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Analysis of changes in population's cross-city travel patterns in the pre- and post-pandemic era: A case study of China

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ABSTRACT

The coronavirus disease (COVID-19) outbreak has immensely changed people's travel behaviour. The changes in travel behaviour have had a huge impact on different industries, such as consumption, entertainment, commerce, office, and education. This study investigates the impact of COVID-19 on population travel patterns from three aspects: total trips, travel recovery degree, and travel distance. The result indicates that COVID-19 has reduced the total number of cross-city trips and flexible non-work travel; in the post-pandemic era, cross-city travel is mainly short-distance (distance < 100 km). This study has significant policymaking implications for governments in countries where the population shares a similar change in travel behaviour.

1. Introduction

COVID-19 evolved from a local epidemic to a global pandemic within a few months. As the virus spread rapidly through population activities and gatherings, it profoundly changed the population's travel pattern. This change has had a huge impact on different industries, such as consumption, entertainment, commerce, office, and education, ultimately changing the economy, politics, and even human society culture. Since all these changes stem from the impact of the pandemic on the population's travel patterns, conducting a systematic study on such changes in travel patterns is greatly significant.

Both domestic and international scholars have conducted a series of studies on the impact of the pandemic on people's lives. The current study focuses on two categories: short-distance travel within cities and long-distance travel across cities. Short-distance travel mainly entails the travels within inner cities to fulfill people's daily needs, while long-distance travel is mainly associated with business, tourism, and family visits, among others. Research on the impact of the pandemic on short-distance travel primarily focuses on how the pandemic changed people's travel modes within cities (Aloi et al., 2020; Bhat, 2020), including the changes in the total trips and travel distances (de Haas et al., 2020; Klein et al., 2020). Studies on long-distance travel mainly focus on changes in people's attitudes toward long-distance travel and changes in travel preferences (Chen et al., 2020; Jiang et al., 2020). These studies, based on survey data, analysed the changes in people's travel patterns owing to the pandemic. However, because of the very limited sample sizes, these studies only discuss the changes in people's travel patterns and travel frequency, without using various indicators, such as travel distance and travel purpose, to analyse the overall trend and changes in population travel.

The current study contributes to the existing literature on the impact of the pandemic on population travel patterns. Compared with survey data, the mobile signalling data adopted in this study are highly representative in revealing cross-city travel patterns of a population. By mining mobile signalling data, this study constructs indicators of total trips, travel recovery degree, and the travel distance that could characterise population travel patterns, thereby enriching the methods used to study the impact of the pandemic on population travel patterns. The changes in travel patterns due to the pandemic, as revealed by this study, not only have long-term domestic policy implications in economic

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recovery, remote working and studying, and e-commerce, among others, but also provide a valuable policy reference to countries other than China.

This study aims to systematically study the impacts of the pandemic on people's travel patterns by analysing cross-city travel among 345 cities in China; China was chosen as the subject of the case study because it has effectively contained the pandemic, and population travel has mostly returned to normal. Therefore, the pre- and post-pandemic comparison in China can accurately reflect the impact of the pandemic.

2. Data and methodology

Quantitative indicators for crowd travel measurements generally include total trips, travel recovery degree, travel distance, and travel radius. As the travel radius is mostly used for inner-city travel analysis, this study uses total trips (inflow and outflow), travel recovery degree, and travel distance to quantitatively analyse the impact of the pandemic on people's travel behaviour.

2.1. Total trips

Total trips refer to the total population inflows and outflows, which represent the total number of trips made per city. The total number of trips can be defined as

\[ F_i = \sum_{j=1}^{n} F_{ij} \]

where \( F_i \) represents the sum of inflows and outflows in city \( i \), \( F_{ij} \) represents the total population flows between city \( j \) and city \( i \), and \( n \) is the number of cities that have population flows with city \( i \).

