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Behavior Characteristics Analysis of Travel Mode Shift: A Case Study of Beijing

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Abstract: Empirical analyses of behavior characteristics under the combined controllable variables scenarios of planning and policy are relatively rare in existing studies on travel mode shift. Taking Beijing as an example, a Stated Preference (SP) survey was conducted on 3 351 travelers, identifying four groups with different travel mode shift intentions. This paper starts with an assessment of the impact of two variables—travel time ratio and parking fees—on different groups. Subsequently, the changes in travel mode shift rates under different combination scenarios are compared to reflect the impact of improving public transit efficiency and increasing the cost of passenger car use on the intention to shift travel modes for different groups. The results show that reducing the travel time ratio is effective in increasing passenger dependence on public transit and reducing passenger loss, but it is still difficult to attract travelers highly dependent on private cars. Increasing parking fees significantly guides the swing group to shift modes from private cars to public transit. The travel mode shift rates resulting from both variables are influenced by the existing baseline values and their interactive relationship needs to be considered in a holistic way when formulating policies. Finally, the paper recommends developing region-, group-, and purpose-specific strategies to enhance the attractiveness of public transit based on travel survey data. This approach aims to explore refined, implementable, and comprehensive paths for public transit development and transportation management.

Keywords: public transit; passenger cars; Stated-Preference (SP) surveys; travel mode shift; travel time ratio; parking costs; Beijing

0 Introduction

In recent years, there has been a growing trend among residents to choose passenger cars for transportation, leading to a decrease in the willingness to use public transit. In 2020, the proportion of urban rail transit trips in the central urban area of Beijing decreased by 1.8 percentage points compared to the previous year, while the proportion of public bus and trolley bus trips decreased by 3.6 percentage points. Conversely, the proportion of passenger car trips increased by 1.77 percentage points year-on-year. Therefore, it is imperative to conduct a stated preference (SP) survey to clarify the characteristics of different groups' willingness to travel mode shift and provide support for the development of plans and policies to enhance the attractiveness of public transit.

In the existing studies on travel mode shift, logit models are adopted by most scholars to calculate transfer probabilities. For instance, Qian et al. [1] develop a binary logit model to explore the travel mode shift of buses under the context of information services, examining the influence of real-time information services on passengers' travel behavior intentions. Cao et al. [2] formulate a nested logit (NL) model to investigate the transfer mechanism of urban rail transit ridership. Zhang et al. [3] employ a multinomial logistic regression model to construct travel mode shift models for four distinct rainfall scenarios. Wang et al. [4] devise an NL model and a multinomial logit (ML) model to predict the transfer of urban rail transit ridership. Wu et al. [5] establish a multivariate logit model to analyze the impact of time-shared rental cars in urban complexes on travel mode shift behavior. Furthermore, some scholars have integrated psychological latent variables into their models, leading to the development of multiple indicators and multiple causes (MIMIC) models. For example, Han et al. [6] introduce a MIMIC-random forest (RF) model incorporating psychological latent variables to explore commuters' travel mode shift from passenger cars to public transit. Shu et al. [7] combine the MIMIC model with the multinomial logit model to elucidate the phased transition process from passenger cars to bicycles. Some scholars utilize the technology acceptance model (TAM) or construct impedance functions to investigate the behavior of travel mode shift. For instance, Ji et al. [8] establish an enhanced TAM to examine the travel mode shift mechanism of passenger cars influenced by bike-sharing services. Zuo et al. [9] develop speed curves for public buses and private vehicles under varying proportions of public buses on a specific road segment based on impedance functions, thereby constructing a model for the shift from passenger cars to public buses.

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Furthermore, some scholars have delved into the study of travel chain transfers. Yang [10] and Lv [11] formulate commuting travel chains and utilize structural equation modeling to elucidate the relationships between different factors and travel mode shift behavior.

Existing studies on travel mode shift mostly focus on the impact of individual socio-economic attributes, travel characteristics, and other factors on travel mode shift. However, there is a lack of empirical analysis on the characteristics of travel mode shift under the combined controllable variables scenarios of planning and policy. This study conducts a SP survey on travel mode shift among residents of various administrative districts of Beijing to determine whether residents are willing to switch to public transit and the intensity of this willingness. It specifically examines the public transit-to-car travel time ratio (hereinafter referred to as travel time ratio), which serves as an indicator of public transit efficiency, and parking costs, the primary policy variable used to guide and control car travel demand. It investigates the willingness of different groups to travel shift modes under the combined scenarios of these two major variables, thereby providing decision-making support for further promoting the shift from passenger cars to public transit.

