

## Article

# Research of Park and Ride Parking Spaces Tiered Pricing Methodology Based on Subway Ride Distance

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**Abstract:** Park and Ride (P&R) as a demand management tool has the effect of reducing traffic congestion in urban centers, saving energy and reducing pollutant emissions. Since 2000, many cities in China have been constructing P&R facilities, which have partially alleviated urban traffic congestion and provided a time-reliable mode of travel for commuters heading to urban centers. However, in recent years, due to the pricing policy of the P&R facility, there has been an insufficient supply of P&R facilities in many places. In fact, the P&R system prefers to welcome travelers who make long-distance subway rides and does not want those who make short-distance subway rides to occupy more parking spaces. To address this, this paper proposes a tiered pricing strategy that considers charging parking fees based on the distance traveled by commuters after switching to public transportation, to improve the utilization of P&R. That is, charge less for parking for long-distance subway riders and more for short-distance subway riders. Firstly, based on questionnaire data from SP surveys, a fixed pricing mixed logit model (FP model) and a tiered pricing mixed logit model (TP model) for P&R facilities are constructed. Utilizing two models, we explored the mechanisms underpinning traveler's mode choice influenced by daily habits and travel considerations through the comparison of the two models to validate the effectiveness of the tiered pricing for P&R facilities. The study found that the implementation of a tiered pricing method for P&R facilities increases its attractiveness to long-distance subway ride travelers, resulting in a higher proportion of long-distance subway riders among P&R commuters. In the study's last section, a marginal effect analysis was conducted on the per-kilometer cost (Pkm) within the P&R model. This analysis determined the optimal Pkm for three subway travel distances within the P&R model. Consequently, it calculated the corresponding P&R parking fees for these three subway travel distances. Additionally, we have predicted the implementation effects of the tiered pricing scheme.

**Keywords:** park and ride; tiered pricing strategy; insufficient parking spaces; mixed logit; marginal effects



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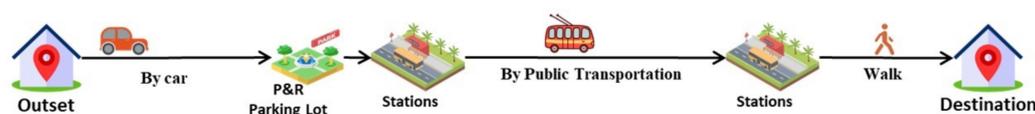


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## 1. Introduction

The expansion of urbanization and economic growth has given rise to an escalating need for travel, thereby magnifying the urgency of resolving transportation challenges in many cities. This predicament is particularly pronounced within urban core zones, where severe road congestion and a dearth of parking spaces significantly impede daily routines. The P&R travel paradigm, initially introduced by American scholar Austin MacDonald as a strategic demand management tool, encourages commuters to initially drive to city peripheral transfer parking facilities before seamlessly transitioning to subway or bus services for the following journey. This approach aims to curtail the volume of inner-city car trips, thereby alleviating traffic congestion and ameliorating the strain on parking resources. The travel illustration is shown in Figure 1. Conclusive findings from academic investigations conducted in the United Kingdom and Hong Kong underscore the practical

efficacy of the P&R model in ameliorating traffic congestion [1–3]. A striking illustration can be observed in Oxford, where the establishment of a P&R system has elicited a notable 20% reduction in vehicular journeys originating from the circumferential ring road and destined for the city center [4]. Since the 1960s, the P&R model has gained widespread traction in cities across the globe. Scholars from various nations have undertaken comprehensive research to refine the implementation of the P&R model. Some researchers have delved into optimizing the placement of P&R facilities. With the objective of covering as much potential demand as possible with P&R facilities, as close as possible to major roads, a multi-objective spatial optimization model was developed, taking into account the existing transport system [5]. Felipe Aros-Vera built a hybrid linear program to maximize the utility of fixed quantity facilities [6]. Joana Cavadas has established a P&R facility site selection model with the objective of minimizing car use in urban areas [7]. Furthermore, an array of studies has proactively prognosticated the post-construction demand for P&R facilities, to better scale P&R facilities [5,8–11].



**Figure 1.** Schematic diagram of P&R travel process.

With the global proliferation of P&R facilities, scholars have begun to look at the selection behavior of P&R facilities and the current status of facility usage as an entry point for exploring ways to maximize the use of existing P&R facilities [12]. Through a comparative analysis of the two main P&R facility sites in Kuala Lumpur, Norlida Abdul Hamid revealed that travelers using P&R facilities are predominantly long-term users [13]. Through interviews, Arne Risa Hole perceived that parking restrictions downtown would increase P&R usage [14]. Ibrahim A.N.H found that trust positively affects attitudes toward using P&R facilities and perceived behavioral control, while perceived behavioral control positively affects intent to use P&R facilities, thus advocating increased reliability of P&R facilities [15]. By analyzing travelers' personal characteristics and driving travel barriers on the choice of P&R modality, Baohong He considers that an increase in age and driving experience negatively affects travelers' choice of P&R mode, while traffic congestion and a lack of parking in downtown areas boosts people's P&R use [16]. In Poland, scholars have meticulously probed the existing usage of P&R parking, extending prior research through the application of multinomial logit models to unravel the drivers underpinning the park-and-ride selection process [17], and found that most users of P&R facilities are commuters with relatively low holiday usage, while travel time is the most important factor for users of P&R facilities [18]. Shahi Taphsir Islam studied the effects of travel costs and travel time on P&R choices and found that transfer times and parking prices significantly affect people's choices [19]; Xiaopeng Shen reached similar conclusions after a model study of a Beijing subway station [20]. In summary, factors affecting travelers' mode choice include individual-related variables such as age, gender, and underlying psychological factors and travel mode-related variables such as time, price, and road traffic conditions. Among these, parking prices is a key factor in regulating the effectiveness of P&R facilities [21]. Therefore, it is important to understand the role of parking prices in regulating P&R use.

Some scholars have studied P&R site selection and parking fee strategies with the goals of maximizing profits and minimizing costs [22,23]. In Vancouver, Habib K.N. conducted an SP survey among users of P&R facilities, through an analysis of parking cost elasticity, it was discerned that an escalation in parking fees at transfer stations would likely lead current P&R users to shift their preference towards utilizing public transportation [24]. Hua Wang's research focused on the optimal pricing method for P&R networks with multiple starting points and a single destination under limited parking supply at the destination [25]. In Xiaopeng Shen's research based on factors impacting travelers' mode selection, with

construction costs and reducing pollution emissions as optimization objectives, an optimal P&R parking fee policy and construction location model was established [20]. Jing Wang investigated strategies for combining parking charges and destination parking restrictions in a P&R network, and it was found that parking permits reduced system costs by eliminating competition for insufficient parking spaces, and that a management scheme combining parking permits and parking charges outperformed a management scheme using only parking charges [21]. P&R facilities face supply shortages in San Francisco. Sarah Syed examined how travelers react to the introduction of parking fee policies in P&R services, and found that the implementation of fees increases the availability of parking spaces without causing significant shifts in travel mode preferences. Moreover, as P&R facilities' service quality was enhanced, the majority of travelers seemed more inclined to accept the introduction of new fees [26].

