and network structures of major integrators (e.g., Bowen, 2012; Malighetti et al., 2019), the topological properties of the global air cargo transport network (ACTN) (Bombelli et al., 2020), and the reliability of international air-cargo networks (Yu et al., 2020); and (iv) assessments of the impacts of COVID-19 and airline performance under pandemic pressure. These studies often adopted complex network methods. For example, Bombelli (2020) examined how COVID-19 affected the global capacity of three integrators (FedEx, UPS, and DHL) as well as other cargo airlines, finding that the integrators escaped the early months of the pandemic thanks to the resilience of their networks. Deng et al. (2025) analyzed how China's international scheduled freighter network (CISFN)

[3] In terms of flight movements, the data were estimated by the authors based on the lists of CAAC approvals for international non-scheduled flights. These lists classify non-scheduled flights into temporary extra flights and charter flights. Following ICAO (2022) and CAAC (2019), this study regards all non-scheduled cargo flights as cargo charter flights.

[4] The CAAC reported that about 207,000 international cargo flights (include both scheduled and non-scheduled flights) were operated in 2021, implying that charter flights could account for up to 39% of total operations without adjusting for cancellation rates. In the same year, the annual planned (available) volume of international scheduled cargo flights is estimated at approximately 283,000 flights is according to scheduled flight timetable. The CAAC does not differentiate between scheduled and charter flights in its internal data on international flight operations. If the execution rate of international scheduled cargo flights were similar with that of the domestic scheduled cargo market such as below 50% (Zhang et al., 2025), charter share still exceeded 32%.

[5] The CAAC officially reported that totally 69,000 preighter flights were operated to and from China in 2021.

adapted during the pandemic, finding that it densified its hub-and-spoke structure to meet demand at major hub cities. They argued that this hub-and-spoke configuration improved the overall robustness and resilience of China's international freighter network, but did not explain how those city-level networks were established or the driving factors.

International passenger charter operations have attracted researchers' attention from various perspectives. Unlike scheduled flights that are regulated primarily based on bilateral agreements between States, international charter flights are generally authorized based on national regulation (ICAO, 2022). The national aviation authorities always limit charter operations to protect scheduled services in the context of routes (Wu et al., 2018). In addition to the changes in the tourism market and the development of LCCs, aviation deregulation often led to an increase in scheduled services particularly provided by LCCs and a decline in charter flights (Dobruszkes et al., 2016). Numerous researchers have explored the extent to which LCCs could replace CCs or the impacts of increases in scheduled flights on charter demand. A few of which found that, in some markets, scheduled flights could not replace charter flights and LCCs could neither crowd out nor substitute for CCs, probably due to charterers (tour operators) selecting alternative carriers and routes following the launching of scheduled flights (Wu and Hayashi, 2013) or long-term cooperation among CCs, tour operators, and destination stakeholders (Rodríguez & O'Connell, 2018). Castillo-Manzano et al. (2017) further found that the charter transport system was unsensitivity to adverse events that may occur in the scheduled transport system, such as terrorist attacks or air accidents, supporting by the complexity of the tourism market. It was also concluded that tour operators could offset the negative impacts of increased in scheduled flights (Wu et al., 2023). Nevertheless, these assertions have yet to be examined systematically from a theoretical perspective. It remains unclear whether there are typical patterns of resilience development or whether developmental pathways are shaped by the charterers.

Charter flights are operated based on the demand of clients (charterers) rather than following fixed departure times or routes (ICAO, 2022), enjoying greater operational flexibility than scheduled flights. Meanwhile, charter flights are typically missing from widely used aviation databases, which has limited the studies on passenger charters (Wu et al., 2018). Similar to charters, operational flexibility is a defining feature of integrators, and the absence of databases has constrained studies on integrators (e.g., Bowen, 2012; Malighetti et al., 2019). To address the operational flexibility, Bowen (2012) utilized several graph-theory indicators to investigate evolutionary patterns and network structures of U.S. integrators, finding that integrators' networks display the importance of time in providing shippers with time flexibility. Recently, Malighetti et al. (2019) built a framework to analyze how four major integrators restructured their networks after obtaining traffic rights in China, using graphical methods and complex network metrics. Bombelli (2020) investigated the topological characteristics of integrators' networks and found that integrators escaped the early months of the pandemic largely unscathed, thanks to the robustness of their network configurations. As cited above, prior studies employed graphical analyses and complex network indicators to examine the evolutionary patterns, flexibility, efficiency, and robustness of integrators' flight networks, providing methods for our study.

Flexibility enables a transport system to adapt to crises or new conditions: higher flexibility implies greater robustness to disruptive events (Scott et al., 2006). Linking route flexibility to charterers' activities, this paper explores the evolution and change patterns of the cargo charter network and seeks to explain the mechanisms underlying the resilience of air charter transport systems. In the context of transport networks (Gu et al., 2020), resilience refers to the ability to resist, absorb, adapt to, and recover from the negative impacts of perturbations; flexibility is closely related to resilience. The key difference is that resilience studies typically consider supply-side changes in addition to demand-side changes. In air transport, flexibility and robustness are complementary: a robust network can enhance the flexibility of airline operations (Malighetti et al., 2019). In this study, the term 'resilience' refers to the ability of the charter transport system to adapt to new policies, adverse events, market changes, and increases in scheduled flights.

3. Data and methods

3.1. Data source and processing

Data limitations have constrained research on air charters (Wu et al., 2018), since non-scheduled flights are typically excluded from widely used databases such as OAG and do not appear in airline reservation systems or published schedules. The data used in this study were extracted from CAAC approvals for non-scheduled international flights. Each approval takes the form of a list. The CAAC issued two lists each month: one for Chinese-flag carriers and another for foreign carriers. In the list for Chinese-flag carriers, flight volumes refer to operated flight frequencies (actual flight operations). In the list for foreign carriers, flight volumes refer to approved flight frequencies (planned flight data according to operating permits issued by the CAAC).

The lists classify non-scheduled flights into two categories: temporary extra flights and charter flights. Following ICAO (2022) and CAAC (2019), we regard all non-scheduled cargo flights as cargo charter flights. This classification is also consistent with CAAC (2020), which applies the same administrative procedures and regulatory requirements to both extra and charter flights. In 2020 and 2021, the approval lists subdivided cargo flights into three groups: (i) passenger-to-cargo (P2C) flights operated by Chinese flag carrier, (ii) full cargo (FC) flights operated by Chinese flag carrier, and (iii) cargo flights operated by foreign airlines. Accordingly, we classify the P2C flights operated by Chinese airlines as "preighter charter", full-cargo flights operated by Chinese airlines as "freighter charters", and the flights operated by foreign airlines as "mixed charters".

The list includes information on the airline, route, operating period, application type, and flight volume. We classified the datasets by departure and arrival cities, number of flights, and application types. Specifically, we define each departure or arrival city as a "navigable city" and treat each as a node. For cities served by multiple airports, all airports were consolidated into a single node; for example, Shanghai Pudong and Shanghai Hongqiao were grouped as the node "Shanghai." Consequently, approximately 5% of charters operated by Chinese-flag airlines and 9% of those operated by foreign airlines involved two departure or arrival airports in 2020. The shares declined to 1% and 3% in 2021, respectively. For such flights, we selected the city with the shorter distance. For instance, Wuhan/Beijing–Montreal was treated as Beijing–Montreal, and Shanghai–Addis Ababa/Cape Town as Shanghai–Addis Ababa. Following the CAAC's statistical standards and prior studies on passenger charter, we calculated the flight volumes on a one-way basis: each takeoff or landing counted as a single movement (one flight represents one aircraft movement).

It should be acknowledged that the dataset is subject to several limitations, including the unavailability of actual operational data for foreign airlines and the omission of aircraft-type information for these operators. Despite these constraints, the dataset is sufficient for the purposes of this study, as it provides comprehensive actual operational data for charters operated by Chinese airlines and allows preighter and freighter charters to be distinguished for performance analysis. Moreover, evaluating performance differences between Chinese and foreign airlines lies beyond the scope of this paper. Furthermore, the CAAC has incorporated foreign airlines' monthly charter execution rates into the

operating permit approval process, whereby an execution rate below 90% may be considered a negative factor in evaluating an airline's permit applications for the relevant or subsequent month (CAAC, 2019). This threshold is substantially higher than the CAAC's policy target for scheduled international cargo flights (60%). Assuming that the execution rate of international scheduled cargo flights was comparable to that of domestic scheduled cargo flights (i.e., below 50%) (Zhang et al., 2025), the total number of international cargo charter flights operated by both Chinese and foreign airlines can be conservatively estimated to have surpassed 6500 in each of 2020 and 2021. This implies that the execution rate of cargo charters operated by foreign airlines was generally high.

3.2. Major methods

To begin, we conducted a document analysis to track changes in CAAC charter policies, with attention to the effectiveness of these policies. We then applied descriptive statistics and geospatial visualization to examine the spatial distribution and evolutionary patterns of nodes (airports), edges (routes), and the overall network structure. Clients (charterers, e.g., tour operators or freight forwarders) typically pay charter carriers (airlines) round-trip fees in advance, regardless of whether sufficient passenger/cargo can be collected to fill the cabin. This business model suggests that classifying the direction of charter flows is unnecessary, making an undirected graph more appropriate than a directed one. Subsequently, we conducted a case study to elucidate the role of charterers (freight forwarders). In August 2022, we interviewed senior staff and experts from cargo agents and airlines to gather market information; these are cited as "personal communications" (Walcott and Fan, 2017).

