Tradable Permits versus Congestion Charge on Managing Morning Peak Travel Behavior: A Field Experiment in Beijing

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SHORT SUMMARY

The efficiency of tradable permits on managing morning peak travel and its comparison with congestion charge have been discussed theoretically but not practically. This study contributes to providing the first practical evidence of both tradable permits and congestion charge to manage actual scheduling decisions in the morning peak using real car drivers. By conducting a two-month field experiment among 532 car drivers in Beijing, we investigate the effectiveness and drivers' attitudes of these two policies. We designed a step-size tradable permits scheme and a similar congestion charge scheme based on Beijing real traffic conditions. The OBD box and phone App have been used to record real-time travel information and online trading. Preliminary results show that both treatments reduce the rush-hour departures. Compared to congestion charge, tradable permits scheme is more acceptable for car drivers.

Keywords: Tradable permits, Congestion charge, Field experiment, Departure time choice

1. INTRODUCTION

Traffic congestion is pervasive in most metropolises around the world, causing serious social and environmental costs. Because of limitations on increasing capacity, policymakers have attempted to reduce car usage by managing transportation demand. However, the experiences of many cities show that both management and pricing measures have their own pros and cons. For example, the car restriction policies in Beijing and Mexico cities have shown a significant effect on car usage in the short term. However, results show that this effect decrease over time (Zhang et al., 2019). Some authorities have attempted to use road pricing to reduce traffic congestion, while road pricing is scarcely implemented due to the issue of equity and the redistribution of the revenues (Harsman et al., 2011).

Currently, the emerging tradable mobility permit scheme, as a policy alternative to road pricing, has received growing attention in the transportation literature, with initial work by Verhoef et al. (1997) and many more recent contributions (see e.g., Akamatsu & Wada, 2017; de Palma et al., 2018; Yang & Wang, 2011). Under such a scheme, the regulator initially sets a constraint on the total car use in a specified area and period and distributes credits to all eligible recipients. The credits are freely tradable among travelers and the price of the credits is determined by the competitive market. As a result, the tradable permits scheme can take advantage of both management and pricing measures. It can be made revenue-neutral and would therefore probably be more easily accepted.

To date, most of the existing literature on tradable mobility permits (or credits) uses a theoretical or simulation approach, however, relatively few empirical contributions have been made. Existing empirical studies observe respondents' virtual behavior using questionnaire-based surveys or lab-setting experiments (such as Dogterom et al., 2018; Brands et al., 2019; Tian et al., 2019). However, it might be risky to take human behavior as measured by such stated preference techniques as real behavior. Some studies even simplified the dynamic market mechanism into a static credit price or used virtual agents instead of human participants. In addition, there is no empirical evidence on the efficiency comparison between tradable permits and traditional congestion charge in real life. Given these research gaps, the following three research questions are investigated:

1. How can we design a feasible tradable permits scheme for the Beijing morning peak commuting context?
2. How will the tradable permits scheme and congestion charge work in Beijing morning peak?
3. What are drivers' attitudes toward tradable permits scheme and congestion charge?

2. METHODOLOGY

Experiment design

The subjects of this experiment are from Beijing Smart Driver Company. Smart Driver (i.e., Zhijia in Chinese) Company is an enterprise providing vehicle management services based on internet technology. It has more than 30,000 users in Beijing. They are very randomized sample from different districts of Beijing with different brands of cars. Products offered by the company include both on-board equipment for cars (OBD box) and mobile app for each user. The OBD box collects and records vehicle status data and travel information in real time. Users can know the car conditions and travel details through the phone app. Data begin to be recorded from engine start-up to engine shutdown. The device collects real-time data every second and uploads it to the server every five minutes.

Table 1 shows the group design of this study. We designed four groups to compare the effects of tradable permits and congestion charge, which include 1) Mix group: 4 weeks congestion charge incentive plus 4 weeks tradable permits incentive; 2) TP group: 4 weeks tradable permits incentive; 3) CC group: 4 weeks congestion charge incentive; and 4) Control group: no incentive.