However, most of the previous studies on P&R are based on the local transportation status quo, and the research optimization methods are not sufficient to solve the problems faced by P&R facilities in China. As the world's most populous country, China's residents have an even greater need to travel, and the problem of insufficient parking is even more pronounced. Chinese scholars have studied P&R in China and found that the inadequate supply of P&R parking facilities has resulted in a large amount of unmet demand for interchange parking [27–30]. Ange Wang believes that on-street parking for short-term and temporary parking and P&R facilities for longer-term parking is a more scientific way of parking [31]. KeKe Liang analyzes the short supply of P&R facilities, analyzing the daily evolution pattern of P&R facility saturation to guide travelers in making rational travel choices [32]. Furthermore, Hongzhi Guan analyzes the responses of P&R travelers following unsuccessful transfer parking endeavors and proposes a strategy involving secondary transfers to nearby public parking lots to alleviate the oversupply of P&R facilities [33]. Using parking facilities other than P&R to increase the parking supply is not a lasting solution to the problem. The parking pricing policy for P&R facilities has led to excessive demand. This paper considers that the positive impact of P&R facilities on urban transport, whether easing urban traffic congestion, reducing carbon emissions or boosting suburban public transport revenues, is positively correlated with the distance travelled by cars, which is reduced by the P&R travel process. Combined with China's current situation of an oversupply of P&R parking spaces, we believe that when the proportion of long-distance and medium-distance subway ride P&R users among all P&R users increases, the travelling distances of cars will be reduced, which in turn will enhance the role of P&R facilities in relieving traffic congestion. Therefore, we attempt to propose a tiered pricing methodology for P&R facilities based on subway ride distance to enhance the effectiveness of P&R facilities and to alleviate the problem of oversupply of P&R parking spaces from a demand management perspective. Firstly, we designed and distributed a P&R travel SP survey questionnaire, and then based on the questionnaire data, we investigated the travel mode choice behavior of travelers using a four-mode transport network of cars, P&R, public transport and taxis, with different total travel distances. We explored how variables spanning travel attributes, personal characteristics, daily travel habits, and travel considerations impacted mode preferences through a comparative analysis of the two models. Ultimately, the marginal effect of the P&R mode per kilometer cost (Pkm) was calculated, and the optimal Pkm of P&R mode was determined for the three subway ride distances, which was converted to obtain the P&R parking fee for the three subway ride distances.

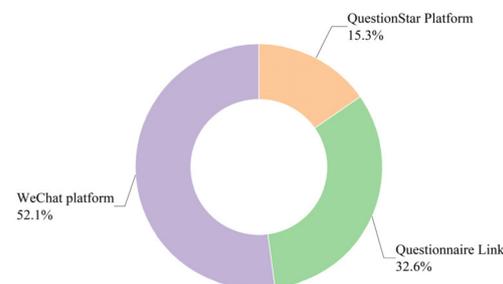
## 2. Materials and Methods

### 2.1. Survey Design

The survey questionnaire employed an SP survey approach, encompassing three primary segments: Current Status of P&R Travel, Mode Choice Preferences, and Personal Characteristics Survey. To enhance the credibility of the data, an illustrative depiction of P&R services was presented before the commencement of formal questioning, ensuring

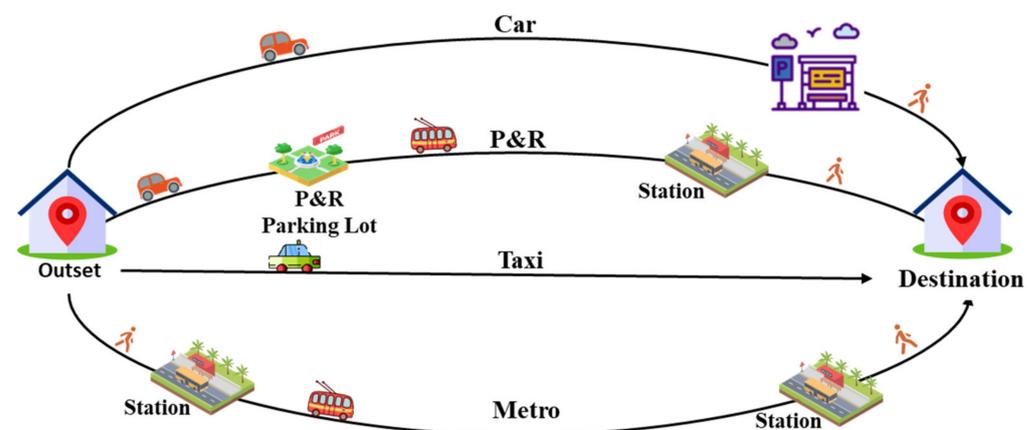
that respondents without prior P&R travel exposure could grasp a lucid understanding of P&R services.

The questionnaire was made public on platforms such as WeChat and Questionnaire Star and was used to collect data. Interested viewers could click on the link to fill out the questionnaire, and in order to be able to collect enough data, after verifying the validity of the questionnaire, we offered a cash incentive to the respondents who completed the questionnaire. The questionnaire survey lasted for two weeks, from 16 March to 30 March 2023. A total of 711 questionnaires were collected, with 592 valid responses, resulting in an effective response rate of 83.3%. The sources of questionnaire data are illustrated in Figure 2. Data analysis results indicate that fewer than 42% of the respondents had engaged in P&R travel. The initial section of the questionnaire focused on the current status of P&R travel. It included questioning whether respondents had previous P&R travel experience, the purposes of their trips, and the relative importance of several factors influencing their travel choices. These factors encompassed travel time, P&R parking fees, travel comfort, road traffic conditions, and more. Furthermore, respondents with prior P&R travel experiences were specifically queried about their most recent P&R travel encounter.



**Figure 2.** Statistics on the sources of questionnaires.

The questionnaire's section Mode Choice Preferences is a central focus of this study. We designed this part with an orthogonal arrangement involving two parking pricing options for P&R facilities (fixed and tiered) and three total travel distances: short (4 km), medium (10 km), and long (20 km). Within these settings, we presented respondents with ten scenario-based questions [34]. Each scenario offered four travel choices: private car, metro, taxi, and P&R services. To simplify the scenario, we assumed that all car trips headed to a public parking lot near their destination for parking. A schematic diagram of the scenario is depicted in Figure 3.



**Figure 3.** Schematic diagram of P&R travel process traveling scenario.

Participants were informed about the travel attributes associated with each mode, including travel time, costs, walking/cycling distance, and the likelihood of available

parking spaces at the P&R facility. In order to align the attributes as closely as possible with real-world scenarios, we determined the settings of some of the attributes that could be observed such as parking cost and walking distance by means of a field survey. The rest of the attributes such as fuel cost and travelling speed were determined by reviewing the relevant information and literature. The set rules are outlined in Table 1. It should be noted that under the tiered pricing strategy, a significant increase in parking prices caused some travelers to stop travelling by P&R [24], which in turn caused the probability of there being an available parking space in P&R to rise. However, the interviewees in this study have not experienced P&R trips under the tiered pricing strategy. To help them make a more accurate judgement, we drew on P&R parking demand survey data and the price elasticity of P&R parking demand from previous studies [33,35]. Using the formula (probability of having an available parking space in P&R = P&R parking demand/number of P&R parking spaces) we set the probability of there being an available parking space in P&R in our scenarios to be 50% under the fixed pricing strategy and 90% under the tiered pricing strategy.