In the case study, we emphasize the role of charterers (freight forwarders) in flight organization, freight consolidation, and city-centered route network optimization. This emphasis is motivated by several considerations. First, in terms of airline–client relationships, it is the client (charterer) who assumes commercial responsibility and risk for charter operations (ICAO, 2022). Accordingly, charterers determine departure cities and select airlines, rather than airlines making these decisions themselves. Second, air cargo charter transport within China was supported by surface transport, following the outbreak of COVID-19 (Deng et al., 2022). In practice, truck-to-air transfer systems were established to support charter operations. So, charterers (freight forwarders) assumed a central coordinating role in this integrated transport mode: they were responsible for airport selection, consolidating cargo from dispersed locations, and transporting it to selected airports in a flexible, timely, and reliable manner. This coordinating role implies that the charterers (freight forwarders) played a pivotal role in building and optimizing charter routes, and that their operational decisions can significantly shape route network configurations at the city level. Third, we aim to interpret the mechanisms underlying the resilience of air charter services by linking charterers' activities to freight forwarder-led city-level route (re)construction. Chengdu was selected as the study area to illustrate the extensive geographical coverage of charter flight catchment areas supported by a nationwide truck-to-air cargo charter transit system. As the largest international cargo gateway in western China, Chengdu provides a representative context for examining the spatial extent of both the truck-to-air cargo transit system and the associated charter flight catchment areas.

In addition to analyzing the observed (real) network, we used complex network indicators to quantify changes in network performance and reconfiguration trends in preighter charter networks. Several studies have employed graph theory and complex network metrics to examine air cargo transport networks. In particular, Malighetti et al. (2019) and Bombelli (2020) introduced five node-specific indicators to evaluate the configurations, topology, or robustness of networks built by global integrators DHL, FedEx, UPS, and TNT. Besides node-specific indicators, Bombelli et al. (2020) further introduced one edge-specific indicator (edge betweenness centrality) to characterize topological and robustness features of the global air cargo transport network. In this study, we likewise apply edge betweenness centrality to identify critical edges in the network formed by preighter charters. This allows us to capture structural evolution in terms of both nodes and edges. By doing so, we fill a research gap in the structural and dynamic analysis of highly flexible transport networks, such as those formed by integrators' flights and cargo charter flights. The following complex indicators were used.

(1) Average degree $\langle k \rangle$

The degree of a node k_i is the number of edges incident upon it. For a point-to-point air network, higher k values correspond to greater resilience (Liao et al., 2022). Average degree $\langle k \rangle$ is calculated as the mean of all individual node degrees across the network, see Eq. (1).

$$K = \frac{1}{N}\sum_{i=1}^{n} k_i \tag{1}$$

(2) Average path length (L)

This indicator measures the overall accessibility of a network. For an air transport network, lower values of L are associated with greater efficiency, see Eq. (2).

$$L = \frac{1}{n(n-1)/2}\sum_{i>j} d_{ij} \tag{2}$$

(3) Node betweenness centrality (NBC)

Often referred to simply as betweenness centrality, this indicator quantifies the extent to which a node acts as a bridge or connector within a network. It is calculated as the proportion of all shortest paths between any two nodes in the network that pass through the given node, see Eq. (3).

$$NBC_i = \frac{2}{(n-1)(n-2)}\sum_{i=1, i\neq k}^{n}\sum_{j\neq k}^{n}\frac{\delta_{ij}^{k}}{\delta_{ij}} \tag{3}$$

Where δ_{ij} denotes the total number of shortest paths d_{ij} from node v_i to node v_j. The significance of a node with high betweenness centrality lies in its role as a critical intermediary.

(4) Edge betweenness centrality (EBC)

It is defined by the number of geodesics (shortest paths) going through an edge, reflecting the importance of each edge in a network, see Eq. (4).

$$\mathrm{EBC_i} = \frac{2}{\mathrm{n(n-1)}}\sum_{\mathrm{i\in v}}^{\mathrm{n}}\sum_{\mathrm{j\in v}}^{\mathrm{n}}\frac{\delta_{\mathrm{ij}}^{\mathrm{e}}}{\delta_{\mathrm{ij}}} \tag{4}$$

When $i \neq j$, δ_{ij} denotes the total number of shortest paths d_{ij} from node v_i to node v_j, δ_{ij}^{e} denotes the total number of shortest paths d_{ij} from node v_i to node v_j,which go through edge $e \in E$.

In this study, we calculated the average degree (k) and average path length (L) for passenger-to-cargo (P2C) and full-cargo (FC) charters operated by Chinese airlines, as well as all (mixed) charters operated by foreign airlines. This enables a comparative analysis of the evolutionary patterns across these networks, with a particular focus on P2C charter (preighter) operations. Furthermore, node and edge betweenness

centrality are employed to capture the structural evolution and network reconfiguration of preighter charters operated based on actual operational data.

On a related note, we estimated the average degree and average path length of the network formed by foreign charter flights, although data completeness cannot be fully guaranteed. This introduces a potential mismatch between planned flight volumes and actual operations. From a network science perspective, measurement error is an inherent issue in empirical network construction and extends beyond simple missing data (Wang et al., 2012). Even high-resolution operational datasets cannot fully eliminate data ambiguity; for instance, Sun et al. (2022) note that it is not possible to distinguish preighters in real-time flight datasets. However, the data incompleteness may significantly affect the metrics such as centrality (Martin and Niemeyer, 2020), whereas simpler structural metrics tend to be comparatively more robust (Wang et al., 2012).

The impact of data imperfections also depends on network topology. Scale-free networks, for example, exhibit strong tolerance to random failures. According to Albert et al. (2000), such networks follow a power-law degree distribution $(k) \sim k^{\gamma}$, and their inhomogeneous connectivity implies that most removed nodes are low-degree nodes, which have limited impact on overall connectivity. Consistent with this mechanism, Albert et al. (2000) found that the network diameter remains largely unchanged even when a non-negligible fraction of nodes (e.g., around 5%) are randomly removed, indicating that the global connectivity structure is preserved under random perturbations. Moreover, the network does not undergo abrupt fragmentation under random failures; instead, the giant connected component (GCC) persists even at relatively high levels of node removal, further demonstrating the inherent structural stability of such networks. Empirical evidence further suggests that many real-world networks exhibit power-law exponents within the range $2< \gamma < 3$, under which such robustness is particularly pronounced.

This mechanism is also supported by empirical evidence in air transport networks. For example, airline route networks exhibit relative robustness to random node failures, with the size of the GCC decreasing by only 5–10% when approximately 5% of nodes are randomly removed (Lordan et al., 2016). Similar to passenger flight networks, air cargo transport networks exhibit both small-world and scale-free properties (Bombelli et al., 2020; Li et al., 2022). It has been observed that the average path length of China's domestic air cargo network remains relatively stable over time despite network expansion and structural evolution (Li et al., 2022). These findings indicate that international charter networks provide a certain degree of tolerance to random data incompleteness.

Taken together, above studies provide both theoretical and empirical support for the choices of this study. In particular, foreign charter operations are characterized by relatively high execution rates. For instance, CAAC (2019) requires foreign airlines to maintain execution rates typically exceeding 90%, indicating that the majority of planned flights were effectively operated. In addition, during the COVID-19 period, elevated charter premiums and increased marginal returns further reduced the likelihood of widespread cancellations. Under these conditions, discrepancies between planned and actual operations can be reasonably approximated as random perturbations rather than systematic removals. Consistent with the theoretical assumption of random failures in scale-free networks, the charter network is unlikely to experience structural fragmentation. While minor deviations may still exist, their impact on aggregate structural indicators is expected to be limited. Therefore, the use of scheduled charter data does not materially affect the estimation of key network indicators, such as average degree and average path length. This supports the validity and interpretability of the comparative analysis of network evolution across different charter types.

Using complex network theory, a growing body of literature has analyzed China's air cargo network since the outbreak of COVID-19. Although existing studies differ in terms of temporal scales and analysis perspectives, they generally take scheduled cargo flight networks as their primary research object. For example, Deng et al. (2022) evaluated the topological properties and their change trends of the Chinese scheduled freighter network (CSFN); Zhang et al. (2025) analyzed the spatiotemporal evolution and robustness of China's Air Cargo Network (CACN); and Deng et al. (2025) investigated the structural changes and resilience demonstrated by China's international scheduled freight network (CISFN). Using city-pair air freight transport data, Li et al. (2022) modeled China's domestic air cargo network and identified its structural characteristics and key socioeconomic drivers; He et al. (2024) explored the spatiotemporal evolution and topological characteristics of China's domestic air cargo network before and during COVID-19 and its relationship with regional economic factors. Unlike existing studies that mainly focus on scheduled cargo flights, this study takes cargo charter flights as its research object, with particular emphasis on preighter operations.

Our study is closely related to Zhang et al. (2025) in terms of network construction and analytical methods, yet it differs substantially in research scope and the operational characteristics of the air cargo system examined. Like Zhang et al. (2025), we construct the network based on monthly operational data and adopt an indicator presentation approach used in previous studies, such as Liao et al. (2022) to illustrate the time-varying fluctuations of network performance metrics. However, Zhang et al. (2025) investigated China's domestic scheduled air cargo transport network, without distinguishing between aircraft types. By contrast, this study concentrates on the international cargo charters and further classifies aircraft into preighters and freighters, thereby revealing the network performance and transformation patterns associated with preighter charters. Moreover, charter flights are strongly demand-driven and characterized by operational flexibility. Their routes are opened or withdrawn more frequently, resulting in greater structural volatility and dynamic adjustments in the network. Therefore, this study further introduces an edge-specific indicator, jointly examining network dynamics from both “node–route” dimensions. To the best of our knowledge, this is the first study to apply such an edge-specific indicator to the analysis of China's air cargo route network.