Table 1 Group Design

	Mix	TP	CC	Control
Pre experiment	Pre-survey			
First month incentive	Congestion charge	Pre-survey		
Second month incentive	Tradable permits	Tradable permits	Congestion charge	
Post experiment	Post-survey			

Each subject received CNY 80 as a participation fee at the beginning of the treatment period. For users in mix group, they received CNY 160 participation fee. Participants' other earnings from our experiment were recorded in Smart Driver App accounts. When the treatments ended, subjects would get payments in their electronic wallets of WeChat based on the records in the app accounts.

Design of tradable permits scheme

In this study, we proposed a step-size permit scheme according to the morning hour in Beijing. We defined the time windows of 6:30 a.m. to 7:00 and 8:00 a.m. to 8:30 a.m. as small peaks. The time window of 7:00 a.m. to 8:00 a.m. is defined as a big peak. For Monday to Friday, if drivers depart in the small peaks, they need to use 1 permit. And if they depart in the big peak, they need to use 2 permits. The permits can be automatically calculated and deducted based on individuals' travel records. Participants can trade permits in a phone APP whenever and wherever they like, as shown in Figure 1. The market design follows Devi et al. (2020), in which the permit price will adjust automatically based on the pre-defined target (i.e., total number of initial permit allocation), real-time permit consumption and possession. The initial permit price has been set to CNY 10 (about 1.39 euro) based on our pilot results and survey.

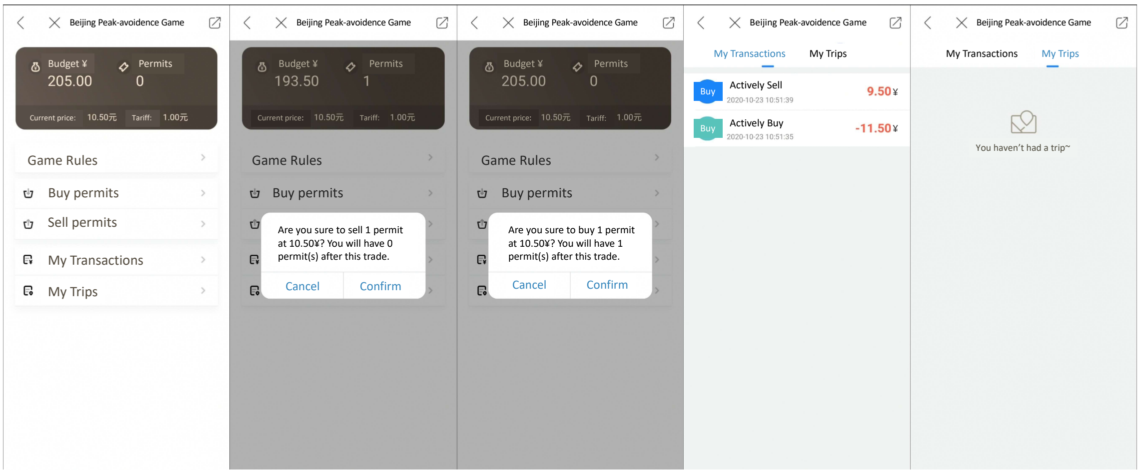

Figure 1 The App screen shots of tradable permits scheme

Before each experimental week, participants are allocated a certain amount of monetary budget and permits budget. The initial permit allocation is depended on their pre-experiment behavior. By using participants historical travel data one month before the experiment, we can calculate the original week-average permits usage for each participant. Then, the initial permit allocation per week is based on the weighted original week-average permit usage, which equals the original week-average permits usage multiple a pre-defined aiming peak avoidance ratio. The pre-defined aiming peak avoidance ratio is settled based on the peak avoidance rate for Mix group users in the first congestion charge incentive month.

Considering the effects of driving restriction policy in Beijing, the maximum permit usage per week is defined as 8 (i.e., 2 permits multiple 4 days), which equals CNY 80 at the beginning. Therefore, the maximum monetary budget is set to CNY 320 (i.e., CNY 80 multiple 4 weeks). Hence, the one-off initial monetary budget for each user equals CNY 400 (i.e., CNY 320 plus CNY 80) minus the equivalent monetary value of the initial permit allocation (initial permits allocation multiple CNY 10).