1 SP survey on travel mode shift

1.1 Questionnaire design

To quantify residents' willingness to travel mode shift under combined scenarios, the SP survey is conducted with different scenarios. The survey aimed to analyze the behavior characteristics of residents' travel mode shift by considering two major variables: travel time ratio and parking costs. The travel time ratio represents the ratio of travel time between public transit and passenger cars under the same origin and destination conditions, serving as an indicator of the competitiveness of public transit relative to cars in terms of travel efficiency. Generally, a reduction in the travel time ratio enhances the attractiveness of public transit. Parking costs mainly refer to fees at employment and shopping/leisure locations. Increasing parking costs generally serves to deter car usage. The combination of these two variables influences the mode shift from passenger cars to public transit by exerting a pulling effect through reducing the travel time ratio and a pushing effect through increasing parking costs. The survey sets various levels of travel time ratios and parking costs to ascertain respondents' intentions regarding travel mode shift (as seen in Tab. 1).

1.2 Data description

The SP survey is carried out targeting travelers around residential, employment, and commercial zones in different areas of Beijing, including the core functional area of the capital, the urban sub-center, the central urban area (excluding the core functional area of the capital), Pingyuan New City, and the ecological conservation area. The survey encompasses travelers from diverse industries, age groups, and income levels. It was conducted from September to October 2022, with a total of 3 351 valid questionnaires collected.

1) Socioeconomic characteristics

In the valid sample, the proportion of males slightly exceeds that of females, with males accounting for approximately 57% and females 43%, aligning closely with the gender distribution in Beijing's population in 2020. Respondents are predominantly within the age range of 18–40, with each age group of 18–25, 26–30, and 31–40 constituting around 25% of the sample (as seen in Fig. 1a).

The ownership of cars within households and individual income are important factors influencing the choice of travel modes. Approximately 55% of respondents belong to the group without cars, slightly higher than the group with cars (approximately 45%). The distribution of respondents' monthly income across different levels is relatively balanced, with around 66% of respondents having a monthly income of 6 000 yuan or more (as seen in Fig. 1b). About 13% of respondents have young children in their families, while approximately 38% have elderly family members with mobility limitations.

Tab. 1 Scenario design with combined travel time ratio and parking costs

Travel time ratio	Insistence on public transit	Parking costs/(RMB·h^{-1})					Insistence on passenger cars
		10	12	14	16	18	
1.0 times	○	○	○	○	○	○	○
1.2 times	○	○	○	○	○	○	○
1.5 times	○	○	○	○	○	○	○
1.8 times	○	○	○	○	○	○	○
2.0 times	○	○	○	○	○	○	○

Note: Respondents need to select the scenarios under which they will abandon passenger car travel (single choice).

2) Basic travel characteristics

A majority of over 76% of respondents travel within a distance of 10 km for commuting/school travel. The distribution of distances for shopping/leisure travel exhibits two peaks at 2~ < 5 km and 5~ < 10 km, constituting approximately 33% and 31% respectively. The top three travel modes for commuting/school travel and shopping/leisure travel are subway, passenger car, and bicycle, with proportions of 30.81%, 20.36%, 16.60% and 26.33%, 23.85%, 16.96% respectively. In terms of transportation structure, there is little difference between the two types of trips. The usage of public buses/trams for commuting/school travel surpasses that of walking, whereas the reverse is observed for shopping/leisure travel.

2 The impact of variables on groups with shift intentions

2.1 Four groups with shift intentions

Under different combinations of travel time ratios and parking costs, the study analyzes the changes in the proportions of four groups with shift intentions among commuters/students and shoppers/leisure travelers who insist on using public transit, lean towards public transit, lean towards passenger cars, and insist on passenger cars. The four groups are defined as follows.