4. A review of charter policies and cargo charter traffic to and from China

The CAAC has historically restricted international charter operations to protect scheduled services. In 1989, the State Council of the People's Republic of China issued the Interim Provisions on the Administration of Non-scheduled Flights in Civil Air Transportation, stipulating that non-scheduled operations must not disrupt normal scheduled services. Consequently, in 1990, the CAAC promulgated the Provisions on the Administration of Non-scheduled Flights in Foreign Civil Air Transportation (CCAR-119TR-R), which stated that charter flights should not operate on routes served by scheduled flights unless an exception applies. In 2006, CCAR-119TR-R was replaced by the Detailed Rules for the Business Permission for Non-scheduled Flights of Foreign Air Transport Enterprises (CCAR-119TR-R1) (CAAC, 2006), which regulate international charter operations with respect to documentation requirements, application deadlines, operational restrictions, and penalties for violations. The CCAR-119TR-R1 further affirms that the CAAC shall apply the principle of reciprocity in licensing non-scheduled flights. It was even reported that the CAAC suspended international cargo charters from three major airports during the 2015 peak season, likely to protect Chinese carriers (Harris, 2015).

The CAAC also adopted a range of measures to restrict Chinese airlines. For example, the CAAC (2001) stated that Chinese carriers should impose strict limits on international and Hong Kong/Macao non-scheduled flight operations, as excessive charter activity had become a key factor contributing to the sharp deterioration of the economic performance of their scheduled flights. Subsequently, the CAAC

(2002) established an approval-based system under which Chinese-flag airlines were required to apply to the CAAC for authorization before arranging additional or charter flights. By the late 2000s, a series of corruption cases related to the approval and operation of international charter flights (e.g., the Capital Airport charter scandals and the China Southern charter case) reinforced the CAAC's decision to impose stringent controls on international non-scheduled operations throughout the 2010s.

After a prolonged period of strict regulation, the CAAC began to relax controls on charter operations in the late 2010s. This shift originated in 2015, when the CAAC issued the Notice on Simplifying the Approval Procedures for International Charter Flights Operated by Domestic Airlines, which replaced the prior approval regime with a record-filing system. Under this system, Chinese airlines are required to flight plans for record filing in advance and to report actual operational data to the CAAC on a monthly basis. However, the CAAC continues to require foreign airlines to obtain flight operating permits in advance. To obtain a permit, foreign airlines must complete slot coordination beforehand and submit applications to the CAAC together with the required supporting documentation and, where applicable, pay the air traffic rights compensation fee in advance. Furthermore, the CAAC still regulated charter operations on scheduled routes.

Following the outbreak of COVID-19, the Chinese government established the Joint Mechanism of the State Council on Prevention and Control of COVID-19 (hereinafter, the Joint Mechanism) to make integrated arrangements for prevention and control efforts. In line with the Joint Mechanism's requirements and related provisions, the CAAC imposed strict limits on international passenger flights while adopting measures to bolster air-cargo capacity, stabilize global supply chains, and utilize 'idle' aircraft (ICAO, 2021). In April 2020, the CAAC issued the notice on Review and Approval of the "Green Channel" for International Air Cargo Transport During the Period of Epidemic Prevention and Control (hereinafter, the Green Channel) (CAAC, 2020). The 'Green Channel' focused on facilitating scheduled cargo operations using passenger-to-cargo aircraft and promoting non-scheduled cargo operations. In particular, the Green Channel policy relaxed several application restrictions for foreign airlines, permitted cargo charter operations on routes already served by scheduled flights, and supported charter operations by third-country airlines (Table 1).

Subsequently, the CAAC issued the Operation Safety Bulletin on the Transport of Cargo in the Passenger Cabin on April 21, officially giving airlines the green light to preighter operations. On May 26, jointly announced with the Ministry of Finance (MOF), the CAAC announced subsidies for Chinese airlines to modify passenger aircraft to freighter configurations, as well as financial incentives for both Chinese and foreign airlines engaged in international cargo-only operations, whether scheduled or charter. In 2021, the MOF expanded the scope of the Civil Aviation Development Fund to support logistics systems, enabling local governments to increase cargo subsidies. For example, the Guangzhou Airport Economic Zone provided USD 13 million in international cargo-route subsidies to nine airlines and eight freight forwarders in 2021, and the number of international preighters departing Guangzhou rose by more than 50% year over year.

Table 1
CAAC (2020) relaxed controls international cargo charters.

	Previous limitations	Deregulation measures
1	Applicants (airlines) should terminate a ground-handling agency agreement between carriers and service providers.	The ground-handling agency agreement could be replaced by a ground-handling guarantee letter.
2	Applicants (airlines) should provide charter contracts when handling application.	The contract could be replaced by a letter requesting assistance from airlines produced by local government or authorities.
3	Applicants (airlines) must run slot coordination in advance and operate the flight as approved.	Airlines could obtain nonscheduled flight operation permits without going through slot coordination in advance.
4	No charter on route served by scheduled flights.	Nonscheduled (charter) flights on routes with existing scheduled service could be approved.
5	Foreign airlines need to hold full CCAR 129 certifications	Conditionally support the operation of cargo charter flights by a third-country carrier

Table 2
Changes in charter amount and rout density in terms of carriers.

	2020	2021	Variations
Cargo charters operated by Chinese flag airlines			
Flight amount	35,996	42,220	17%
No. of routes (edges)	441	313	−29%
Average flight per route (route density)	82	135	66%
Cargo charters operated by foreign airlines			
Flight amount	39,258	38,456	−2%
No. of routes (edges)	901	628	−30%
Average flight per route (route density)	44	62	41%

Table 2 shows that charter flights rose sharply to 75,000 in 2020 and 81,000 in 2021. Compared with Chinese carriers, foreign airlines exhibited broader geographical coverage but experienced a decline in flight volume. This pattern may be partly attributable to reductions in preighter operations by some foreign airlines. As vaccination emerged as a key measure for mitigating the risk of COVID-19 transmission, several countries began to adopt air travel policies in the second half of 2021 that relied primarily on passenger vaccination rates. These policy shifts were associated with a gradual recovery of international air passenger traffic. In response, many foreign airlines started to reconvert freighters back to passenger aircraft to accommodate rising passenger demand. Aviation authorities, such as the Federal Aviation Administration and the European Union Aviation Safety Agency, also began to phase out preighter operations during this period. By contrast, the CAAC continued to strictly restrict international passenger flights and further strengthened support for Chinese airlines in utilizing preighters, including through financial subsidies. It should be noted that evaluating airline performance lies outside the scope of this paper, given significant cross-country differences in regulatory environments and market conditions. For example, during the study period, most cargo charters between China and the United States were operated by U.S. airlines.

Table 2 also shows that, from 2020 to 2021, both Chinese and foreign airlines experienced significant reductions in the number of routes alongside increases in route density, indicating a substantial transformation of the overall charter flight network. Meanwhile, charter volume increased by 7% year over year, despite a 28% rise in scheduled cargo services over the same period (Table 3). These trends raise

Table 3
The availability of scheduled cargo flights to and from China per week.

	Passenger flight	Cargo flights		
		Freighter aircraft	Preighter aircraft	In total
Winter 2019/Spring 2020	18,230	1968	0	1968
Winter 2020/Spring 2021	592	2780	1718	4498
Winter 2021/Spring 2022	408	3472	2292	5764
Winter 2022/Spring 2023	840	N/A	N/A	6148
Winter2023/Spring 2024	6502	N/A	N/A	3676

Note:the CAAC issues scheduled flight timetables twice a year. One for Summer/Fall season (begins on the last Sunday of March), and another for Winter/Spring (begins on the last Sunday of October). For consistency, we used data from the Winter/Spring timetable to represent the availability of scheduled cargo flights. Data source: CAAC scheduled flight timetable.

concerns about the resilience of the air charter transport system in the face of disruptive events, such as the rapid expansion of scheduled cargo flight capacity. Among charter flights operated by Chinese airlines, the share of preighter charters increased from 71% in 2020 to 78% in 2021. Airlines operated preighters in three modes: (i) belly-hold only; (ii) belly hold plus cabin without seat removal; and (iii) belly hold plus cabin with seats removed. Although mode (iii) offers the greatest capacity among these options, it still provides only about one-third of the cargo capacity of a comparably sized freighter. Preighters are also less efficient than freighters due to labor-intensive loading processes. These constraints motivate our research questions: Which markets were primarily served by preighters, and how did preighters perform?

5. Evolution patterns and driving factors

5.1. Spatial distributions

Fig. 1 illustrates the spatial distribution of navigable cities (nodes) serving as origins and destinations for cargo charters. Within China, cities were more concentrated in the east than in the west, more in the south than in the north, and clustered around the Yangtze River Delta and Pearl River Delta. Outside China, many overseas cities disappeared while new ones emerged in 2021. The cities that disappeared were predominantly in South America and the Middle East, along the West African coast, and on the northern coast of the Mediterranean, with island cities nearly vanishing altogether. Newly appeared cities were concentrated along the Silk Road, the Strait of Malacca, and the west coast of the Gulf of Guinea, indicating a shift in charter routes toward inland hubs and major maritime gateways.

Fig. 2 indicates that, within China, charters were highly concentrated in the eastern coastal region, moderately represented in the central and southwestern regions, and least frequent in the northern and western regions. In 2021, there was a further concentration of flights to the eastern region. Outside China, charter activity was concentrated in Europe, North America, Northeast Asia, South Asia, the Middle East, and Central Asia. Russia- and Central Asia–based airlines were leading charter operators in Asia, operating a significant number of former Soviet military turboprop and jet airplanes on charter freight flights (Boeing, 2022). Several Russian and Central Asian airports have traditionally served as technical stopovers for these carriers; during the pandemic, they also became important stopover or transit points for P2C charters between China and Europe.

Fig. 3 depicts the network formed by passenger-to-cargo charters (P2C, preighter charters) and full-cargo charters (FC, freighter charters) operated by Chinese-flag airlines, as well as mixed charters provided by foreign airlines. In terms of charters operated by Chinese airlines, Fig. 3 (a) and (b) show that preighter charters established and reinforced a dual-hub structure in North America centered on Los Angeles and New York. In Europe, the network evolved into a stable polycentric configuration. The Asia-Pacific region was the primary destination for P2C charters. Within Asia, network structures in Northeast and Southeast Asia remained stable, while routes to Central Asia declined. Overall, the preighter charters exhibited a highly concentrated and rapidly shifting regional structure. By contrast, full-cargo charters reduced their network coverage in Asia while retaining a relatively rigid network structure in North America and Europe (Fig. 3(c) and (d)).