Design of Congestion charge

Similarly, given the morning peak in Beijing, we designed a step-size congestion charge incentive (as shown in Figure 2). For Monday to Friday, if drivers depart in the small peaks, they need to pay CNY 10. And if they depart in the big peak, they need to pay CNY 20. Since we cannot ask participants to really pay some money in the experiment, each participant has been allocated a total of CNY 400 (i.e., CNY 320 plus CNY 80) at the beginning.

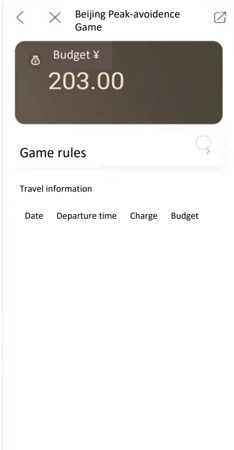

Figure 2 The App screen shots of congestion charge incentive

Sample recruitment

The user recruitment steps are as follows. First, screen the sample pool of subjects that meet the experimental conditions. According to the data of Zhijia users (as of April 1, 2021), the users who only have one car installed the OBD box were selected. Based on the travel data in March 2021, each user's daily trip which is larger than 500 meters, during 6:30-8:30, and has the earliest departure time is selected. For users who live within the Fifth Ring Road, all trips that meet the above conditions are reserved; for users who live outside the Fifth Ring Road, only the trips whose destination is within the Fifth Ring Road is reserved. Further, count the number of peak trips within the Fifth Ring Road that each user meets the above conditions each week. Eligible subjects need to meet: have at least 2 eligible trips in the last week; or at least 4 times in the last 2 weeks; or at least 6 times in the last 3 weeks; or at least 8 times in the last 4 weeks. Based on the above conditions, a total of 2424 qualified Zhijia users were selected.

The experimenters recruited users through three methods: APP notification, SMS and phone calling. Users who are taxi drivers or deliveryman, don't have private cars, have more than 1 available car on typical workdays, and didn't install Zhijia box on their car were screened out through the pre-survey questionnaire. The first-round recruitment was from May 19 to 22, 2021. A total of 110 users were recruited and allocated to the mixed group. The second-round recruitment was from May 31 to June 16, 2021. A total of 422 users were recruited. According to the location of the sample residence, the number of peak travel days in the past month, the average travel distance, and the average departure time, users is randomly divided into 5 groups. The balance test is shown in Table 2. Users in each group have no significant difference. Note that this experiment is part of a larger experiment. In the larger experiment, there are 6 groups, which also include 2 groups about nudge information. Here we just focus on four groups shown in Table 1.

Table 2 Group balance

	Group (Mean ± Std.Err)						F	p
	Mix (n=110)	TP (n=108)	Control (n=80)	CC (n=78)	IF (n=80)	IFCC (n=76)		
Residence inside 2nd ring road	0.18±0.39	0.16±0.37	0.16±0.37	0.15±0.36	0.15±0.36	0.14±0.35	0.120	0.988
Residence bet. 2nd and 5th ring road	1.49±0.88	1.53±0.85	1.52±0.86	1.54±0.85	1.50±0.87	1.53±0.86	0.047	0.999
Residence outside 5th ring road	0.22±0.78	0.21±0.77	0.23±0.80	0.23±0.80	0.30±0.91	0.28±0.87	0.162	0.976
Number of peak trips in the past month	11.79±4.83	11.49±5.02	11.24±5.17	11.59±4.71	12.06±4.48	11.24±4.42	0.371	0.868

	Group (Mean ± Std.Err)						F	p
	Mix (n=110)	TP (n=108)	Control (n=80)	CC (n=78)	IF (n=80)	IFCC (n=76)		
Average travel distance (m)	16614.53± 14155.97	15704.65± 11734.26	14849.54± 9227.54	16581.76± 11671.40	16856.41± 11810.16	15637.13± 10593.61	0.355	0.879
Average departure time (mins from 12 a.m.)	439.53± 28.00	441.76± 25.56	446.49± 27.52	446.90± 27.03	441.61± 27.12	444.46± 27.76	1.058	0.383
Gender	0.91±0.29	0.83±0.38	0.94±0.24	0.90±0.31	0.89±0.32	0.92±0.27	1.381	0.230
Age	42.51±6.51	60.96±190.82	41.45±9.75	41.63±7.90	40.80±6.27	41.25±6.94	0.870	0.501
Income	5.24±2.11	5.56±2.05	5.53±2.04	5.59±2.07	5.00±2.56	5.50±2.21	0.992	0.422

Mix: Mix group; TP: Tradable permits group; Control: Control group; CC: Congestion charge group; IF: information group; IFCC: Information plus congestion charge group.