2.2. Travel recovery degree

The travel recovery degree measures the travel demand of urban residents, which is defined as:

\[ S_i = \left( \sum_{j=0}^{n} M_{ij} / P_i \right) \]

where \( M_{ij} \) represents the number of people travelling from city \( i \) to city \( j \) after the pandemic, \( P_i \) represents the total population of city \( i \) in the pre-pandemic period, and \( N \) represents the total number of cities.

2.3. Travel distance

The travel distance between cities indicates the straight-line distance (Euclidean distance) from city \( i \) to city \( j \) per travel, which is defined as:

\[ D_{ij} = \frac{\sum d_i}{P_i} \]

where \( d_i \) represents the level 1 cross-city travel distance for residents in cities involving ultra-long distances (>800 km, \( l = 1 \)), long distances (300–800 km, \( l = 2 \)), medium distances (100–300 km, \( l = 3 \)), and short distances (<100 km, \( l = 4 \)), and \( P_i \) represents the number of residents travelling in the corresponding travel distance level.

This study's data were derived from the mobile signalling data provided by the China Unicom. Given the pandemic eruption period, prevention and control, and work resumption and production progress, this study uses data from 345 cities in China from two periods (holidays are avoided): June 2019 and June 2020, to compare the travel characteristics of the population before and after the pandemic. The study mainly focuses on the comparative analysis of typical weekdays, weekends, and the May Day holiday.

3. Results and discussion

To study the impact of the pandemic on cross-city travel, this study conducts a comparative analysis, based on three dimensions: total trips, travel recovery degree, and travel distance.

3.1. Analysing the impact of the pandemic on total cross-city trips and the travel recovery degree

The analysis of daily total trips in June 2019 and in June 2020 revealed that regardless of weekdays, weekends, or holidays in the post-pandemic period, the total trips are significantly fewer than those in the pre-pandemic period at the national level. On average, in the 345 cities across the country, the daily total trips were 127 million on weekdays before the pandemic and 80.9 million post pandemic, with a recovery rate of 63.7%; the total number of trips was 137 million on weekends before the pandemic and 86.9 million in the post pandemic period, with a recovery rate of 63.6%. The pandemic has had the least impact on weekday travel and the largest impact on holiday travel. Taking the May Day holiday as an example, on average, the daily total trips were 177 million before the pandemic, which decreased to 106 million post pandemic. The travel recovery rate is only 59.9%. Cross-city travel on holidays is mainly for purposes such as leisure, which are neither work nor business-related, while travel during weekdays is associated more with necessary travel. Evidently, the pandemic has noticeably reduced flexible non-work travel.

In different regions (Fig. 1), the number of inter-provincial and long-distance trips in the post-pandemic period has significantly reduced, compared with that in the pre-pandemic era. The number of cross-city trips among most cities shows a downward trend. However, it is apparent that during the weekdays and weekends, the number of cross-city trips in the post-pandemic period was higher than that before the pandemic in the regions of Hebei-Shandong, Shaanxi-Gansu-Ningxia and Yunnan Province. During the holidays, the number of cross-city travel in the post pandemic in the region of Harbin-Jilin-Liaoning increased significantly compared with that in the pre-pandemic.

Within 36 key cities, the total cross-city trips on weekdays were 23.3 million, with a recovery rate of 67.4%, which is 3.7% higher than the national average level. The total number of cross-city trips on weekends was 24.3 million, with a recovery rate of 65.3%, which is 1.7% higher than the national average level. The total number of cross-city trips on holidays was 29.8 million, with a recovery rate of 56.9%, which is 3% lower than the national average level. The relatively strict measures of pandemic prevention and control in the 36 key cities may have caused the degree of holidays travel recovery to be lower than the national average level. On the other hand, owing to the advanced economic level and high volumes of commutes in the 36 key cities, the degree of travel recovery on weekdays was much higher than the national average level.