In detail, the volume of preighter charters increased from approximately 25,000 flights in 2020 to around 33,000 flights in 2021, largely driven by growth on routes to Europe and North America (Table 4). In 2020, roughly one-third of preighter operations were concentrated on routes between China and other Asian cities, while Europe and North America accounted for approximately 30% and 28% of the total, respectively. By 2021, the share of flights to Europe rose to 41%, and that of North America increased to 29%, whereas Asia's market position declined to third place. The expansion of preighter charters serving European and North American cities appears to be associated with a sharp surge in freight rates. In some cases, charter prices on routes to Europe and the United States reached USD 1.55 million and USD 2.17 million per flight, respectively, approximately three to four times higher than pre-pandemic levels.

With the increase in scheduled freighter, the number of freighter charters declined by approximately 7%, from over 10,000 flights in 2020 to about 9300 flights in 2021. Despite this reduction, Asia maintained a dominant market share in both years. The size and composition of the Chinese freighter fleet appear to be closely associated with the direction of charter operations. By the end of 2019, Chinese-flag airlines operated a total of 173 freighters, of which only 50 were wide-body aircraft suitable for long-haul routes (Li, 2020). This fleet structure

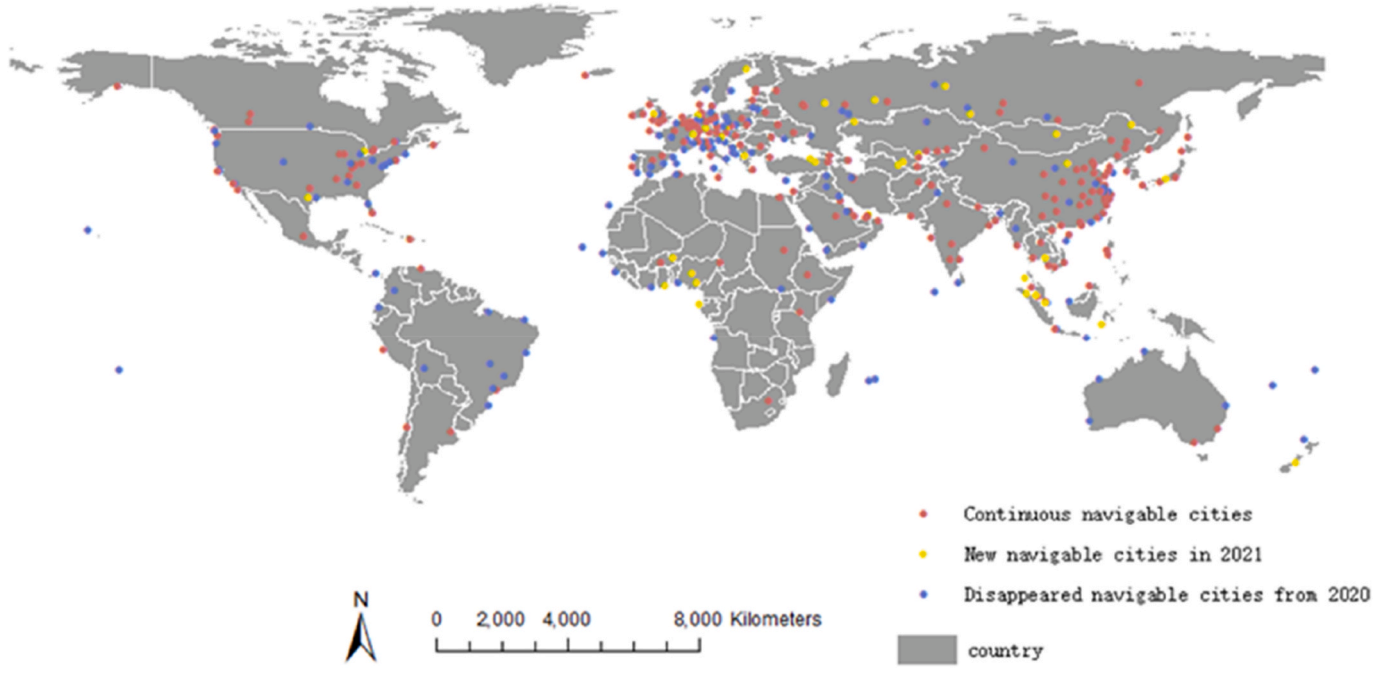

Fig. 1. Spatial distribution of all navigable cities (nodes) s: 2020 vs. 2021.

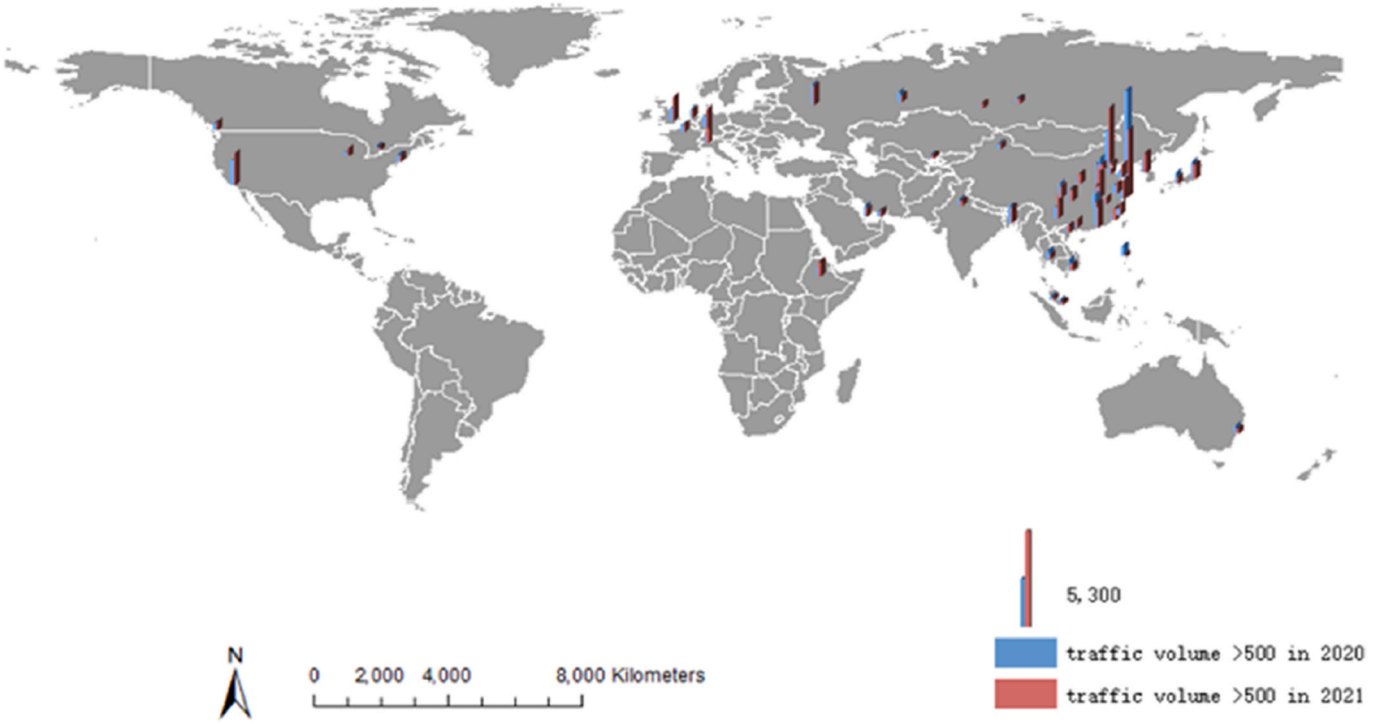

Fig. 2. Spatial distribution of cities (nodes) with at least 500 charters: 2020 vs. 2021.

may have constrained the spatial pattern of charter flows, with over 70% of freighter charters operating on routes to Asian cities, particularly on short-haul routes to cities in Northeast and South Asia.

At the regional level, Africa, North America, and Oceania were predominantly served by preighters; in other words, Chinese-flag airlines mainly operated preighters on routes to these regions (Table 4). At the city level. On city level, preighter charters were operated on 322 routes in 2020 and 235 routes in 2021, and freighter charters on 179 routes in 2020 and 109 routes in 2021 (Table 5). The smaller reduction for preighters indicates a more stable network. The number of overlapping routes served by both aircraft types suggests that preighters were deployed mainly on routes rarely served by freighters, especially in 2021. Notably, the share of overlapping routes fell from 22% to 10%, indicating that freight forwarders reduced duplicate routes and that route competition between aircraft types diminished.

Fig. 3(e) and (f) reveal that foreign airlines reached more islands and long-haul destinations. In 2021, Europe experienced a reduction of nodes, while no fundamental change occurred in the North American market. In Africa, the charters created a regional aggregation network, with a decrease in overall routes but an increase in traffic to Addis Ababa and West African port cities. The geographical location of Addis Ababa suggests that cargo charter was supported by air-to-air transport. For example, Ethiopian Airlines' official page noted that Ethiopian Airlines played a critical role in shipping COVID-19 vaccines from China and distributing Chinese-made vaccines to other African countries and some South American cities.

It is worth noting that the number of key nodes (cities) within the network formed by all foreign charter operations increased in 2021, with Shanghai, Beijing, Guangzhou, Shenzhen, Tianjin, Chengdu, and Zhengzhou emerging as major hubs (Appendix 1). The geographical distribution of these hubs, together with their operational performance, indicates that air cargo transport was strongly supported by surface transportation during the COVID-19 period (Deng et al., 2022; He et al., 2024). In charter operations, Chinese freight forwarders (charterers) assume a central coordinating role within this integrated air–truck transport mode, particularly in linking dispersed production locations with selected airports. This coordinating role, in turn, implies that the freight forwarders play a pivotal role in building and optimizing charter route networks under a less regulated, more market-oriented environment. Section 5.3 therefore aims to empirically validate this role and examine how freight forwarder–led coordination shapes city-level network configurations.