3. RESULTS AND DISCUSSION

Sample description

The social demographic information of samples is shown in Table 3. Male users account for a relatively high proportion, reaching 89.3%. 52.1% users are aged between 35 to 44 years old. The education level of our samples is relatively high. 91% of users have an education level of college or higher. About the industry they involved, most users are from transportation, storage and communications (16.0%), or public administration and social security (15.8%) industry. About 47.2% of users belong to high-income groups.

Table 3 Sample social demographic characteristics

Variable	**Option**	**Proportion（N=532）**
Gender	Male	89.3%
	Female	10.5%
Age	25-29	1.7%
	30-34	15.0%
	35-39	25.4%
	40-44	26.7%
	45-49	15.2%
	50-54	10.0%
	55-59	4.7%
	60-64	0.8%
	65 and above	0.4%
Industry	Real estate and industrial and commercial services	3.6%
	Public administration and social security	15.8%
	Housework	1.9%
	Construction	8.5%
	Education	7.9%
	Financial sector	10.7%
	Hotel and catering industry	2.1%
	Wholesale and Retail	6.8%
	Water, electricity and gas production and supply	4.1%
	Entertainment, gaming and other services	4.3%
	Health and social welfare	5.1%
	Transportation, storage and communications	16.0%
	Manufacturing	13.2%
Education	Junior high school	0.9%
	High school	4.3%

	Secondary vocational education	1.7%
	Higher vocational education	1.9%
	College	20.7%
	Bachelor	47.7%
	Master and above	22.6%
Annual household per capita disposable income (Unit: Yuan)	=<8000	5.3%
	8001～12000	6.0%
	12001～16000	3.0%
	16001～21000	3.0%
	21001～26000	4.3%
	26001～33000	4.7%
	33001～40000	6.4%
	40001～60000	11.1%
	60001～80000	8.8%
	>80000	47.2%

Behavior Changes

Through the kernel densities, we compare the departure time distribution of each group before, during and after the experiment. As shown in Figure 3, the x-axis represents the number of minutes from 0 o'clock, and the y-axis represents the kernel density. It can be seen that after the experiment shifts the treatment groups' distribution to the left of the control group's, and the difference remains post-experiment.

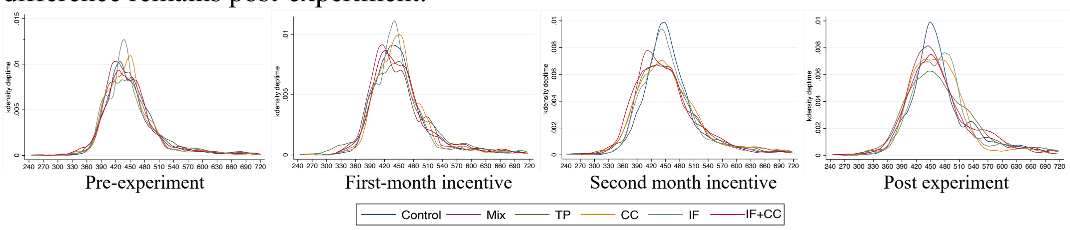

Figure 3 Kernel Densities for control and treatment groups

Next step, we will focus on participants' number of permits usage before and during the experiment, and regression models will be used to identify the treatment effects of tradable permits and congestion charge.

Policy attitudes

In the pre- and post-experiment surveys, participants were asked to score the acceptability, usability, fairness, the effectiveness of congestion mitigation and emission reduction of congestion charge and tradable permits. The results are shown in Table 4.

Before the experiment, a total of 532 participants answered the questionnaire. The percentages of approbate or strongly approbate with congestion charges and tradable permits were 15.1% and 25.8%, respectively. After the experiment, a total of 488 participants completed the questionnaire again, and the acceptability of both measures was improved. The proportion of participants who approbate or strongly approbate rose to 31.1% (congestion charges) and 44.7% (tradable permits).