**Table 1.** Scenario attributes set rules.

Count parameters	Fuel cost	RMB 0.64/km
	Parking fees for public parking lots	First hour RMB 6, RMB 10 per hour after the first hour Fixed pricing standard: RMB 2 per time; Tiered pricing standard: subway ride distance lower than 5 km RMB 20 per time; 5–15 km RMB 8 per time; more than 15 km RMB 4 per time;
Count parameters	Parking price for P&R	Metro: 35 km/h; walk: 4 km/h; ride: 12 km/h Drive: city center area: 20 km/h; suburban area: 40 km/h (within a 10 km radius of the destination is the city center area)
	Speed	
Probability of having an available parking space in P&R		Fixed pricing standard: 50% Tiered pricing standard: 90%
Walking distance	Car	300 m
	Taxi	0 m
	Metro	Walking distance = basic distance + level distance Basic distance: 500 m for short-distance (4 km); 1000 m for medium-distance (4 km); 3000 m for long-distance (4 km); Level distance: 0 m; 300 m; 600 m
	P&R	Walking distance = basic distance + level distance Basic distance: 300 m Level distance: 0 m; 300 m; 600 m
Travel costs	Car	Costs = fuel cost + parking fees for public parking lots (this study considers a parking duration of 4 h). Cost calculated based on the taxi fare standard.
	Taxi	Travel distance lower than 3 km, starting price RMB 10; 3–15 km plus RMB 2 per kilometer beyond; more than 15 km plus RMB 3 per kilometer beyond;
	Metro	RMB 3 for short-distance (4 km); RMB 5 for medium-distance (10 km); RMB 7 for long-distance (20 km);
	P&R	Costs = fuel cost + parking fees for + metro fare Metro fare as above
Travel times	Car	Travel time = driving time + walking time Driving time = distance/speed; walking time = walking distance/speed;
	Taxi	Travel time = waiting time + driving time Waiting time: 5 min; driving time as above
	Metro	Travel time = walking or riding time + metro time Walking or riding time = distance/speed; metro time = metro distance/speed
	P&R	Travel time = driving time + walking time + metro time

The final section of the questionnaire inquired about the respondents’ personal attributes, including their preferred modes of daily travel and socio-economic characteristics such as gender, age, occupation, driving experience, household income, and number of household vehicles.

2.2. Statistical Analysis

The SP questionnaire data provided information related to individual respondents such as daily travel habits, individual characteristics and information related to travel modes such as distance travelled and cost of travel. Based on this information and the factors identified in previous studies as having a serious impact on travel mode choice behavior, the model variables were selected as shown in Table 2.

Table 2. Variables and their codes.

	Variables	Code	Ratios
Mode attributes	Travel cost per kilometer (Pkm)	Scene Setting Values	—
	Walking distance	Scene Setting Values	—
Individual characteristics	Gender	0 = Female	48.0%
		1 = Male	52.0%
	Age	0 = Less than 24	25.8%
		1 = 25~44 years	59.2%
		2 = Older than 45	15.0%
Purpose	0 = Official business and study	53.2%	
1 = Leisure and entertainment	46.8%		
Occupation	0 = Student or no stable job	43.5%	
	1 = Have a stable job	56.5%	
Daily travel habits	Car	0 = not	72.1%
		1 = yes	27.9%
	Public transportation (PT)	0 = not	43.0%
		1 = yes	57.0%
	Taxi	0 = not	91.1%
		1 = yes	8.9%
Cycling or Walking	0 = not	93.8%	
1 = yes	6.2%		
Travel consideration	Prices in public parking lots (PP group)	0 = non-consider	23.6%
		1 = consider	76.3%
	Traveling comfort (CF group)	0 = non-consider	51.5%
		1 = consider	48.5%
	Season and weather (SW group)	0 = non-consider	52.5%
1 = consider		47.5%	
Availability of spaces in the P&R parking lot (PS group)	0 = non-consider	13.1%	
1 = consider	86.9%		

Given that the independent variables encompass two types, the most suitable statistical approach is the mixed logit model. Therefore, both the FP model and the TP model in this paper are modeled using the mixed logit model, and the difference between the two models lies in the different travel attributes in the corresponding scenario of the questionnaire; the setting rules are shown in Table 1.

In different choice scenarios, each respondent  $n$  ( $n = 1, 2, \dots, N$ ) can preferentially choose one out of four modes of travel  $m$  ( $m = 1, 2, \dots, M$ ). These individual preferences culminate in a preferred combination  $C_n = \{m_1, m_2, \dots, m_M\}$ . Each element in combination  $C_n$ , denoted as  $m_M$ , represents a binary choice. If mode  $m$  is selected by traveler  $n$ ,  $m = 1$ ; otherwise,  $m = 0$ .

Hence, this paper establishes two preference models for mode selection based on fixed and tiered pricing methods. These models predict the probabilities of different modes of travel being chosen by travelers across various travel distances.

Defining the utility function  $U_{nm}^{C_n}$ , representing respondent  $n$ 's preference for travel mode  $m$ , can be expressed as follows:

$$U_{nm}^{C_n} = V_{nm}^{C_n}(\beta) + \varepsilon_{nm}^{C_n} = \beta X_{nm} + \gamma Z_{nm} + \varepsilon_{nm} \tag{1}$$

In this equation,  $V_{nm}^{C_n}(\beta)$  represents the deterministic term, which depends on parameters  $\beta$ , and  $\beta$  conforms to a general normal distribution (GND), used to indicate the heterogeneity of each traveler [36], while  $\varepsilon_{nm}^{C_n}$  denotes the stochastic term. The deterministic term's utility function  $V_{nm}^{C_n}(\beta)$  comprises  $\beta X_{nm}$  and  $\gamma Z_{nm}$ , and  $X_{nm}$  are model attribute explanatory variables whose coefficients are the stochastic parameters  $\beta$ .  $Z_{nm}$  are variables other than model attribute explanatory variables in Table 2. For individual characteristics, daily travel habits and travel consideration explanatory variables, their coefficients are unknown parameter  $\gamma$ .

The overall utility function of traveler  $n$ 's travel mode choice preference combination  $C_n$  can be expressed as Equation (2):

$$\mu_{nC_n} = \sum_m U_{nm} = \sum_m (V_{nm}(\beta) + \varepsilon_{nm}) \tag{2}$$

Assuming the error term follows a Gumbel distribution and conditional on  $\beta = \beta_n$ , the probability that individual  $n$  will choose  $C_n$  among all possible preference combinations  $C_n^*$  can be written in the usual multinomial logit form [37]:

$$P(C_n | \beta_n) = \frac{\exp(\sum_m V_{nm}(\beta_n))}{\sum_{C_n^*} \exp(\sum_m V_{nm}(\beta_n))} \tag{3}$$

The unconditional probability can be subsequently obtained as Equation (4):

$$P(C_n) = \int \frac{\exp(\sum_m V_{nm}(\beta))}{\sum_{C_n^*} \exp(\sum_m V_{nm}(\beta))} f(\beta | \varphi) d\beta \tag{4}$$

In this equation,  $f(\beta | \varphi)$  is the density function for the random distribution of  $\beta$ , and  $\varphi$  is the vector of parameters that define the density function.

In the verification phase of the tiered pricing strategy, the effectiveness of the implementation is assessed using two indicators: the proportion of different subway ride distances of P&R users  $\delta$  and the average revenue per parking session  $Wp$  at P&R facilities.  $\delta$  represents the proportion of individuals using P&R facilities for a specific public transportation ride distance relative to the entire population of P&R facility users.  $Wp$  represents the average revenue generated per parking spot at a P&R facility per parking session.