5.2. Changes in charter amounts and driving factors

5.2.1. Monthly volume in terms of charter types

Fig. 4 depicts the monthly frequency of different charters. In 2020, cargo charter amount started to ascend in March, surged in April and May, then declined steadily throughout the summer. In March, numerous charters were inbound supply charters, carrying personal protective equipment (PPE) and other medical supplies to China. Outbound supply charters emerged at the end of March and peaked in May, shipping masks, protective clothing, ventilators, and then test kits overseas. The decline after June was likely due to the increase of scheduled cargo flights (the FY2020 Summer and Autumn Scheduled flight timetable went effect in June), the reduction in supply charters, and the MOF and CAAC suspension of financial incentives for international cargo flights.

Notably, the monthly change patterns suggest that increases in scheduled cargo had negative effects on cargo charter traffic, but these effects were uneven and temporary. Firstly, foreign charters increased in September 2020 and remained constant thereafter. Secondly, the P2C and FC charters declined in October 2020, April 2021, and October 2021, when the new timetable took effect, but all recovered in the following months. Thirdly, the P2C charters escalated rapidly in November and December 2020. This surge was driven by soaring air freight rates, rising exports of rapid detection kits, growth in general cargo and e-commerce shipments, and the traditional Q4 peak season driven by Black Friday and Christmas shipments.

In 2021, the charters displayed a more variable but sustained

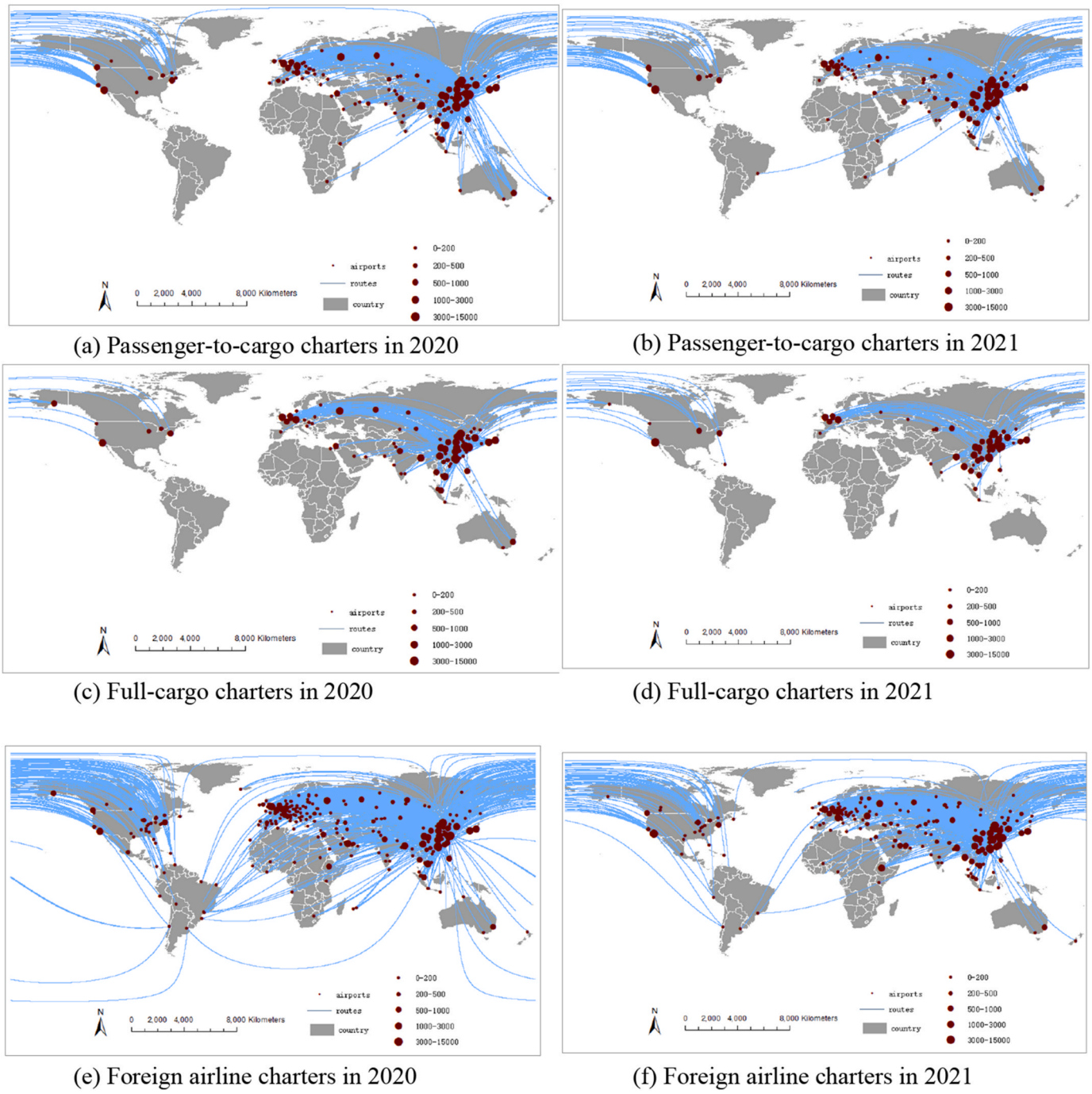

Fig. 3. Route networks in terms of charter types: 2020 vs. 2021.

pattern, with four peak months in February, March, June, and September. Several factors contributed to this volatility, including the increase in scheduled cargo flights, the sharp rise in freight rates, the growth of cross-border e-commerce shipments, and the distribution of COVID-19 vaccines. We found a strong alignment between monthly P2C charter volumes and the monthly export volumes of China-produced COVID-19 vaccines (Appendix 2).

5.2.2. Major cities

Table 6 shows that all top-ranked Chinese cities in 2020 experienced a decline in charter flight volumes in 2021, except Beijing, Guangzhou, and Kunming. This decline was likely influenced by the increase in scheduled flights, though other factors also played a role. For example, at Shanghai Pudong International Airport, the CAAC's 'closed-loop management' for frontline cargo-handling staff caused significant manpower shortages, forcing the airport to prioritize scheduled flights and thereby reducing charter operations in 2021.

Table 4
Market served by the passenger-to-cargo (P2C, preighter) in term of overseas cities by regions.

Overseas city in terms of region	In 2020		In 2021		2020-2021 changes	
	Flight Amount	Market Share[a]	Flight Amount	Market Share[a]	Flight amount	Market Share[a]
Africa	54	96%	24	100%	−30	4%
Asia	8528	53%	8494	56%	−34	4%
Central Asia	224	68%	142	27%	−82	−41%
Northeast Asia	1956	37%	2544	46%	588	9%
South Asia	1682	35%	1042	29%	−640	−6%
Europe	7584	76%	13572	87%	5988	11%
North America	7116	93%	9572	93%	2456	−1%
Oceania	2192	99%	1254	100%	−938	1%
South America	0	N/A	0	N/A	0	N/A
Total	25474	71%	32916	78%	7442	7%

[a] Proportion of preighter among the charter operated by Chinese airlines (preighter + freighter).

Table 5
Number of cargo charter routes served by preighter and freighter.

	In 2020	In 2021	2020-2021
	routes (edges)	routes (edges)	Changes
Charters operated by Chinese flag airlines	441	313	−29%
1 Preighter charters	322	235	−27%
2 Freighter charters	179	109	−39%
No. of overlapping routes	90(22%)	31(10%)	−59(-12%)

The experiences of Beijing, Guangzhou, and Kunming further suggest that additional city-level factors affected charter activity. For Beijing, home to Beijing Capital International Airport, charter traffic was partly driven by CAAC special measures and global anti-COVID-19 measures. in March 2020, the CAAC required all international passenger flights bound for Beijing to first land at one of twelve designated "first-entry" airports. This policy indirectly increased charter traffic to and from Beijing and nearby airports such as Zhengzhou. In 2021, China became the world's largest exporter of COVID-19 vaccines, with Sinopharm and Sinovac Biotech as the main manufacturers. Both companies established headquarters and initial production facilities in Beijing. This geographic concentration of vaccine manufacturing, combined with the airport's cold-chain infrastructure, significantly boosted COVID-19 vaccine and medical supply charters from Beijing in that year.

Guangzhou's experience highlights the impact of airport customs clearance capacity. To facilitate cargo charter and preighter operations, Guangzhou Baiyun International Airport Customs created an expedited-clearance model known as 'Whole-Unit Load Device (ULD) Collection and Rapid Sorting.' Under this model, cargo listed on the same Export Customs Declaration Sheet was consolidated into a single ULD upon

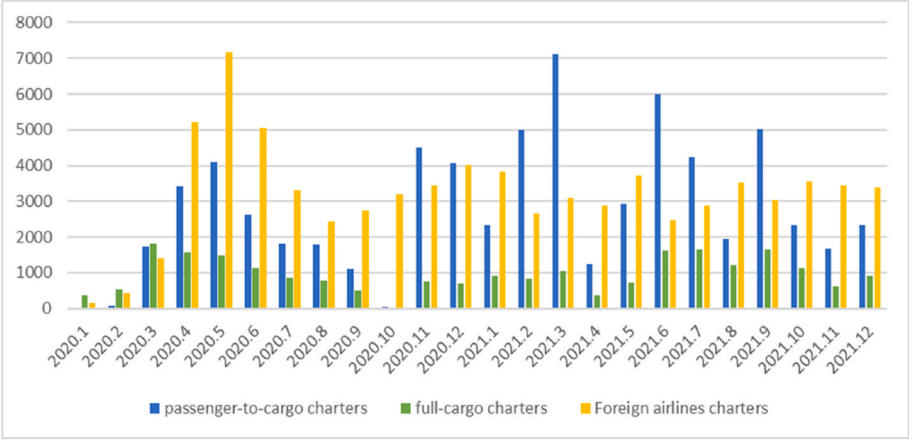

Fig. 4. Monthly number of different cargo charter flights.