In addition, cities with high average daily total trips do not have a similarly high degree of travel recovery. Guangzhou, Shanghai, Shenzhen, Chengdu, and Zhengzhou had the highest average daily total trips on weekdays, but their degrees of travel recovery rank 13th, 29th, 4th, 11th, and 21st place in the 36 cities, respectively. Small cities, such as Lhasa, Lanzhou, and Yinchuan rank top three in terms of travel recovery degree on weekdays, with rates of 122.8%, 87.4%, and 86.0%, respectively; however, their average daily total trips are not high. Tourism cities, such as Haikou, Xining, and Chengdu rank higher in terms of travel recovery degrees on holidays, compared to weekdays and weekends. Affected by the second wave of the pandemic in June, Beijing ranks last in terms of travel recovery degree on weekdays, weekends, and holidays (Table 1).

3.2. Analysing the pandemic's impact on cross-city travel distance

Table 2 and Fig. 2 present the comparison of cross-city travel distance in the pre- and post-pandemic eras. Regarding the travel structure,
the proportion of short-distance travel (<100 km) in the post-pandemic period has increased, compared with that in the pre-pandemic period, and the proportions of short-distance travel on weekdays, weekends, and holidays have increased by 4.5%, 6.9%, and 4.7%, respectively. The difference between the proportion of ultra-long distance travel (>800 km) in the post-pandemic period and that in the last year is less than 1%; the proportion of medium-distance travel (100-300 km) has decreased the most, with the largest drop of 4% on weekends, and the smallest drop of 2.4% on weekdays. As the flexibility of medium-distance travel on weekends was relatively high, it was most strongly affected by the fluctuation of the pandemic.

For the travel recovery degree, short-distance cross-city travel (<100 km) has the highest degree of recovery, followed by medium- and long-distance cross-city travel (100-300 km and 300-800 km, respectively), and ultra-long distance travel (>800 km). In terms of different periods, regardless of travel distance, the degree of travel recovery on weekdays was the highest, followed by that on weekends and holidays. The recovery rates of short-distance travel on weekdays and weekends were 82.6% and 83.8%, respectively, which were much higher than the recovery rate of 65.0% on holidays. The recovery rates of the medium- and long-distance cross-city travel (100-300 km and 300-800 km) were 70.2% and 66.4% on weekdays, 64.9% and 59.3% on weekends, and 53.5% and 55.4% on holidays, respectively. The recovery degree of the ultra-long-distance travel was low in all three periods. The recovery rate was 66.9% on weekdays, 64.3% on weekends, and 51.5% on holidays.

4. Conclusion

By analysing the changes in characteristics of cross-city travel in 345 cities across China, before and after the pandemic, the following main conclusions can be drawn:

(1) At the national level, the recovery degree of cross-city travel on weekdays is the most optimal, followed by that on weekends and holidays. In the post-pandemic era, people reduced their demand for non-work travel. Changes in travel patterns are objective outcomes, which are mainly affected by prevention and control policies, prevention and control effects, and international trends. Domestic pandemic prevention and control policies are the most direct causes of change in travel patterns. For example, to contain the spread of the pandemic, cross-regional travel is not allowed without providing a green health code. The unconventional prevention and control measures adopted in the early stage of the pandemic restricted population flows across cities, which caused the total trips and total cross-city trips in 2020 to be lower, compared to those in 2019. Meanwhile, the prevention and control measures adopted by firms and other entities during the pandemic also hindered inner-city travel to a certain degree. Currently, some entities still practise the work rotation system, which causes a relative decrease in the total inner-city trips and travel frequency in 2020. The decrease is especially significant on weekends and holidays, as people have reduced flexible non-work travel.

(2) For cities with higher economic development levels, larger populations, or higher tiers, the reduction in workday commuting due to the pandemic is relatively small; however, the reduction in non-work travel is relatively large. Meanwhile, owing to the pandemic, some rural labourers opt to work and live in their countryside, which explains why Hebei-Shandong, Shaanxi-Gansu-Ningxia, Yunnan, and Harbin-Jilin-Liaoning have more total cross-city trips in the post-pandemic era than in the pre-pandemic era.
In the post-pandemic era, people prefer short-distance cross-city travel (<100 km). This change in travel distance has some implications for urban planning and governance in China and other countries. Governments in China and other countries could develop planning, such as 30-minute work circles, 30-minute entertainment circles, or 15-minute community-life circles, to cope with the newly adopted travel behaviour.

