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Effectiveness investigation of travel demand management measures in Beijing: Existing measures and a potential measure–tradable driving credit

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ABSTRACT

Facing serious challenges of traffic congestion and air pollution, Beijing has implemented a series of traffic polices. In this paper, we first investigate the effectiveness of existing traffic measures in Beijing and analyse the underlying factors from the perspective of drivers, which provide insights for the traffic regulations in other cities worldwide. While the car ownership restriction has effectively limited the total number of vehicle in Beijing, the effect of the car use restriction only lasts for a short period. A survey on drivers' opinions and attitudes towards the traffic situation and a potential measure, i.e., tradable driving credit (TDC), is conducted. Although traffic data shows that congestion improved and traffic was slightly congested in recent years in Beijing, most respondents believe congestion is still serious in Beijing. However, they think the impact of traffic congestion on their personal car use is relatively low, which could partly explain why so many travellers still depend on driving given the relative convenient transit facilities in Beijing. In addition, a large proportion of respondents treat personal cars as a representation of social status and think driving bring them pleasures, which indicates that it may be hard to further decrease the share of car trips in Beijing. According to their attitudes and social-economical characters, respondents' willingness on their changes of travel behaviours under TDC is investigated. The results show that individuals' social-economic characters such as income level, education and family size and the symbolic meaning of personal cars have significant influence on respondents' willingness to switch to other transport modes.

1. Introduction

While car mobility may increase access to important facilities for many, it is associated with serious disadvantages with respect to sustainability and accessibility at the aggregate level. First, the exponential increase in car ownership and use generally exceeds the capacity of the road network, resulting in severe congestion in urban areas. These lead to excess travel times (for instance in daily commuting), and a reduced accessibility. The detrimental effects of long car trips in congested situations on physical and mental health and well-being have been well documented. Another issue caused by the increase of car traffic in megacities is its consequences for air quality, resulting in concentrations of particulate matter, NOx and other

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gasses that severely damage citizens' health. The adverse effects of massive car mobility raise questions as to how car ownership and use can be controlled in order to maintain accessibility and limit negative health impacts.

This is especially true for the Chinese capital, Beijing, where traffic congestion and air pollution have become a severe issue concerned the whole country. Beijing is the major political, commercial, and financial centre in China with a high population density. Its motorized transport infrastructure development has a distinctive lay-out comprising multiple outer ring roads with inter-ring road connections. The overall pattern of development in Beijing has been characterised by the rapid population and economic growth over several decades (Xu, Grant-Muller, Huang, & Gao, 2015). However, traffic congestion and pollution problems have become notorious and have brought remarkable economic loss, travel inconvenience and health-related problems. In order to mitigate traffic congestion and improve air quality, the Beijing government proposed to reduce the particle density by 25% or more on the PM 2.5 scale until 2017. To achieve this aim, the Beijing Municipal Clean Air Action Plan 2013–2017 (BMCAAP, 2013) released a series of policies to cut vehicle emissions and industrial pollution. The government also issued a series of transport policies ("28 specific measures for congestion mitigation", Xu et al., 2015), which include some contractive policies, such as curbing car ownership and car use restrictions based on the last digit of license plate numbers.

As a typical megacity with large travel demand and well-developed public transport network, the numerous measures adopted in Beijing make it an ideal candidate to analyse the effectiveness of traffic regulation measures and their impacts on drivers' travel, which could provide insights on the traffic management in other cities worldwide, especially in large cities in developing countries. Wang, Gao, Xu, and Sun (2014) analysed the effect of the driving restriction policy in Beijing and found out that nearly a half of drivers did not follow the restriction rules. Sun, Zheng, and Wang (2014) suggested that driving restriction policy helps improve the city-wide traffic speed but has little effect on the improvement of air quality. Yang, Liu, Qin, and Liu (2014) reviewed Beijing's vehicle registration lottery. They found out that the growth of cars has been curtailed while the reduction of fuel consumption is limited. Li and Jones (2015) also investigated the car ownership restriction in Beijing and think it is effective in controlling the growth of vehicles and reducing CO_2 emissions. Nie (Marco) (2016) investigate the license plate rationing and car purchase restriction in Beijing and concluded that they result in considerable welfare loss. Currently, with the rising on-demand mobility services discussion in Beijing, understanding and modelling traveller behaviour in response to these services are also important to sustainable travel incentives. Xie et al. (2019) presented a modelling framework for accounting the impacts of real time on-demand system's dynamics on traveller behaviours and capturing consumer heterogeneity.

In this paper, we first evaluate the effectiveness of the current vehicle restriction policies in Beijing based on the reports from the government. Then, it will be analysed from the perspective of the drivers, i.e., the drivers' opinions on traffic congestion and its effect on personal driving and on the environment. Although the vehicle restriction measures in Beijing has been intensively investigated, both in theoretical studies and in empirical studies (e.g., Viard & Fu, 2015), to our knowledge, this is the first time that they are investigated from the view of drivers.