Table 6
Top 10 Chinese and overseas cities (nodes) in terms of flight amount: 2020 vs. 2021.

	In 2020				In 2021			
	Chinese cities	Flight volume	Overseas cities	Flight volume	Chinese cities	Flight volume	Overseas cities	Flight volume
1	Shanghai	21,278	Los Angeles	5166	Shanghai	13,368	Los Angeles	6322
2	Guangzhou	7296	Moscow	4112	Beijing	11,244	London	4896
3	Beijing	6568	Tokyo	3684	Guangzhou	9704	Seoul	3976
4	Shenzhen	5694	Seoul	3562	Kunming	5116	Moscow	3932
5	Zhengzhou	4204	Dhaka	3264	Shenzhen	4560	Yangon	3490
6	Hangzhou	2954	London	2566	Zhengzhou	3908	Frankfurt	3370
7	Chengdu	2908	Doha	2242	Hangzhou	3632	Dhaka	3208
8	Kunming	2292	Osaka	2138	Wuhan	2458	Addis Ababa	2862
9	Changsha	2274	Frankfurt	2038	Qingdao	2374	Tokyo	2840
10	Chongqing	2206	Manila	1980	Xiamen	2312	Milan	2796

Note: it does not necessarily correlate to the amount recorded by the respective airports.

arrival at the airport's export cargo sorting zone. Each ULD was linked to a Master Air Waybill (MAWB), enabling unified processing for security, inspection, and loading, while rapid sorting minimized secondary handling within the cargo terminal. According to an official report, this model reduced average clearance times from 24.38 to 12.53 h for imports and from 1.54 to 0.87 h for exports. With these innovations in airport customs clearance capacity, combined with the cargo subsidies offered by the airport authority to airlines and agents, the number of international preighters departing from Guangzhou increased by more than 50% year over year, while cargo charter flights grew by over 33% in 2021.

As the only airport in Southwest China designated by the General Administration of Customs as an entry port for imported fresh fruit, Kunming Changshui International Airport likely benefited from this status. This growth may also have been driven by its strategic position as the principal cargo hub serving South Asia, Southeast Asia, and the Indian Ocean region. In 2021, the local government increased subsidies to support the international cargo logistics system. Although the official report did not disclose the precise subsidy amount, the subsidies clearly played a pivotal role in shaping charter operations. This was partly reflected in the statistic that 80% of Chinese-made PPE and vaccines exported to Myanmar were shipped via charter flights between Kunming and Yangon.

Among the top 10 overseas cities, Los Angeles, Moscow, London, Seoul, Frankfurt, Dhaka, Tokyo, and Milan were the top 10 cities for the second year running. All nonstop scheduled passenger flights between China and the United Kingdom were suspended in January 2021, as a result, London moved up from sixth to second in that year. In Asia, Seoul increased in both flight amount and rank, one city (Yangon) appeared, and two cities (Doha and Osaka) disappeared. More than that, the African city of Addis Ababa ranked eighth in 2021, from where some charters departed to the third destinations without unloading cargo immediately. It is difficult to explain why Los Angeles and Seoul experienced such large growth in 2021. One possible explanation is that should be those two countries had already established more mature charter operation models. For example, the share of charter operations in U.S.–South Korea nonstop air freight traffic increased from 35% in 2019 to 50% in 2020.

In summary, at the city level, charter operations were influenced not only by scheduled flights but also by a range of additional factors, such as airport operational efficiency, civil aviation and central government policies, local measures and subsidies, global epidemic prevention regulations, airport location, and market demand. Driven by profit incentive and constrained by these factors, freight forwarders leased aircraft from airlines, which then operated flights under charter contracts. The next section presents case studies that illustrate how freight forwarders organize outbound charters, optimize operational efficiency, and enhance the resilience of the air charter transport system.

5.3. *The role of freight forwarders*

Primarily, this section examines how charter flights are organized and how city-centered route networks are optimized through this truck-to-air transit system. After the outbreak of COVID-19, Chinese charterers (freight forwarders) and their agents often consolidated cargo and trucked it to charter departure airports, typically using container trucks. Over time, multiple city- (airport-) centered trucking networks coalesced into a nationwide truck-to-air cargo transit system. Chengdu was selected as the case study area because it ranks first in air cargo throughput in western China, and the analysis aims to demonstrate the spatial coverage of the trucking networks and charter catchment areas.

Fig. 5 maps a network centered on Chengdu. This network connects Chengdu with major airports and logistics hubs across China, extending eastward to Shanghai, northward to Beijing, and southward to Guangzhou. Supported by this system, the forwarders (charterers) collect shipments from factories, warehouses, and logistics centers, consolidate them in Chengdu, and dispatch them overseas via charters. In practice, the charter catchment area extended to a 56-h trucking radius. Theoretically, the coverage of this network changed dynamically, synchronizing with the consolidation strategies adopted by charterers for each flight. To be more precise, each charter operation contributes to greater flexibility of the whole truck-to-aircraft charter cargo transit system. Flexibility enables a transport system to adapt to crises or new conditions: higher flexibility means stronger robustness against disruptive events (Scott et al., 2006). In this way, we explained the mechanisms underlying the resilience of air charter transport

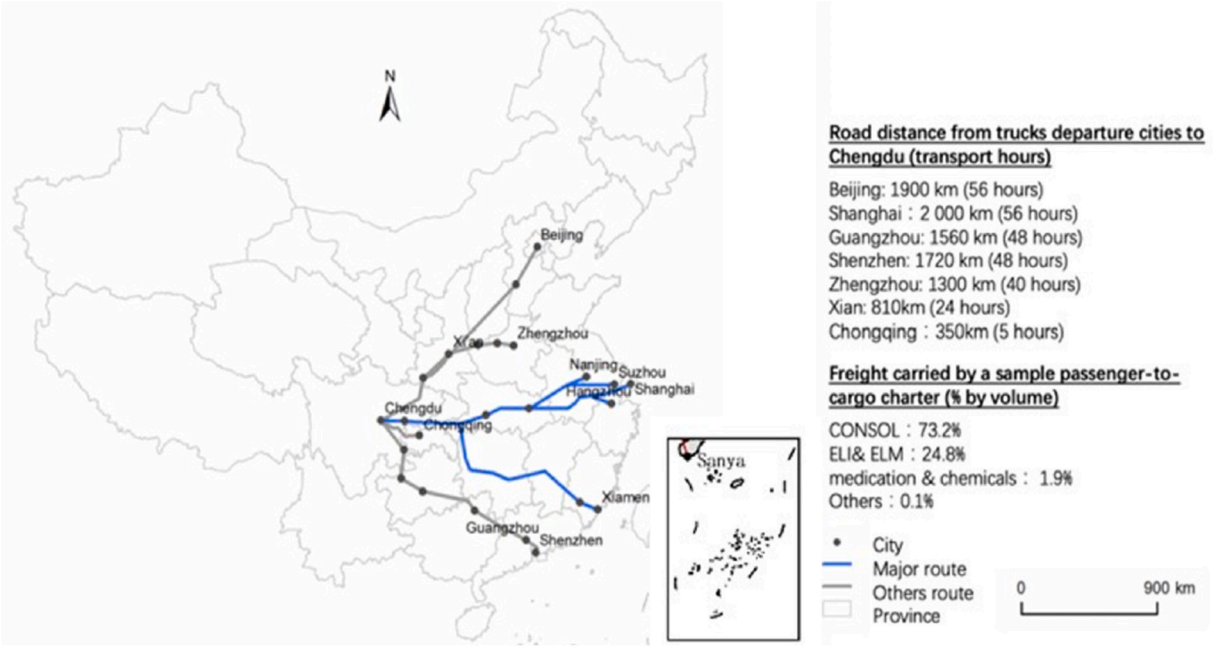

Fig. 5. A truck route network with key information. Source: Feight forwarder.

systems in the context of charterer activities.

Fig. 5 also lists the shipments carried by a Boeing 777-300 preighter. A local factory needed to export lithium-battery products and entrusted the task to a freight forwarder. Based on the factory's dispatch schedule and final destination, the forwarder signed a charter agreement with an airline and, after receiving the factory's advance payment, paid a deposit to the airline. Because the Boeing 777-300's capacity far exceeded the volume of the lithium-battery shipment, the forwarder distributed the surplus space to its agents and other forwarders. Ultimately, the flight carried 4.5 tons of cargo, comprising 1185 items across 38 MAWBs. By volume, 73% were consolidation consignments (CONSOL), while only 25% consisted of lithium-ion batteries. This case demonstrates that preighter charter operations rely on multi-party cooperation. To reduce commercial risk, the freight forwarder redistributed excess capacity among other forwarders and consolidated shipments from multiple sources, thereby acting as a capacity broker among shippers, airlines, and other agents.

China's major cities (airports) are well connected by expressways, which enables charterers to consolidate cargo from geographically dispersed places to charter departure airports. The cargo collection points can be regarded as spokes, while the charter departure airport functions as the hub; together, they form an airport-centered hub-and-spoke network. Supported by surface transportation, the freight forwarders can transport cargo not only from various spoke to airports but also between airports. As such, the charterers could respond to abrupt changes (e.g., shortages of airport loading staff, adjustments in epidemic control measures, or fluctuations in infection rates) by selecting alternative departure airports. They may also bypass the nearest airport by transporting cargo to a more distant one or by leasing aircraft from a specific airline, driving by various factors. Gradually, they established specialized destination groups for each hub city (airport).