$\theta g_j$  represents the proportion of users for three different subway ride distances under the fixed pricing strategy ( $\theta j_j$  represents the proportions under the tiered pricing strategy).  $Pg_i$  represents the probability of choosing the P&R travel mode under the fixed pricing strategy ( $Pj_j$  represents the probability under the tiered pricing strategy), where  $g$  and  $j$  denote different pricing models, and  $i$  represents various subway ride distances. Then, the ratio  $\delta_i$  of the demand of different subway ride distances to the total demand is calculated as in Equation (5):

$$\delta_i = \frac{\theta g_i / P g_i}{\sum_{j=1}^3 \theta g_j / P g_j} \tag{5}$$

The percentage of users of each subway ride distance  $\theta j_j$  under the stepped fare model is calculated as in Equation (6):

$$\theta j_i = \frac{P j_i \delta_i}{\sum_{j=1}^3 P j_j \delta_j} \tag{6}$$

The formula for obtaining the average revenue  $Wp$  for a single vehicle stop is given in Equation (7);  $p_i$  represents the P&R car parking pricing for each subway ride distance under the tiered pricing strategy.

$$Wp = \sum_{i=1}^3 \theta_j p_i \tag{7}$$

### 3. Results and Discussion

In the process of establishing two mixed logit models, it is essential to account for the pronounced correlation between travel costs and the overall travel distance. To mitigate the distorting effect of travel distance on the cost analysis, the modeling will be based on the concept of the travel per kilometer cost (Pkm). Additionally, the probability of there being an available parking space in a P&R facility solely relates to the parking fee strategy of the P&R facility. As a result, when constructing the FP model and the TP model separately, this variable’s standard deviation will be 0, and, therefore, it has not been integrated as a contributing factor in the model. However, the influence of this factor will be considered during the comparative discussion of the two models. Employing stepwise regression, the mixed logit models underwent a refinement process. Variables lacking statistical significance at the 0.1 threshold were pruned, culminating in the selection of 14 pertinent explanatory variables for fitment within the two mixed logit models. The final segment of the study quantitatively examines the impact of P&R fees on commuters across varying travel distances by calculating the marginal effects of the P&R facility Pkm. Subsequently, based on specific principles, it offers tiered pricing recommendations and predicts their implementation outcomes.

#### 3.1. Factor Analysis

In establishing the mixed logit model, the choice of the P&R mode is used as a reference group to fit the preferences for car, metro, and taxi options. The fitted coefficients indicate the preference for choosing a certain transportation mode relative to the P&R mode under the influence of explanatory variables. The McFadden’s  $R^2$  values for the two models, respectively, stand at 0.247 and 0.201, underscoring the models’ robust goodness of fit. In presenting the results, this paper will showcase the goodness-of-fit tests for the models, along with the modeling outcomes for mode attributes and individual characteristics, daily travel habits, and travel considerations. These findings will be presented in Tables 3–5, respectively. Furthermore, a separate discussion of the results will be provided for each category.

**Table 3.** Results of mode attributes and individual characteristics (values in parentheses indicate the standard error of the random parameters).

Variable	Mode	Fixed Pricing Strategy		Tiered Pricing Strategy		
		Coef. ( $p >  z $ )	Odds Ratio	Coef. ( $p >  z $ )	Odds Ratio	
Mode attributes	Pkm	—	—	−0.148 (0.363) ***	0.863	
	Walking distance	−0.936 (0.951) ***	0.392	−0.292 (0.637) **	0.747	
Gender	PT	−0.568 ***	0.567	−0.458 ***	0.633	
	Car	—	—	—	—	
	Taxi	−0.738 ***	0.478	−0.323 *	0.724	
Individual characteristics	Age	PT	0.220 *	1.246	−0.438 ***	0.645
		Car	—	—	−0.215 *	0.806
		Taxi	—	—	−0.241 *	0.786
Occupation	PT	−0.903 ***	0.405	−0.394 **	0.675	
	Car	—	—	0.240 *	1.271	
	Taxi	—	—	0.269 *	1.308	
Purpose	PT	0.640 ***	1.896	0.278 *	1.321	
	Car	0.426 ***	1.532	0.218 *	1.244	
	Taxi	0.376 **	1.456	0.829 ***	2.290	

Table 3. Cont.

Variable	Mode	Fixed Pricing Strategy		Tiered Pricing Strategy	
		Coef. ( $p >  z $ )	Odds Ratio	Coef. ( $p >  z $ )	Odds Ratio
Travel distance	PT	0.249 ***	1.282	−0.052 #	0.949
	Car	0.075 **	1.078	−0.039 ***	0.962
	Taxi	−0.102 ***	0.903	−0.163 ***	0.849
Constant	PT	−0.230	0.794	1.792 ***	6.003
	Car	−2.244 ***	0.106	1.699 ***	5.467
	Taxi	−0.584	0.558	2.418 ***	11.223
Mode	LL(0)		−4088.653		−4011.655
	LL(Final)		−3080.158		−3204.084
	McFaddens R <sup>2</sup>		0.247		0.201
	BIC		6488.027		6735.880

Note: #:  $p < 0.1$ ; \*:  $p < 0.05$ ; \*\*:  $p < 0.01$ ; \*\*\*:  $p < 0.001$ .

Table 4. Results of daily travel habits.

Variable	Mode	Fixed Pricing Strategy		Tiered Pricing Strategy		
		Coef. ( $p >  z $ )	Odds Ratio	Coef. ( $p >  z $ )	Odds Ratio	
Daily travel habits	Car	Metro	−1.031 **	0.357	−1.028 **	0.358
		Car	1.041 ***	2.832	−0.436 #	0.646
		Taxi	0.908 **	2.479	−0.818 **	0.441
	Taxi	Metro	—	—	—	—
		Car	1.101 **	3.007	—	—
		Taxi	2.819 ***	16.756	1.542 ***	4.675
	PT	Metro	0.736 **	2.088	—	—
		Car	−1.054 ***	0.349	−0.860 ***	0.423
		Taxi	—	—	−1.740 ***	0.176

Note: #:  $p < 0.1$ ; \*\*:  $p < 0.01$ ; \*\*\*:  $p < 0.001$ .

Table 5. Results of travel consideration.

Variable	Mode	Fixed Pricing Strategy		Tiered Pricing Strategy		
		Coef. ( $p >  z $ )	Odds Ratio	Coef. ( $p >  z $ )	Odds Ratio	
Travel consideration	PP group	Metro	−0.667 ***	0.513	—	—
		Car	−1.147 ***	0.318	−0.679 ***	0.507
		Taxi	−0.967 ***	0.380	−0.199	0.820
	SW group	Metro	—	—	—	—
		Car	0.521 ***	1.684	0.710 ***	2.034
		Taxi	0.348 **	1.417	0.210	1.233
	CF group	Metro	—	—	—	—
		Car	0.400 **	1.492	0.726 ***	2.066
		Taxi	0.146	1.157	0.474 ***	1.606
	PS group	Metro	—	—	—	—
		Car	—	—	−1.080 ***	0.339
		Taxi	0.491 *	1.633	−0.662 **	0.516

Note: \*:  $p < 0.05$ ; \*\*:  $p < 0.01$ ; \*\*\*:  $p < 0.001$ .