1) The group that insists on using public transit: It refers to the group that insists on using public transit under the given parking cost of X RMB h^{-1} and travel time ratio of Y. Theoretically, the proportion of individuals within this group should decrease with the increased travel time ratio Y.

2) The group inclined to use public transit: It refers to the group that chooses to abandon the use of passenger cars when the given parking cost is below X RMB h^{-1}. Theoretically, the proportion of individuals within this group should decrease with the increased travel time ratio.

3) The group inclined to use passenger cars: It refers to the group that chooses to abandon the use of passenger cars when the given parking cost is above X RMB h^{-1}. Theoretically, the proportion of individuals within this group should increase with the increased travel time ratio.

4) The group that insists on using passenger cars: It refers to the group that insists on using passenger cars under the given parking cost of X RMB h^{-1} and travel time ratio of Y. Theoretically, the proportion of individuals within this group should increase with the increased travel time ratio.

2.2 The impact of travel time ratio on groups with shift intentions

Taking commuting/school travel with the parking cost of 10 RMB h^{-1} as an example (as seen in Fig. 2), when the travel time ratio is 1.0 times, the group with the intention to use public transit accounts for 66.04%. When the travel time ratio increases to 2.0 times, the group with the intention to use public transit accounts for 50.34%, showing a decrease of 15.7 percentage points compared to the scenario where the travel time ratio is 1.0 times. This indicates that for public transit users, travel efficiency is an important factor influencing travel mode choices.

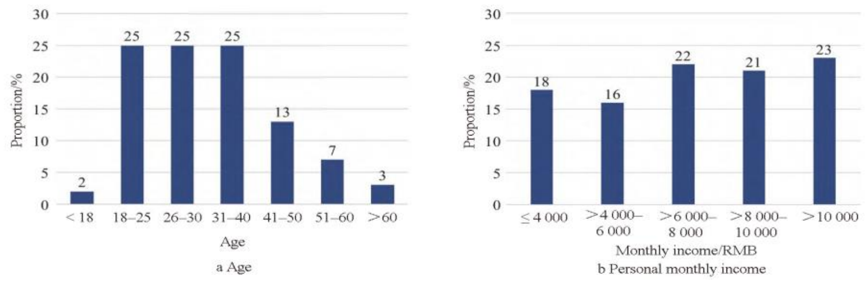

Fig. 1 Analysis of respondents' socioeconomic characteristics

Tab. 2 Distribution of travel modes for two different travel purposes/%

Travel mode	Travel purpose	
	Commuting/school travel	Shopping/leisure
Subway	30.81	26.33
Passenger car	20.36	23.85
Bicycle	16.60	16.96
Public bus/tram	13.34	9.76
Walking	11.88	15.52
Taxi (including online car-hailing service)	3.04	6.09
Shuttle bus	0.93	
Others	3.04	1.49