Fig. 6 reveals how top 10 Chinese cities (ranked by charter volume in 2020) differ in their major destination. It could be generally observed that each Chinese city is connected to a distinct set of major destinations, with limited overlap across cities. A detailed analysis is conducted for Shanghai, Zhengzhou, and Chengdu, which serve as leading logistics hubs in China's eastern, central, and western regions, respectively. Shanghai was connected to numerous destinations via charters (bright yellow routes). The charters primarily connected Zhengzhou with Russia, Central Asia, and EU cities, with Zhengzhou–Moscow and Zhengzhou–Luxembourg as key routes (bright green routes). The network centered on Chengdu (bright blue routes) was relatively sparse and featured a large proportion of routes heading to Southeast Asian cities. In 2021, this differentiation becomes more pronounced.

Fig. 6(b) illustrates that differences became more pronounced in 2021, suggesting that the forwarders reinforced the variability among cities in terms of destination groups. This freight-forwarder-led city-level route (re)construction approach enabled each city (major airport) to present one or more distinct destination clusters, thereby reducing route competition among cities and improving the overall performance of the charter system. Regarding the factors that impacted freight forwarders' airport selection, this approach reduced the importance of ground-transport distance. To a certain degree, the location of the destination became a factor impacting airport selection by freight forwarders.

6. The performance of preighters

6.1. Performance evolution

As can be seen in Fig. 7, preighter charters achieved better performance in 2021: k values increased and remained at a higher level throughout the year, and L values declined with less fluctuation. Unlike P2C's sharp optimization, the freighters kept a stable but limited performance. It is worth noting that preighters outperformed freighters in both resilience and efficiency in 2021, as well as (mixed) foreign charters, particularly in terms of network efficiency. Compared with freighter charters, preighter operations are characterized by higher labor intensity and complex consolidation requirements, which demand closer collaboration between freight forwarders, shippers, airlines, airports, and governmental authorities. For example, due to the manual handling required for cabin loading, freight forwarder staff were sometimes needed to load cargo or assist airlines in supervising the process in some cases. It seems that deep cooperation enabled preighter charters to outperform freighters.

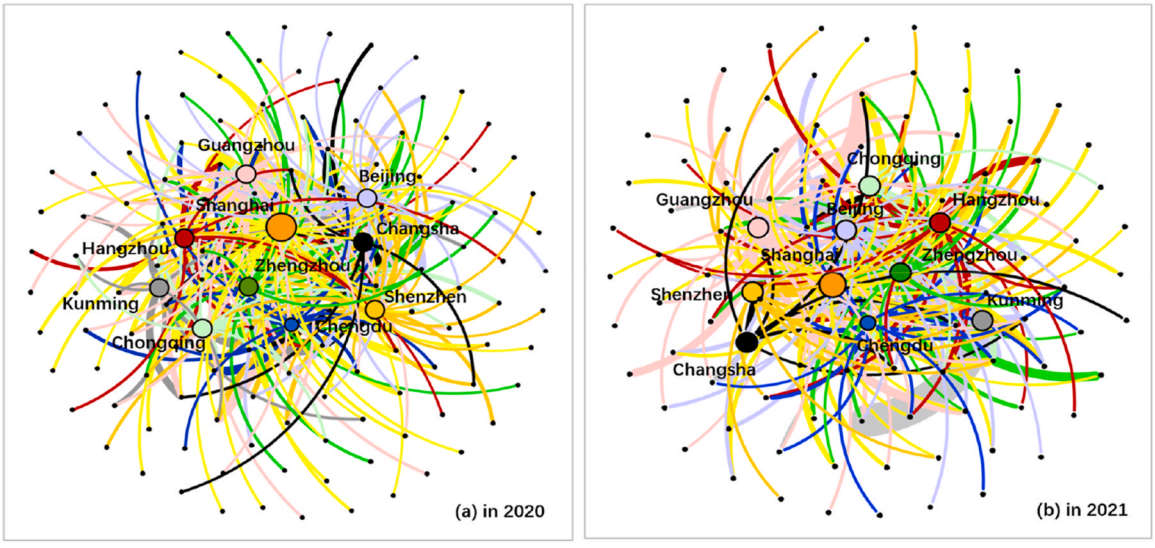

Fig. 6. Major charter destinations of the top 10 Chinese hubs: 2020 vs. 2021.
Note: the major destinations refer to cities served by 10 or more charter flights, represented by black dots in the figures.

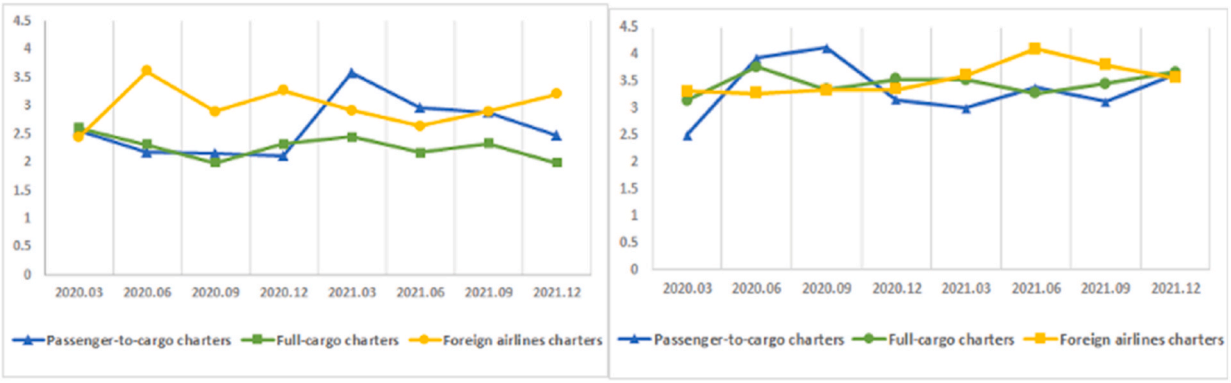

Fig. 7. Visual indication of average changes in the values of each indicator.

6.2. Network reconfiguration trends

Table 7 lists the top 10 nodes and edges within the network formed by preighter charter flights. The NBC ranking reveals that the preighter network shifted from a China-dominated structure to a more globally dispersed configuration. In 2020, seven of the top 10 nodes were located in China. By 2021, overseas cities increased to six. London and Los Angeles consistently served as the most important overseas nodes. Vancouver emerged as a new North American gateway, Paris appeared as an EU anchor city, and Almaty became a key bridging hub between China and Europe.

EBC measures the importance of a route within an air freight network by capturing its bridging function. In 2020, the majority of top-ranked routes were linked to Shanghai; the top three edges were Urumqi–London, Shanghai–Seoul, and Urumqi–Yekaterinburg; and five of the top 10 edges connected with Asian cities. By 2021, the bridging pattern underwent a marked reorientation: Guangzhou surged to the forefront with four key bridges; the top three routes became Guangzhou–Almaty, Urumqi–Almaty, and Guangzhou–London; and Central Asian routes appeared for the first time.

Table 7
Top 10 nodes and edges within passenger-to-cargo (P2C) charter networks.

	In 2020		In 2021	
	NBC	EBC	NBC	EBC
1	Shanghai	Urumqi-London	Guangzhou	Guangzhou-Almaty
2	Guangzhou	Shanghai-Seoul	Shanghai	Urumqi-Almaty
3	Chengdu	Urumqi-Yekaterinburg	Beijing	Guangzhou-London
4	Beijing	Shanghai-Islamabad	London	Guangzhou-Osaka
5	London	Shanghai-Osaka	Chengdu	Shanghai-London
6	Seoul	Shanghai-London	Los Angeles	Guangzhou-Los Angeles
7	Shenzhen	Chengdu-London	Paris	Shanghai-Osaka
8	Chongqing	Shanghai-Yangon	Almaty	Guangzhou-Moscow
9	Urumqi	Shanghai-Ho Chi Minh	Vancouver	Guangzhou-Paris
10	Los Angeles	Guangzhou-Seoul	Osaka	Chengdu-London

Both NBC and EBC results consistently demonstrate significant structural reconfiguration of the preighter network. In terms of spatial location, Guangzhou lies in South China, while Shanghai occupies a strategic position on the eastern seaboard. In 2021, Guangzhou surpassed Shanghai as the principal node within the network, with seven of the ten most significant edges linked to it, indicating a geographical reorientation of the network toward southern China. The reconfiguration also extended the network's reach: the number of long-haul routes (≥6000 km) doubled from three in 2020 to six in 2021, and the average distance of the top ten edges increased from 4067 km to 6386 km. Thus, the network transitioned from a China-concentrated structure in 2020 to a southern-China–centered, globally dispersed, and long-haul-oriented configuration in 2021.

7. Conclusion and discussion

Taking China as the study area, this paper examines the evolution of international cargo charter operations during 2020–2021, focusing on preighter operations and the role of freight forwarders. There are three major results. First, aviation deregulation and the promotion of preighters boosted cargo charter operations, which in turn enhanced China's integration into global supply chains by providing flexible capacity and routes. Other drivers included the surge in e-commerce demand, Chinese carriers' growing recognition of air cargo's strategic importance, and new slot policies and financial subsidies (Deng et al., 2022). Second, cargo charter operations underwent profound network transformations during period 2020 to 2021. The results of descriptive statistics show that charters became increasingly concentrated on routes connected with major overseas hubs; geographic visualization reveals a shift of charter routes toward overseas inland hubs and major maritime gateways; and complex network indicators demonstrate a (re)organization of the network formed by preighter charters from a China-concentrated structure to a globally dispersed and long-haul-oriented configuration. And third, freight forwarders assumed the commercial risk for charter operations (ICAO, 2022), acting not only as capacity brokers but also as central players in route development and network optimization.