### 3.1.1. Individual Characteristics

Table 3 presents the goodness-of-fit tests and findings pertaining to mode attributes and individual characteristics. It can be observed that the insignificance of Pkm fitting is apparent in the FP model, while in the TP model, the fitted coefficient for Pkm is negative. This phenomenon might arise from the fact that, under the fixed pricing mode, the P&R travel costs remain largely unchanged, causing respondents to take other factors

into account more in making their travel decisions. In the TP model, travelers' choices are adversely affected by the negative impact of Pkm. Both models consistently feature negative coefficients in relation to the total walking distance variable. This could be because walking represents a slow speed and less serviced mode of travel. As such, it is natural for most travelers to seek to minimize prolonged walking distances in the course of their journeys. The fitting coefficients of gender, occupation, and travel purpose exhibit no significant distinction between the two models. In the context of gender, negative coefficients are associated with metro and taxi choices, while the coefficient corresponding to car usage lacks statistical significance. This indicative pattern suggests a prevailing trend: female travelers exhibit a preference for taxi and metro alternatives over the P&R mode, while their male counterparts are more inclined towards P&R or car travel. This divergence might potentially be attributed to a greater fondness among male travelers for the act of driving itself. The presence of a stable job has a negative impact on the preference for the metro in the FP model. However, in the TP model, a stable job negatively affects the preference for the metro and positively affects the preference for cars and taxis. The fitting coefficients for travel purpose yield positive values across both models, underscoring a clear trend. This reveals that the P&R mode resonates predominantly with travelers embarking on official duties or daily commutes. Conversely, leisure and recreational travelers manifest a proclivity for alternative transportation modes beyond the P&R. This distinction can be attributed to the distinct exigencies of diverse travel intents. Commuters and those engaged in official obligations prioritize efficiency and punctuality, with their paramount concern being reaching their destinations in a timely manner. Driving a car in suburban areas and utilizing P&R for commuting to densely populated urban centers by the subway precisely caters to the requirements of commuters and business travelers. In contrast, travelers seeking leisure and recreational pursuits exhibit a heightened sensitivity to the experiential aspects of their journey. The intermediate mode shift in the P&R approach might potentially disrupt their travel experience. The overall travel distance has a positive impact on travelers' preferences for choosing metro and car travel, while negatively affecting their preference for taxi travel in the FP model. Differently, in the TP model, travelers' preferences for all three modes of travel are negatively impacted. This indicates that within the fixed pricing mode, an increase in travel distance corresponds to a stronger preference among travelers for the metro, followed by car travel, and the weakest preference for taxi travel. However, in the tiered pricing mode, an extended travel distance leads to an intensified preference for the P&R mode, and the weakest preference was still taxi travel. This demonstrates the effectiveness of the tiered pricing mode in regulating the proportion of commuters at varying subway ride distances. It successfully encourages a greater number of long-distance subway ride travelers to opt for P&R facilities, thereby enhancing the overall effectiveness of such facilities.

### 3.1.2. Daily Travel Habits

Table 4 displays the fitted outcomes, illustrating the impact of daily travel habits on preferences for transportation modes. By querying respondents about their customary travel methods, travelers were categorized into four groups based on their habitual choices: the "C" group, consisting of those who primarily engage in driving for their daily commuting; the "T" group, consisting individuals with a habitual preference for taxis; the "P" group, consisting those who mainly utilize public transportation; and the "W" group, consisting of travelers who opt for walking or cycling. This categorization offers insights into the connections between habitual behaviors and mode preferences for travel.

The results revealed that individuals who habitually choose walking or cycling for their daily travel demonstrate a more neutral mode preference in the scenario-based survey section. Hence, we incorporated the W group as a control variable for model fitting. Within the FP model, the preference coefficient for the metro among individuals categorized as the "C" group exhibits a negative value. Conversely, the coefficients for preferences towards car and taxi travel are positive. However, under the TP model, the "C" group display

negative preference coefficients across all three travel modes. This indicates that under a fixed pricing strategy, the “C” group remains inclined towards car or taxi travel, displaying limited motivation to transition to the P&R mode. Nevertheless, with the introduction of a tiered pricing structure, the “C” group demonstrates a pronounced interest in the P&R mode. Their inclination towards the P&R mode outstrips preferences for all other three transportation modes. This phenomenon could be attributed to the prevailing traffic congestion in urban areas of China and the state of P&R parking facilities. The exceptionally high population density and the abundance of motor vehicles have led to profound road congestion issues in Chinese cities. Consequently, driving often consumes a substantial amount of time due to traffic bottlenecks. While the original intent behind establishing P&R facilities was to provide car users with an alternative route to bypass congestion and reach their destinations more expediently, the fixed pricing strategy has led to an overwhelming demand for many P&R parking lots. The limited availability of parking spaces has perpetuated the “C” group’s travelers towards car travel. The tiered pricing strategy regulates prices to decrease the parking demand for travelers with shorter subway ride distances. This reduction in demand enhances the likelihood of available parking spaces at P&R facilities, providing assurance for the “C” group to efficiently and promptly reach their destinations. Consequently, this encourages the “C” group to choose the P&R mode of travel under the tiered pricing scheme. The “T” group strongly favors taxi travel in both pricing models, with fitted coefficients of 2.819 in the FP model and 1.542 in the TP model. This signifies that under the fixed pricing strategy, the likelihood of the “T” group opting for taxi travel is nearly 17 times higher than that of choosing the P&R mode and nearing 5 times under the tiered pricing strategy. This suggests the “T” group is exceptionally persistent, showcasing a resounding choice of their established daily travel routines. Within the fixed pricing strategy, the “P” group demonstrates a favorable inclination towards PT travel. Simultaneously, this group displays a disinclination towards car travel. Transitioning to the tiered pricing strategy, the “P” group reveals a negative preference for both car and taxi travel. This observed pattern aligns seamlessly with the tendency of “P” users to opt for environmentally conscious and budget-friendly public transportation alternatives. Of particular interest, the “P” group’s response in the FP model yields a fitted coefficient of  $-1.054$  for private car travel, a value lower than the  $-0.860$  derived from the TP model. This discrepancy indicates that, under the tiered pricing strategy, the “P” group’s preference for the P&R mode is comparatively weaker than their preference under the fixed model. This nuanced shift might be attributed to the “P” group’s pursuit of economic frugality, as the tiered pricing strategy escalates the cost associated with the P&R mode.

### 3.1.3. Travel Consideration

Table 5 displays the fitted results, showcasing how travel considerations influence mode preference. In this section, travelers can be categorized using four classification methods based on whether they take specific factors into consideration during their journeys. The “PP” group, emphasizing parking costs; the “SW” group, valuing seasonal and weather conditions; the “CF” group, focusing on comfort; and the “PS” group, considering the availability of P&R parking spaces.

The results revealed that the PP group shows a greater inclination towards choosing the P&R mode of travel compared to the other three modes in the fixed pricing scheme. Under the tiered pricing scheme, the PP group leans towards selecting the P&R mode over the private car mode. This group’s heightened focus on parking prices to some extent signifies their inclination towards economically viable travel choices. The consistently low travel cost associated with the P&R mode in both pricing models provides a plausible rationale for the “PP” group’s preference for this mode of travel. Within the TP model, the “SW” group’s fitted preference for taxi travel is not statistically significant; however, these data have been retained for comparative analysis. Notably, under both pricing models, the “SW” group displays a consistently stronger preference for private car and taxi travel