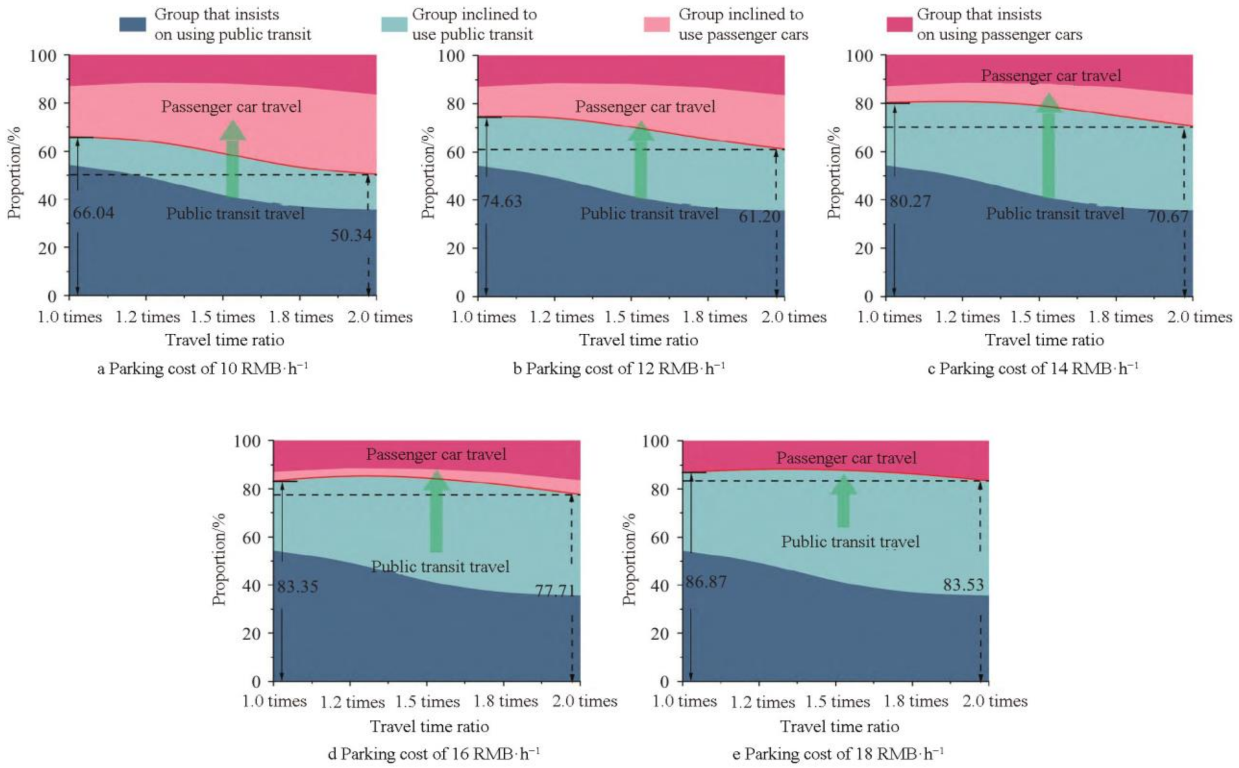

Fig. 2 The proportion of different groups with shift intentions in commuting/school travel with changes in parking costs and travel time ratio

The proportion of different groups with shift intentions in shopping/leisure travel with changes in parking costs and travel time ratios is similar to those in commuting/school travel. Under the parking cost of 10 RMB·h^{-1}, when the travel time ratio is 1.0 times, the group with the intention to use public transit accounts for 62.19%. When the travel time ratio increases to 2.0 times, the group with the intention to use public transit accounts for 48.02%, showing a decline of 14.17 percentage points compared to the scenario where the travel time ratio is 1.0. Compared to shoppers/leisure travelers, commuters/school travelers who insist on using public transit and are inclined to use public transit occupy a relatively higher proportion.

Through an analysis of the proportion characteristics of four different groups with shift intentions, it can be observed that when the travel time ratio remains at 1.5 times or below and the parking cost is set at 18 RMB·h^{-1}, the group that insists on using passenger cars shows relatively low sensitivity to changes in the travel time ratio. In commuting/school travel, this group accounts for approximately 11.67%–13.13%, while in shopping/leisure travel, the group accounts for 15.19%–17.13%. This represents roughly one-third of the respondents who own cars, and the proportion remains relatively stable. However, when the travel time ratio increases to 2.0 times and the parking cost remains at 18 RMB·h^{-1}, the proportion of the group who insist on using passenger cars for commuting/school travel rapidly rises to 16.47%. Similarly, the proportion increases significantly to 19.34% for shopping/leisure travel. This indicates that for individuals heavily reliant on passenger car travel, simply improving the efficiency of public transit may not effectively facilitate the travel mode shift. In situations where there is a significant disparity between the travel efficiency of public transit and passenger cars (with a travel time ratio exceeding 1.5 times), there is an increase in the number of individuals highly dependent on passenger car travel, resulting in the loss of the swing group of public transit. Although these passengers own cars, they sometimes choose to use public transit. However, when the efficiency of public transit becomes excessively low, they completely switch to passenger car travel. Under the same conditions of travel time ratio and parking costs, the proportion of individuals who insist on using passenger cars for shopping/leisure travel is higher than that for commuting/school travel.

When the travel time ratio is less than 1.8 times, the decreased travel time ratio indicates the reduced gap in travel efficiency between public transit and passenger cars, leading to a nearly linear growth trend in the proportion of individuals who insist on using public transit. When the travel time ratio exceeds 1.8 times, the proportion of individuals who insist on using public transit tends to stabilize. This is primarily because these respondents do not own passenger cars, limiting their choices for travel modes. Therefore, improving the travel efficiency of public transit plays a significant role in enhancing passenger dependence and contributes to increasing the proportion of regular public transit users (those who use public transit at least five times a week).