As one of the strategic measures adopted by airlines in response to the COVID-19 crisis, preighter operations offered airlines a convenient and cost-effective way to utilize their aircraft (Zheng et al., 2024). It also

created opportunities for passenger-only airlines, particularly LCCs and CCs, to start international cargo operations. The preighter model remains an influential factor in today's supply chain, which continues to face challenges and uncertainties. Our results revealed that the preighters primarily served routes rarely covered by freighters, experienced route re-construction, and outperformed freighters in both resilience and network efficiency. Furthermore, the charters reached more destinations than scheduled flights, thereby enhancing the resilience and flexibility of China's air cargo system.

In the context of COVID-19, charter operations in China heavily depended on truck networks. Various city (airport)-centered truck networks enabled freight forwarders to extend charter catchment areas to 56 h through truck-to-aircraft systems, a distance far exceeding the general catchment area of air cargo, such as the 12-h radius (Boonekamp and Burghouwt, 2017). Meanwhile, the forwarders may select a more distant airport instead of the geographically closest on, driving by various factors, This freight-forwarder-led city-level route (re)construction approach enabled each city to present one or more distinct destination clusters, thereby reducing route competition among cities. Regarding the factors that impacted freight forwarders' airport selection, this approach serves as a supplement to related research on airlines' airport selection during COVID-19, such as Tanrıverdi et al. (2022). As in scheduled cargo service, local origin-destination demand, airport road access, and airport/local government financial incentive are also crucial factors affecting forwarders' airport selection decisions (Chu, 2014); and the presence of freight forwarders is the most critical factor influencing airport choice for airlines serving major hubs (Franziska et al., 2016).

Our study found that the increase in scheduled service did have negative influences on cargo charter demand, but these negative influences were uneven and not lasting. This resilience results from charter operations being led by freight forwarders within a market-driven, less regulated environment, allowing them to adapt to changes effectively through route optimization and network transformation. Meanwhile, cargo charter flights predominantly follow point-to-point network patterns, and this architecture demonstrates greater resilience to both targeted node and random edge removal compared with the hub-and-spoke system (Wuellner et al., 2010; Wong et al., 2020). During the COVID-19–impacted period, Chinese international scheduled freighters refined a hub-and-spoke network to meet surging cargo demand from major hubs (Deng et al., 2025), implying that charters played different role. Furthermore, various city (airport)-centered truck route networks formed a nationwide truck-to-aircraft charter cargo transit network. The geographic coverage of each city (airport)-centered truck network changed dynamically, synchronizing with the consolidation strategies adopted by charterers for each flight. Therefore, each charter operation would increase the flexibility of the whole charter network. In this way, we explained the mechanisms underlying the resilience of the charter transport system.

Based on these findings, several policy implications can be drawn. First, aviation authorities should recognize cargo charters as a structural component of the air cargo system rather than as purely temporary or exceptional arrangements. Integrating hub-and-spoke networks (scheduled services) with point-to-point networks (cargo charters) could enhance overall system efficiency, even in the post-COVID era. Second, preighter operations represented a policy-enabled response to the COVID-19 crisis and largely disappeared by mid-2023 after aviation authorities phased out related regulatory exemptions (IATA, 2025). Rather than fully phasing out preighter operations, aviation policymakers could consider establishing conditional frameworks that allow such services to be reactivated during periods of demand surges or systemic disruption. Alternatively, preighter operations could be incorporated into the cargo charter regulatory framework, thereby supporting airlines' long-term fleet planning. Third, the CAAC could regulate charter traffic primarily through supervision rather than by tightly limiting charter operations on routes already served by scheduled flights. In addition, the CAAC should improve the statistical framework for cargo charters by requiring all airlines to report actual charter flight data.

For industry practitioners, the findings highlight several recommendations. Airlines and airports should strengthen cooperation with freight forwarders; aircraft manufacturers should place greater emphasis on convertible cargo capabilities, such as quick-change aircraft; and both LCCs and CCs should seek regulatory authorization to operate passenger aircraft on cargo-only missions. Chinese integrators also need to expand their fleets and network coverage. As of 2019, the two leading firms, SF Airlines and YTO Cargo Airlines, operated a combined total of only about 68–72 freighters, revealing a substantial capacity gap compared with FedEx's 681 aircraft and UPS's 572 aircraft. Under normal operating conditions, approximately half of China's international air cargo is transported in the belly holds of passenger aircraft, with the remainder carried by dedicated freighters. Because belly cargo is closely tied to passenger flight operations, cargo movements are embedded within passenger-driven flight networks, making it difficult to separately identify and precisely characterize freight flows. The pandemic-induced suspension of passenger flights created a natural experiment in which cargo flows were dominated by freighters and preighter operations. By integrating our finding with scheduled services, all practitioners can more clearly identify freight volumes and flows, providing valuable guidance for future fleet planning, network design, and route selection.

This study is subject to several limitations. First, the dataset for charter flights operated by foreign airlines is derived from CAAC-issued operating permits. Despite this constraint, the dataset as a whole is adequate to support the analytical framework and to produce robust and reliable findings. Second, the analysis centers on freight forwarders while overlooking perspectives of other stakeholders, including airlines, airports, and regulators. Third, cross-market differences are not examined. Future research should examine the factors affecting charterers' airport selection and the interplay between charter and scheduled services. We view this paper as an initial step in the limited empirical literature on the resilience of the air charter transport system, and the same approaches could be applied to evaluate the performance of passenger charters.

CRediT authorship contribution statement

Chuntao Wu: Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology, Formal analysis. **Xiaohe He:** Visualization, Validation, Software, Data curation. **Yuliang Peng:** Visualization, Validation, Software, Data curation.

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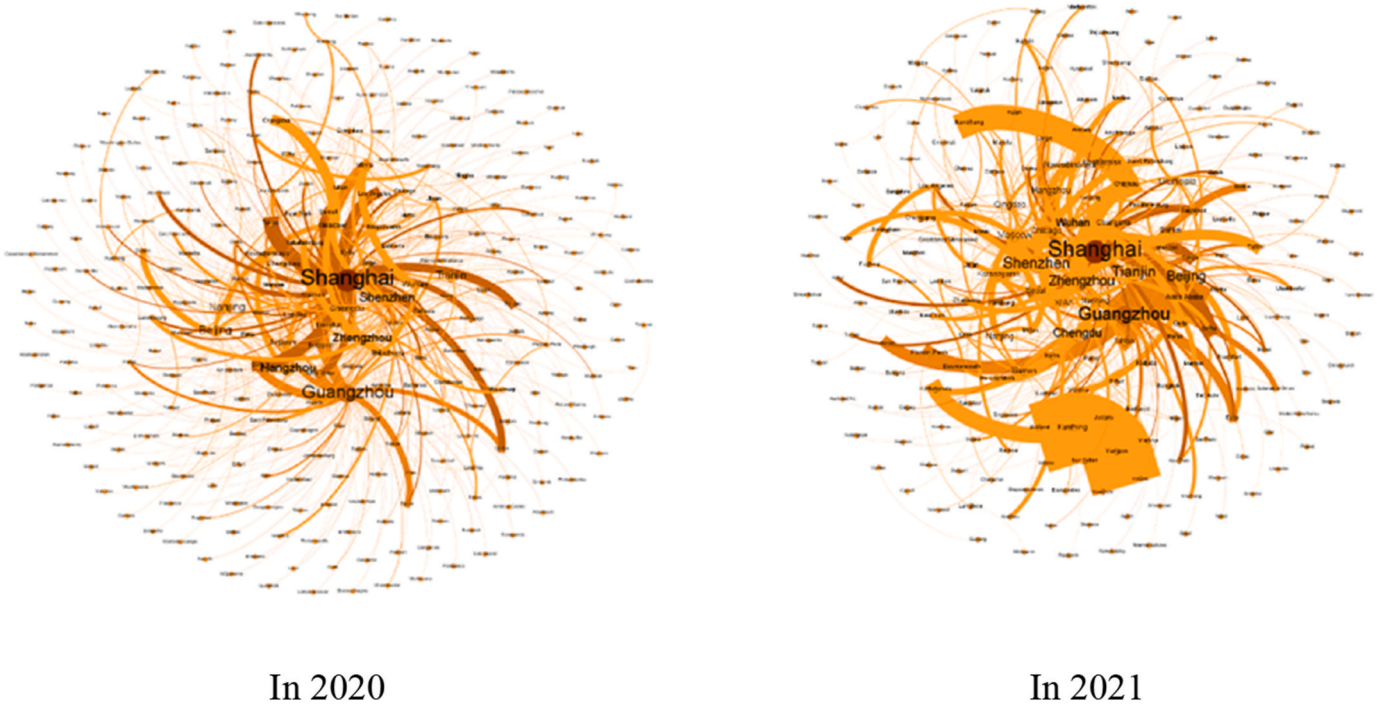
Declarations of conflict interest

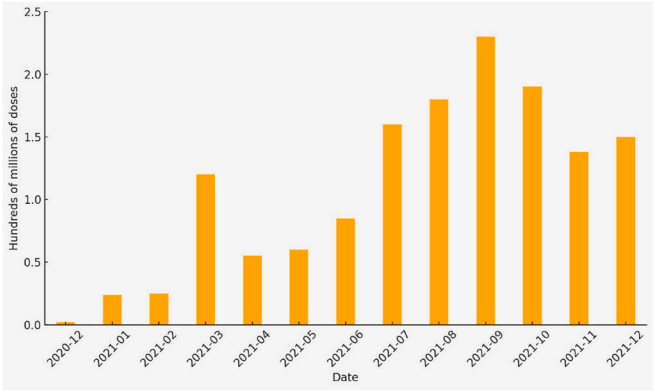
None.

Appendix 1



Visualization of key nodes and edges within network built by foreign charters.

Appendix 2



Overseas supply of COVID-19 vaccines by Chinese companies.
Data source: UNICEF; may include locally produced doses.

Data availability

Data will be made available on request.

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