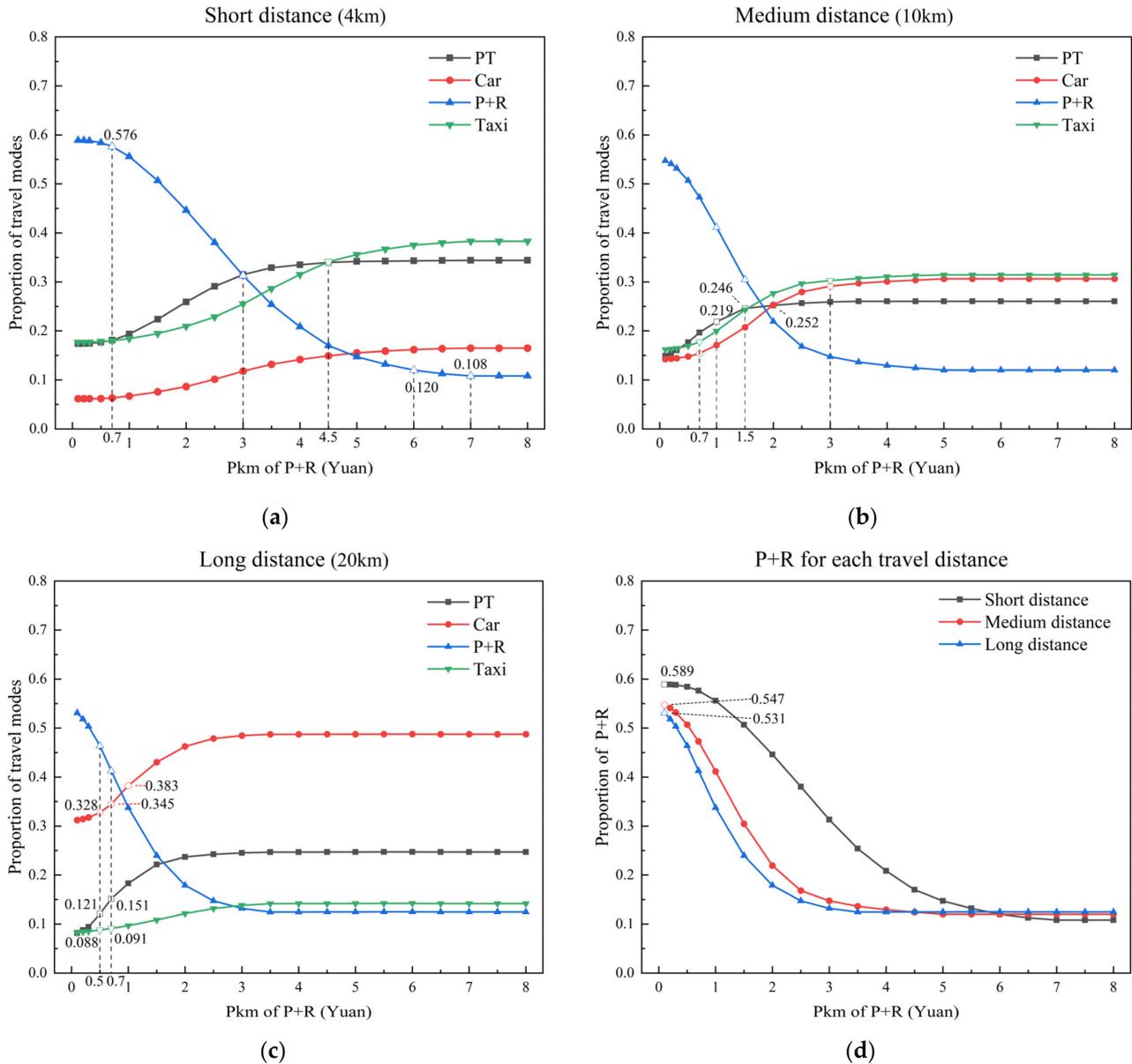
over the P&R mode. Intriguingly, preserving the non-significant fitted outcome of the “CF” group’s preference for taxi travel in the FP model results in a preference pattern strikingly similar to that of the “SW” group. This implies that, within travelers’ perceptions, the comfort and weather resilience of the P&R mode appear relatively inferior when compared to private car and taxi travel. This corresponds to reality, particularly during transfers from P&R parking facilities, and the journey from the subway station to the destination lacks adequate assurance. In the fixed pricing strategy, the “PS” group tends to favor taxi travel over the P&R mode, while conversely, under the tiered pricing strategy, they exhibit a leaning towards the P&R mode over both private car and taxi travel. This marked divergence in preference between the two models emerges as a consequence of disparities in P&R parking space availability. The decision making process of the “PS” group places significant weight on the presence of accessible parking spaces when contemplating the adoption of the P&R mode. The increased availability of P&R parking spaces under the tiered pricing strategy acts as a draw for the “PS” group towards selecting the P&R mode for their travel. In other words, numerous travelers within the PS group are compelled to opt for alternative modes of transportation due to inadequate availability of P&R parking spaces. This observation resonates with the initial conjecture put forth in this study, which posited that the insufficiency of P&R parking spaces might drive numerous travelers to forgo the P&R mode in favor of alternative transportation options.

### 3.2. Marginal Effects Analysis

A crucial consideration when designing P&R parking facilities with tiered pricing based on different subway ride distances is to assess the price elasticity of travelers regarding P&R parking charges. In this study, the cost of adopting the P&R mode encompasses three distinct components: P&R parking fees, expenses for subway tickets, and fuel costs. In constructing the mixed logit model, Pkm has been included as an explanatory variable. The TP model’s fitted outcomes for Pkm demonstrate statistical significance at the 99.9% level, rendering the pursuit of further marginal effect analysis on Pkm a valid endeavor. As a result, this section focuses on marginal effects of Pkm, aiming to derive the P&R parking price through a reverse calculation grounded in Pkm. Furthermore, we hypothesize a positive correlation between subway ride distance and total travel distance; a total travel distance of  $D = 4$  km represents a short-distance subway ride;  $D = 10$  km represents a medium-distance subway ride;  $D = 20$  km represents a long-distance subway ride. Marginal effect computations for Pkm are conducted individually for each of these three total travel distances. Figure 4a–c illustrate the shifting proportions of traveler preferences among P&R, private car, taxi, and PT modes for short-range  $D = 4$  km, medium-range  $D = 10$  km, and long-range  $D = 20$  km trips as Pkm P&R mode varies. For a more visual comparative analysis of the changing proportions of selecting the P&R mode for various travel distances, we have integrated the choice proportion curves for the P&R mode across the three travel distances into a single graph, depicted in Figure 4d.

For short-distance travel, the proportions of PT and taxi mode selections are comparable. When Pkm falls between RMB 1 and 4.5, the proportion of those selecting the PT mode outweighs that of the taxi mode. Yet, as the Pkm surpasses RMB 4.5, more travelers choose the taxi mode, making it the most favored option among the four travel modes. The choice proportion for the car mode remains consistently low and exhibits a low increase. This pattern is primarily attributed to the substantial parking fees charged in public parking facilities, rendering the car mode a considerably less economical choice for short-distance travel. The proportion of P&R mode selection shows a slow shift when the Pkm is below RMB 0.7. At this range, approximately 60% of travelers favor the P&R mode. With the Pkm surpassing RMB 0.7, the rate of decline in P&R mode selection accelerates, reaching its steepest slope at  $Pkm = RMB 3$ . Following this point, as the Pkm continues to increase, the decrease in P&R mode selection becomes more gradual, and beyond a Pkm value of 6, the curve levels off. For short-distance travel, our objective is to minimize P&R mode selections. It is evident that when the Pkm increases by RMB 1 at  $Pkm = RMB 6$ , the

proportion of P&R mode selection decreases by a mere 1.2%. Hence, setting the Pkm for P&R at RMB 6 is deemed suitable. According to the scenario outlined in this study, we can further compute that the optimal P&R mode short-distance subway ride parking fee would be approximately RMB 20.