The newly adopted travel behaviour, such as the preference for short-term travel and the decrease in non-work travel, is likely to last and become a structural change. This alteration has a significant implication for policymaking in terms of economic recovery, remote working and studying, and e-commerce, among others, at the domestic and international levels. The government should develop policies that facilitate the adaption to these changes by the market and people. Specifically, the current trend of working from home is rising domestically and internationally, as work-from-home is often associated with increased productivity and creativity, decreased cost for businesses, less congestion, and an improved environment. Given these benefits, the government could further facilitate the rise of such a trend by providing incentives to businesses that intend to adopt this new operating model. In addition, the online education industry and e-commerce in China are experiencing rapid expansion owing to the restriction of population flow. The rapid expansion of online education and e-commerce requires prompt regulation and oversight from the government, as well as the necessary support, as the development of online education and e-commerce could be used to address the unemployment issue caused by the pandemic. These policy lessons could be applied in countries where the population shares a similar change in travel behaviour.

Table 1
Average daily total trips and travel recovery degree in 36 key cities.

| Cities       | Weekdays | Travel recovery degree | Weekdays | Travel recovery degree | Weekdays | Travel recovery degree |
|--------------|----------|------------------------|----------|------------------------|----------|------------------------|
| Guangzhou    | 231.7    | 83.3%                  | 250.2    | 89.9%                  | 216.8    | 53.8%                  |
| Shanghai     | 132.5    | 63.4%                  | 128.0    | 62.5%                  | 152.2    | 53.5%                  |
| Shenzhen     | 130.4    | 85.6%                  | 155.7    | 94.7%                  | 158.6    | 74.3%                  |
| Chengdu      | 125.4    | 82.0%                  | 134.1    | 77.9%                  | 195.8    | 75.7%                  |
| Zhengzhou    | 119.8    | 71.8%                  | 132.6    | 71.4%                  | 148.3    | 53.9%                  |
| Hangzhou     | 106.8    | 75.1%                  | 99.4     | 66.4%                  | 126.9    | 63.0%                  |
| Xian         | 102.0    | 73.8%                  | 119.9    | 72.7%                  | 149.3    | 62.4%                  |
| Nanjing      | 91.1     | 68.0%                  | 98.0     | 65.9%                  | 114.9    | 56.7%                  |
| Changsha     | 79.0     | 78.5%                  | 90.0     | 80.1%                  | 125.0    | 69.5%                  |
| Jiaxin       | 72.8     | 34.6%                  | 75.9     | 39.0%                  | 104.6    | 48.3%                  |
| Wuhan        | 69.1     | 61.1%                  | 74.8     | 59.0%                  | 77.0     | 35.2%                  |
| Hefei        | 68.1     | 70.1%                  | 73.2     | 66.4%                  | 105.7    | 66.5%                  |
| Beijing      | 66.8     | 32.1%                  | 33.8     | 15.3%                  | 116.5    | 41.2%                  |
| Kunming      | 65.5     | 60.5%                  | 68.4     | 60.1%                  | 66.7     | 45.1%                  |
| Guiyang      | 63.0     | 64.0%                  | 70.4     | 64.6%                  | 93.1     | 64.6%                  |
| Shenyang     | 60.3     | 73.5%                  | 64.3     | 72.3%                  | 73.9     | 53.9%                  |
| Chongqing    | 57.1     | 64.1%                  | 58.9     | 58.6%                  | 79.7     | 57.6%                  |
| Tianjin      | 56.7     | 58.9%                  | 51.4     | 46.4%                  | 78.8     | 51.9%                  |
| Xiamen       | 56.4     | 83.0%                  | 63.6     | 77.5%                  | 72.7     | 64.5%                  |
| Taiyuan      | 51.4     | 81.9%                  | 44.6     | 59.4%                  | 65.0     | 62.1%                  |
| Ningbo       | 46.0     | 84.2%                  | 41.9     | 71.6%                  | 55.2     | 61.4%                  |
| Nanning      | 45.2     | 75.8%                  | 50.7     | 73.5%                  | 59.5     | 62.0%                  |
| Changchun    | 44.7     | 58.8%                  | 45.8     | 58.2%                  | 56.1     | 47.8%                  |
| Qingdao      | 43.1     | 73.1%                  | 46.3     | 64.1%                  | 65.1     | 61.4%                  |
| Shijiazhuang | 42.5     | 67.6%                  | 41.7     | 56.8%                  | 61.1     | 58.1%                  |
| Nanchang     | 39.6     | 75.5%                  | 41.0     | 72.9%                  | 49.2     | 61.2%                  |
| Lanzhou      | 37.5     | 87.4%                  | 39.6     | 86.1%                  | 47.1     | 84.1%                  |
| Fuzhou       | 35.9     | 35.5%                  | 37.8     | 34.9%                  | 51.1     | 37.2%                  |
| Urumqi       | 31.8     | 71.7%                  | 32.2     | 67.9%                  | 35.8     | 61.9%                  |
| Harbin       | 30.2     | 84.8%                  | 29.9     | 88.7%                  | 13.9     | 18.1%                  |
| Yinchuan     | 25.8     | 86.0%                  | 27.7     | 79.6%                  | 33.3     | 65.8%                  |
| Xining       | 24.5     | 83.1%                  | 29.1     | 83.7%                  | 35.3     | 78.1%                  |
| Haikou       | 23.9     | 83.6%                  | 27.7     | 91.3%                  | 31.6     | 85.9%                  |
| Dalian       | 22.1     | 66.8%                  | 23.2     | 66.6%                  | 24.6     | 46.3%                  |
| Hohhot       | 19.2     | 82.6%                  | 20.9     | 73.0%                  | 32.0     | 69.7%                  |
| Haibei       | 9.7      | 122.8%                 | 10.7     | 131.1%                 | 8.0      | 86.8%                  |