2.3 The impact of parking costs on groups with shift intentions

Taking commuting/school travel with a travel time ratio of 1.0 times as an example (as seen in Fig. 2), when the parking cost is 10 RMB h^{-1}, the group with the intention to use public transit accounts for 66.04%. When the parking cost increases to 18 RMB h^{-1}, the group with the intention to use public transit accounts for 86.87%, an increase of 20.83 percentage points compared to the scenario where the parking cost is 10 RMB h^{-1}. This indicates that the swing group of public transit may switch to using public transit due to the increase in car costs, and some of these travelers will significantly increase their dependence on public transit.

For shopping/leisure travel, under the travel time ratio of 1.0 times, when the parking cost is 10 RMB h^{-1}, the group with the intention to use public transit accounts for 62.19%. When the parking cost increases to 18 RMB h^{-1}, the group with the intention to use public transit accounts for 83.62%, an increase of 21.43 percentage points compared to the scenario where the parking cost is 10 RMB h^{-1}.

The increase in parking costs exerts a substantial influence on the intention to shift travel mode for the swing group of public transit. The upper limit of the parking cost scenario set in the SP survey is 18 RMB h^{-1}, surpassing the prevailing parking cost standards in most areas of Beijing. Nonetheless, there remains a significant gap compared to cities with high parking costs like Tokyo, Japan and Hong Kong, China. Consequently, there is great potential for using parking costs as an economic lever to regulate travel demand in the future.

3 Change characteristics of travel mode shift rates under combined scenarios

The travel mode shift rates under different combined scenarios are examined to analyze the scenario under which reducing the unit travel time ratio or increasing the unit parking cost can lead to the highest travel mode shift rate, thus offering more effective support for the development of pertinent plans and policies.

3.1 Travel mode shift rates with increased unit parking costs

With the increase in travel time ratio, the travel mode shift rates in response to an increment in unit parking costs exhibit an initial upward trend followed by a subsequent decline (as seen in Fig. 3). When the travel time ratio reaches 1.5 times, the travel mode shift rates for both commuting/school travel and shopping/leisure travel reach their peak values. Moreover, at the travel time ratio of 1.5 times, the highest travel mode shift rate for commuting/school travel is observed when the parking cost is raised from 10 RMB h^{-1} to 12 RMB h^{-1}, amounting to approximately 3.5%. Similarly, for shopping/leisure travel, the highest travel mode shift rate is attained when the parking cost is increased from 14 RMB h^{-1} to 16 RMB h^{-1}, reaching approximately 2.5%.

The reason for an initial upward trend followed by a subsequent decline in the travel mode shift rate with the change in travel time ratio can be explained as follows. When the travel time ratio is relatively small (clearly less than 1.5 times), the current public transit demonstrates high efficiency, with the majority of potential users of public transit already utilizing it. Those who have not yet adopted public transit place greater value on the service advantages of car travel in terms of comfort, flexibility, and other aspects, and exhibit lower sensitivity to economic factors. In the scenario set in this study, an increment in parking costs is insufficient to prompt their travel mode shift, necessitating a more substantial increase in parking cost levels (exceeding 18 RMB h^{-1}). When the travel time ratio exceeds a significant threshold (clearly more than 1.5 times), the current efficiency of public transit is exceedingly low, with time cost emerging as a critical factor influencing the choice of travel mode. Even with a moderate increase in parking costs, it proves challenging to facilitate a shift from car travel to public transit. When the travel time ratio is approximately 1.5 times, the current efficiency of public transit falls within an acceptable range, characterized by a higher volume of the swing group of public transit, making it easier for them to shift from car travel to public transit in response to a rise in parking costs. The aforementioned analysis indicates that the travel mode shift rates in response to an increment in unit parking costs are related to the current benchmark value of the travel time ratio. The current travel time ratio has an impact on the proportion and quantity of the swing group of