**Figure 4.** (a) Marginal effect of Pkm for proportion of travel modes under short-distance travel; (b) marginal effect of Pkm for proportion of travel modes under medium-distance travel; (c) marginal effect of Pkm for proportion of travel modes under long-distance travel; (d) marginal effect of Pkm for proportion of P&R modes under each travel distance.

For medium-distance travel, the selection proportion curves for car and taxi demonstrate resemblances. This similarity can be attributed to their similar travel costs and preferences among travelers. Following a Pkm threshold of RMB 0.7, the choice proportions for both modes start increasing, and once the Pkm exceeds RMB 3, the curves plateau. Beyond a Pkm value of RMB 5, there are no further changes in the selection proportions. The proportion of choosing the P&R mode demonstrates a notable declining pattern right from the start, with the sharpest decline occurring at Pkm = RMB 1.5. After exceeding a Pkm value of RMB 5, the P&R mode’s selection proportion levels off and ceases to decrease.

On the other hand, the proportion of those selecting the PT mode experiences a rapid surge before reaching a Pkm threshold of RMB 1. Beyond a Pkm value of RMB 2, incremental increases in the cost of P&R travel have a minimal influence on the PT mode selection proportion. Considering the prevailing challenge of limited availability in P&R parking spaces, we designate a Pkm value of RMB 1.5 as the optimal rate for mid-distance P&R travel, corresponding to an approximate P&R parking fee of RMB 10. At this point, the proportion of those selecting the PT mode reaches its highest, while subsequent increments in the cost of P&R travel predominantly steer P&R commuters towards opting for car and taxi modes.

For long-distance travel, the car mode exhibits a consistently elevated selection proportion in the graph, indicating a prevalent inclination towards using the car mode for such journeys. The taxi mode consistently maintains a lower position in the graph, primarily due to the distance-based fare calculation method, which results in higher charges for longer trips. The proportion of those selecting the P&R mode shows a swift decline with rising Pkm values until they exceed RMB 2, and thereafter, it undergoes minimal fluctuations beyond a Pkm value of RMB 3.5. For long-distance travel, the goal is to establish P&R parking prices that encourage a high proportion of PT mode selection while maintaining relatively lower proportions for car and taxi choices. Notably, there is a significant increase in the proportion of PT mode usage when the Pkm is between 0.5 and 0.7 RMB, while the growth in car and taxi selections is less pronounced. Beyond a Pkm value of RMB 0.7, a further increase in P&R travel costs leads to a noticeable rise in the car mode selection. Hence, setting the Pkm for the P&R mode at RMB 0.7 is appropriate for long-distance travel, resulting in a calculated P&R long-distance subway ride parking fee of RMB 6.

Comparing the proportions of P&R mode choices across the three travel distances in Figure 4d, it is evident that at the initial point where Pkm = RMB 0.2, the preference for the P&R mode is higher for short distances, followed by medium distances, and then long distances. This trend emerges due to the methodology employed in calculating marginal effects, with the Pkm being used as the independent variable. Consequently, when the Pkm assumes the same value, the total travel cost for short distances is significantly lower, and the overall travel cost remains a crucial consideration for travelers when determining their mode of transportation. For the same reason, the same increment change in Pkm results in more pronounced alterations in the overall travel costs for medium- and long-distance trips, thereby resulting in a more conspicuous descending trend in the curves associated with these distances.

### 3.3. Prediction of Effectiveness

Here, we assess the practical impact of implementing a tiered pricing scheme in P&R facilities by predicting two factors: the proportion ( $\delta$ ) of subway commuters based on the distance traveled using P&R facilities and the average revenue ( $Wp$ ) per parking session. This evaluation aims to validate the effectiveness of tiered pricing for P&R facilities. In the survey section, 244 respondents who have utilized P&R facilities were asked about the distance they traveled by subway during their last P&R trip. The distribution of subway travel distances for P&R trips is illustrated in Figure 5.

All travelers are categorized into three groups: short-distance subway ride P&R travelers, medium-distance subway ride P&R travelers, and long-distance subway ride P&R travelers. Figure 5 reveals that short-, medium-, and long-distance subway commutes using P&R facilities constitute 19.7%, 56.5%, and 23.8% of all P&R travel, respectively. These data are utilized as the  $\theta g_j$  value under the fixed pricing strategy. Based on the marginal effect analysis in the previous section, we can ascertain the probabilities of respondents choosing P&R modes with varying parking fees. And from the statistics of the results of the fixed pricing scenario questions in the questionnaire, we can obtain the probability of the P&R trip choice for short-, medium-, and long-distance subway rides under the fixed pricing and tiered pricing modes, as shown in Table 6.

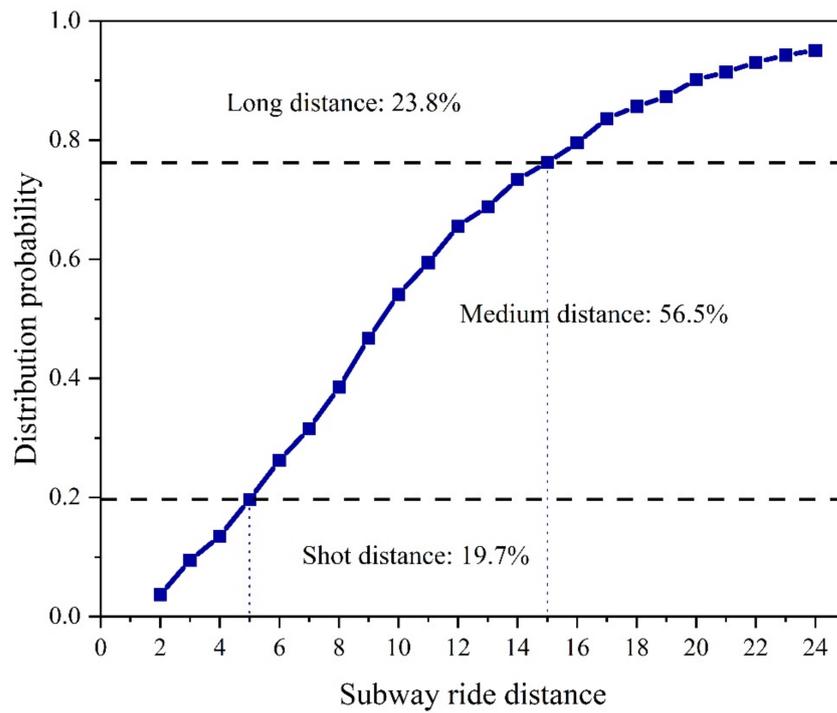


Figure 5. Distribution of P&R travel subway ride distance statistics.

Table 6. Probability of P&R mode choice for travelers according to subway ride distance.

	Near-Distance	Medium-Distance	Long-Distance
Fixed pricing	25.8% ( $P_{g1}$ )	28.0% ( $P_{g2}$ )	33.6% ( $P_{g3}$ )
Tiered pricing	12.0% ( $P_{j1}$ )	30.4% ( $P_{j2}$ )	41.3% ( $P_{j3}$ )

Calculated by Equation (5), the proportions of the potential demand of P&R travelers for each distance of subway ride are depicted in Figure 6. It is evident that the largest potential user group is medium-distances subway ride P&R users, accounting for 57% of the overall total. The long-distance and short-distance subway ride P&R users exhibit a similar proportion, constituting approximately 21% and 22% of the total, respectively.