Table 2
Changes in the proportion of travel distance in post pandemic.

| Weeksdays | Proportion of travel distance in post pandemic | Changes in proportion of travel distance in post pandemic | Weekdays | Proportion of travel distance in post pandemic | Changes in proportion of travel distance in post pandemic | Holidays | Proportion of travel distance in post pandemic | Changes in proportion of travel distance in post pandemic |
|-----------|-----------------------------------------------|--------------------------------------------------------|----------|-----------------------------------------------|--------------------------------------------------------|----------|-----------------------------------------------|--------------------------------------------------------|
| ≤100 km   | 53.3%                                         | 4.5%                                                   | 55.1%    | 6.9%                                          | 48.7%                                                 | 4.7%     |
| 100 km-300 km | 31.3%                                         | -2.4%                                                  | 31.1%    | -4.0%                                         | 36.8%                                                 | -3.6%    |
| 300 km-800 km | 11.0%                                         | -1.5%                                                  | 10.1%    | -2.4%                                         | 11.9%                                                 | -0.7%    |
| ≥800 km   | 4.4%                                          | -0.6%                                                  | 3.8%     | -0.5%                                         | 2.7%                                                  | -0.4%    |
Credit authorship contribution statement

Xuyang Wang: Conceptualization, Methodology, Writing-Original draft, Writing-Editing. Tao Pei: Conceptualization, Validation, Supervision. Kaixi Li: Conceptualization, Formal Analysis, Visualization. Yan Cen: Conceptualization, Formal analysis. Miao Shi: Software, Visualization. Xian Zhuo: Conceptualization, Validation, Supervision. Tianyu Mao: Formal analysis.

Declaration of competing interest

None.

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Fig. 2. Distribution of cross-city travel distance before and after the pandemic.