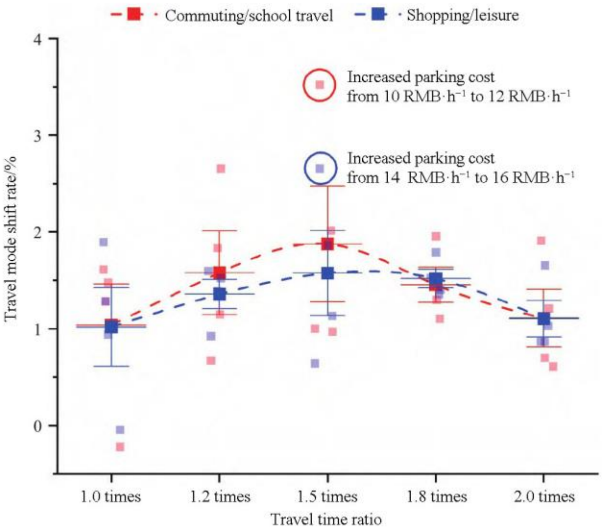

Fig. 3 Travel mode shift rate curve with increased unit parking costs under different travel time ratio conditions

public transit among travelers, thereby influencing the efficacy of employing elevated parking costs to guide travel mode shift.

3.2 Travel mode shift rates with decreased unit travel time ratio

With the increase in parking costs (not exceeding 18 RMB h^{-1}), the travel mode shift rate in response to the reduction in the unit travel time ratio shows a unilateral downward trend, as illustrated in Fig. 4. The travel mode shift rate for both types of travel reaches its peak at a parking cost of 10 RMB h^{-1}, which already surpasses the current parking cost levels in most scenarios in Beijing. With a limited further increase in parking costs on this basis, travelers still demonstrate a high dependence on passenger cars. Even when facing a higher level of parking costs, these individuals continue to use passenger cars for travel. Moreover, given the relatively higher income levels of these travelers, they are not sensitive to the increase in parking costs within a certain degree.

The above analysis demonstrates that the travel mode shift rate resulting from the reduction in the unit travel time ratio is associated with the current benchmark value of parking costs. The current parking costs have an impact on travelers' dependence on passenger cars and their economic sensitivity, thereby influencing the shift effects after the improvement of public transit efficiency. At a parking cost of 10 RMB h^{-1}, the highest travel mode shift rate for commuting/school travel is observed when the travel time ratio decreases from 1.2 times to 1.0 times, reaching approximately 22%. At a parking cost of 16 RMB h^{-1}, the highest travel mode shift rate for shopping/leisure travel is observed when the travel time ratio decreases from 2.0 times to 1.8 times, reaching approximately 20%. This indicates that travel efficiency plays a crucial role in the selection of commuting/school travel modes, whereas shopping/leisure travel allows more flexible time and involves relatively shorter travel distances. Consequently, the improved public transit efficiency has a relatively limited impact on the selection of shopping/leisure travel.

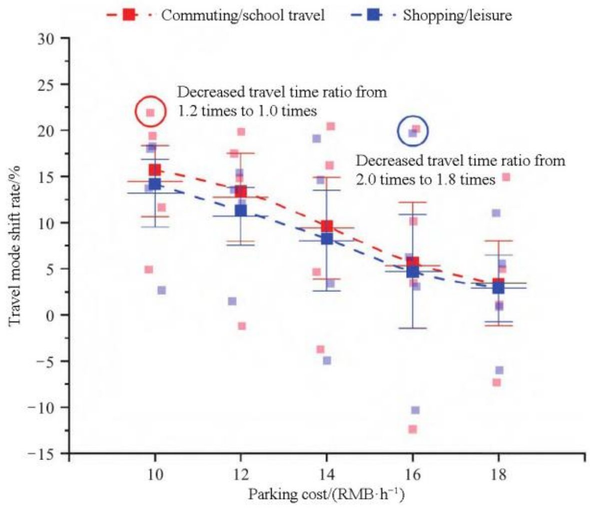

Fig. 4 Travel mode shift rate curve with decreased unit travel time ratio under different parking cost conditions

4 Conclusions and recommendations

By conducting an SP survey on travel mode shift, this study identifies four groups with shift intentions, investigates the effect of travel time ratio and parking cost on different groups, and further analyzes the travel mode shift rate with changes in the unit travel time ratio or parking cost, thus exploring effective strategies for promoting the travel mode shift from passenger cars to public transit. The major conclusions of the analysis are as follows.