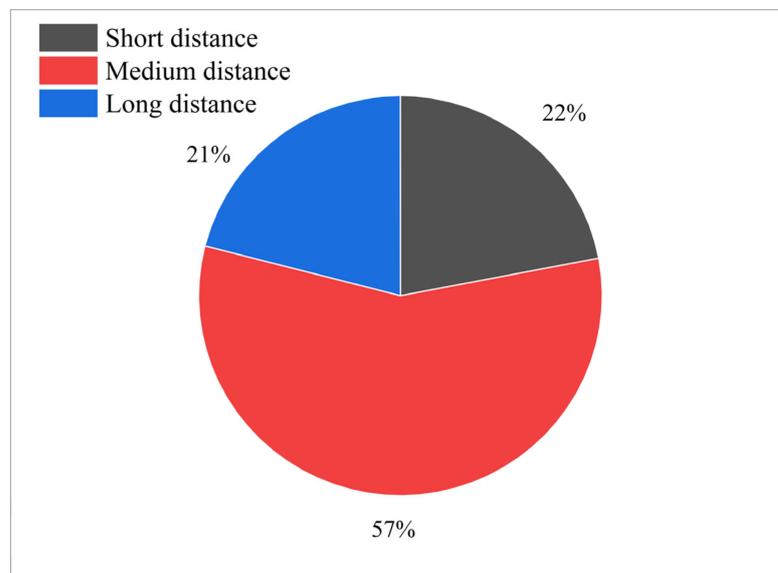


Figure 6. Percentage of potential demand for subway ride distance.

Calculated by Equation (6), the proportions of different distance subway ride P&R users under the tiered pricing strategy are displayed in Figure 7. It is notable that following the implementation of tiered pricing, the proportion of short-distance subway ride P&R users is the lowest, accounting for less than 10% of the total.

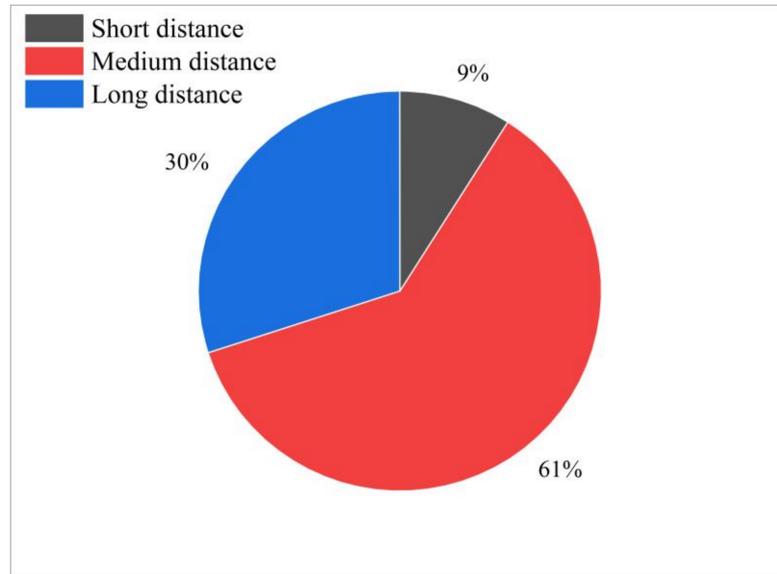


Figure 7. Percentage of subway ride distance users across the tiered pricing strategy.

In Figure 8, a comparison between the proportions of P&R travelers based on the subway ride distance traveled under fixed and tiered pricing strategies is presented. It is evident that following the implementation of tiered pricing, there is a decrease of over 10% in the proportion of short-distance subway ride P&R users. Simultaneously, there is an increase in the proportions of medium- and long-distance subway ride P&R users. This indicates that the implementation of tiered pricing effectively frees up over ten percent of P&R parking spaces for use by medium- and long-distance subway ride P&R users.

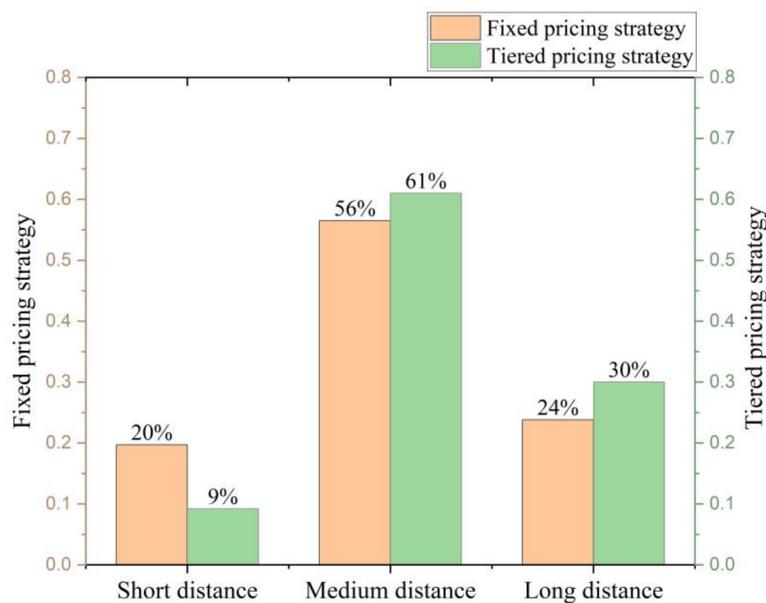


Figure 8. Comparison chart of the percentage of users of fixed pricing and tiered pricing strategies.

In analyzing the composition of P&R facility users on the basis of exploring the P&R facility revenue under the tiered pricing strategy, Equation (7) can be used to predict the

parking revenue. Under the condition of a tiered pricing strategy for P&R facilities, the average revenue  $Wp$  for parking a single car is RMB 9.7, which is an increase of RMB 7.7 in the revenue of the P&R facility operator on average for each car that parks in the facility compared with the fixed charge of RMB 2 per car that is currently in force.

#### 4. Conclusions

In order to more fully utilize the role of P&R facilities in energy conservation, pollutant emission reduction and traffic congestion relief, this study proposes and validates a tiered pricing methodology based on subway ride distance for P&R. The main findings after research and analysis are as follows:

1. The implementation of a tiered pricing strategy increases the attractiveness of P&R facilities to long-distance travelers, increases the proportion of medium- and long-distance travelers among P&R users, and makes the utilization of P&R facilities more effective.
2. The lower comfort of P&R modes, especially the lack of security in parking during both the walk to a public transport station and the walk from a public transport station to the destination, is the reason why travelers choose to travel by car or taxi in bad weather. At the same time, the shortage of parking spaces at P&R facilities is an important reason why many travelers choose to travel by other modes.
3. Based on the research scenarios in this paper, the optimal P&R tiered pricing mode is proposed: RMB 20 for short-distance subway ride P&R parking, RMB 10 for medium-distance subway ride parking, and RMB 6 for long-distance subway ride parking. The effect of implementation is also predicted; a tiered pricing strategy can greatly increase the income of P&R operators and reduce the amount of government subsidies to save social resources.

The limitations of this study include the following two points. First, during scenario setup, an underlying assumption was made, implying that all car travelers, upon reaching their destinations, must seek nearby public parking areas for paid parking. This assumption diverges from actual practice. Future research could encompass a broader range of parking options for car travelers. At the same time, a more detailed design can be carried out in terms of travel mode attributes, such as increasing the consideration of seeking time for car travel and the frequency of metro departures, facilitating a more realistic analysis. Second, assessing the effectiveness of the tiered pricing strategy solely using the percentage of different subway ride distance P&R users may not be clear and accurate enough. Future analytical studies could attempt to assess this through a combination of congestion modeling and behavioral analysis.

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