Before the experiment, more than 50% of participants believed that it would be difficult or very difficult for them to use the congestion charge and tradable permits system. But after the experiment, through the real experience, the percentage dropped to 34.2% (congestion charges) and

25% (tradable permits). Most participants believe that, compared to congestion charges, tradable permits are better in terms of acceptability, fairness, effectiveness in alleviating traffic congestion, and effectiveness in reducing the environmental pollution. After the experiment, the proportion of users who believe that tradable permits policy is better has risen further.

Table 4 Policy attitudes before and after the experiment

Variables	Options	Pre（N=532）		Post（N=488）	
		Congestion charge	Tradable permits	Congestion charge	Tradable permits
Acceptability	Strongly agree	7.0%	8.1%	13.9%	18.9%
	Agree	8.1%	17.7%	17.2%	25.8%
	General	24.4%	34.2%	26.8%	31.1%
	Disagree	20.3%	13.0%	11.9%	8.8%
	Strongly disagree	40.0%	26.9%	30.1%	15.4%
Usability	Very easy	5.1%	5.6%	14.8%	16.6%
	Easy	5.5%	9.0%	19.1%	24.0%
	General	14.3%	27.8%	32.0%	34.4%
	Hard	33.8%	27.6%	15.8%	10.5%
	Very hard	41.2%	29.1%	18.4%	14.5%
More acceptable		23.50%	75.4%	19.3%	80.5%
Fairer		25.75%	72.0%	20.7%	79.1%
More effective in congestion reduction		43.80%	52.3%	38.9%	60.9%
More effective in pollution reduction		43.42%	49.8%	41.6%	58.2%

Overall, 61% of the participants agree or strongly agree that tradable permits are better than congestion charge. Regarding whether congestion charges or tradable permits can replace the current license restriction policy, 32% of participants remain neutral, and 41% of participants believe that congestion charges may be an alternative to the license restriction policy, and 49% for tradable permits.

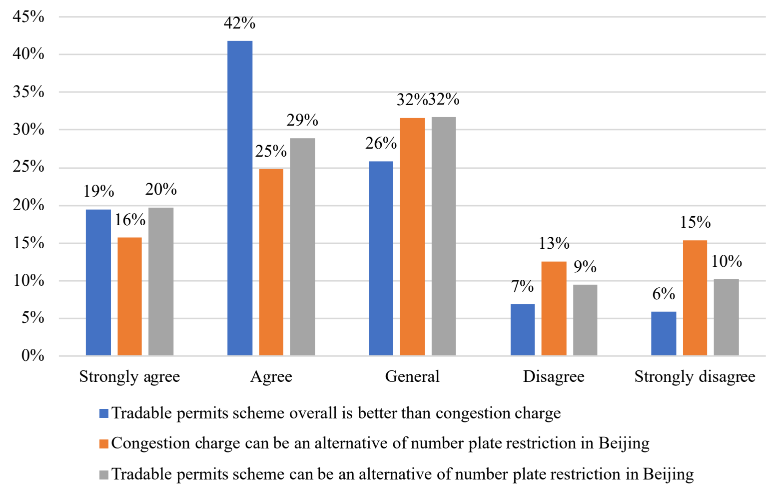

Figure 4 Policy comparison

4. CONCLUSIONS

This study contributes to the literature by providing empirical evidence of tradable permits and congestion charge to manage rush-hour travel behavior. We have conducted an 8-week field experiment from May to July 2021among 532 real car drivers in Beijing. A step-size tradable permits scheme and similar congestion charge scheme have been designed based on Beijing real traffic conditions and tested in natural circumstances. The OBD box and phone app have been used to record drivers' real-time behavior and help them trade and check conveniently. The descriptive results indicate that the proposed tradable permits scheme and congestion charge scheme reduce peak-hour departures. Further tests and models are needed to get more detailed results. More participants think that tradable permits scheme is more acceptable than congestion charge. Besides, the support rate of both polices further increase when drivers have tried the polices in real-life.

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