1) Regarding shift intentions, when the travel time ratio is less than 1.8 times, reducing the travel time ratio contributes to an increase in the proportion of individuals who insist on using public transit. When the travel time ratio is below 1.5 times, the proportion of individuals who insist on using passenger cars remains relatively stable. However, when the travel time ratio exceeds 1.5 times, there is a significant upward trend in the proportion of individuals who insist on using passenger cars. The swing group of public transit exhibits a greater sensitivity to changes in parking costs. Additionally, under the same conditions of travel time ratio and parking costs, the proportion of individuals who insist on using passenger cars for shopping/leisure travel exceeds that for commuting/school travel.

2) Regarding the travel mode shift rates, the current benchmark values of the travel time ratio or parking costs have a significant impact on the travel mode shift rates resulting from the other variable in the combined scenarios. The current benchmark value of the travel time ratio influences both the proportion and quantity of the swinging group of public transit, while the current benchmark value of parking costs affects travelers' reliance on passenger cars and their economic sensitivity. With an increase in the travel time ratio (ranging from 1.0 times to 2.0 times), the travel mode shift rate in response to an increment in unit parking costs exhibits an initial upward trend followed by a subsequent decline, reaching its peak at a travel time ratio of 1.5 times. With an increase in parking costs (not exceeding 18 RMB h^{-1}), the travel mode shift rate resulting from a reduction in the unit travel time ratio demonstrates a unilateral downward trend.

In light of the aforementioned analysis and conclusions, the following transportation planning, governance, and policy recommendations are proposed.

1) It is imperative to holistically consider the socio-economic costs associated with reducing the travel time ratio and increasing parking costs. According to the current benchmark conditions of travel time ratio and parking costs in different regions, a strategic approach should be

devised to plan feasible pathways for the travel mode shift from passenger cars to public transit. Given the prevailing fiscal austerity, it is essential to meticulously formulate strategies according to the travel survey data, thus achieving the most favorable travel mode shift towards green transportation at minimal cost. Taking Beijing as an example, customized strategies and implementation pathways should be designed to enhance the appeal of public transit across major planning units. Reasonable goals for improving the level of public transit services in different regions should be set, and a progressive approach should be adopted to implement traffic demand management strategies focusing primarily on increasing parking costs and optimizing parking supply.

2) By taking into full consideration the differences in travel mode shift intentions among different groups, it is imperative to devise tailored strategies to guide the travel mode shift. In regions where residents exhibit a significant reliance on public transit or where the level of public transit services is subpar, the objective should be to maintain the travel time ratio within 1.5 times. In addition to ensuring the retention of existing public transit passengers, a networked system of exclusive bus lanes and signal priority systems can be established, and the public bus and tram networks can be optimized, thus gradually enhancing the level of public transit services, bolstering the dependence of local residents on public transport, and attracting the swing group to shift from passenger cars to public transit. In areas where residents exhibit a significant reliance on passenger cars, the haphazard development of urban rail systems and rapid bus transit infrastructure should be avoided. Instead, guided by meticulous travel demand surveys, deliberate efforts should be made to provide customized buses, shuttle buses for business purposes, responsive public transit, and other comfortable and flexible public transit methods. It may be appropriate to increase the fare levels of these public transit modes with higher service quality to achieve complementary services that are distinct from conventional public transit facilities. Besides, the cost of using passenger cars can be increased appropriately, thereby guiding the shift from passenger cars to green transit methods by exerting a pulling and pushing effect and exploring a more precise path for urban traffic management.

3) Precise guidance strategies tailored to different travel purposes and time periods should be developed. For commuting travel, the emphasis should be on ensuring and enhancing the time reliability of public transit. For non-commuting travel, the focus should be on elevating the service standards of public transit in terms of comfort, convenience, and flexibility. Additionally, it is possible to reduce the use of passenger cars by implementing time-specific and differentiated parking cost standards. For instance, the parking costs during non-working days and off-peak hours can be further increased while ensuring that public transit services have been elevated to the anticipated level. Public participation and educational campaigns should be effectively carried out in the adjustment of parking cost standards.

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