Given the fact that traffic congestion is still severe, Beijing is also open to other traffic policies, such as economic measures like road pricing (BMCAAP 2013–2017). However, road pricing has been proven to be controversial and raises issues with respect to public acceptance, effectiveness and equity. Another alternative could be TDC, which has received much attention recently. TDC plays essentially the same role as road pricing in the regulation of location-dependent and time-dependent congestion and environmental externalities (Yang & Wang, 2011). However, a TDC scheme is revenue-neutral and is usually regarded as much fairer than road pricing. Under the TDC scheme, drivers receive a certain amount of credits for free at the beginning of every period (e.g., every month) that can be used on the roads. Compared to road pricing, drivers do not need to pay money "out of pocket" unless they spend more than their allowance, which gives them a limited amount of free access to public roads. In contrast to rationing, drivers have the freedom to choose where and when to drive. In addition, the fact that drivers can sell their extra credits for tangible benefits encourage them to limit their travel demand, and thus, leads to the improvement of traffic condition.

To understand the public's attitudes towards the current traffic situation in Beijing and to TDC, we carry out a survey among drivers in Beijing. In the survey, respondents are asked to answer questions about the traffic congestion in Beijing and about TDC. We will analyse the effectiveness of the existing traffic measures from the perspective of the vehicle drivers based on the survey, and compare the results with that from the government reports. Based on their attitudes toward the traffic situation and the exiting traffic measures in Beijing, respondents are then asked their opinions on TDC. They are also asked to make travel choices under different TDC scenarios. The impacts of their social-economic characteristics on the effectiveness of the congestion mitigation measures are analysed. This paper will present evidences on the different opinions on traffic congestion between the government reports and drivers, and provide insights on drivers' willing to change travel behaviours under TDC.

The structure of the paper is as follows. Section 2 gives an introduction of the current vehicle restriction policies in Beijing, while Section 3 introduces the design and data collection of the survey. Section 4 analyses respondents' attitudes on traffic congestion situation in Beijing and their attitudes toward personal car use. Section 5 investigates the potential effectiveness of TDC, followed by conclusions of the paper in Section 6.

2. The car restriction policies in Beijing and their effectiveness

Over the past years, several vehicle restriction policies, such as the car license plate lottery programme and the car use restriction policy, have been implemented to slow down the rapid increase of vehicle numbers and use in Beijing. However, research about the effectiveness of these polices and the attitudes of the public on these policies are still limited. In this section, the vehicle restriction policies in Beijing will be introduced. At the same time, their effectiveness will be reviewed from the reports of the authorities (these reports are mainly from Beijing Transport Institute).

2.1. Vehicle restriction policies in Beijing

Along with the rapid economic development in the past decades, Beijing has experienced sharp growth of vehicle number. In 2015, the number of vehicles and private cars are 5.62 million and 4.25 million respectively (The Annual Report on Transport in Beijing in 2016, 2016). As a result, traffic congestion has become one of the most prominent problems in Beijing. In fact, Beijing has been listed as one of the most congested cities in the world by many international organizations (Yang et al., 2014). According to the Annual Report on Transport in Beijing in 2016, the average travel speed for private cars is 14.7 km/h for morning peak hours and 15.1 km/h for evening peak hours in 2015. At the same time, the motor vehicles also significantly contribute to the air pollution, which is also a major concern of Beijing. About 23% of Beijing's PM_{10} is discharged by vehicles while 30% is attributable to the road dust caused by vehicles (Viard & Fu, 2015).

To deal with these problems, the Beijing Municipal Government has taken a series of policies, such as the priority development of public transportation, bus and subway fees reduction, parking fee growth and so on. Among them, the car ownership restriction and the car use restriction seem to be the most prominent. From October 11, 2008, Beijing began to implement the "one day per week" car use restriction, under which vehicles were forbidden from using the road inside the fifth ring for one workday each week based on the last digit of their license plates. The policy took effect soon and by 2009, the congestion was significantly mitigated. However, it did not last long, mainly due to the rapid increase of car ownerships (Wang, Xu, et al., 2014). In 2010, the total numbers of vehicles and private cars are 4.8 million and 3.57 million respectively while the numbers are 2.58 and 1.34 in 2005 (Sun et al., 2014). At the same time, the total number of daily trips inside the 6th ring road made by automobile in that year is 9.93 million (Wang, Xu, et al., 2014). This made the government further announce another instrument at the end of 2010, the car license plate lottery program, under which individuals must win a lottery to get the permission of buying a private car. At the beginning of 2011, another series of traffic regulation measures, i.e., the "28 specific measures for congestion mitigation" (Xu et al., 2015), were announced, which alleviated the congestion effectively.

2.2. Initial effectiveness analyses

The effectiveness of the current traffic policies is reflected in the change of the traffic situations in Beijing, which is recorded by the government reports. Most of the data is from the "Annual analysis report of the traffic situation in Beijing" and "Beijing Transport Annual Report", issued by the Beijing Transport Institute. The effectiveness of the policies is measured from three aspects, the growth of vehicle number, the change of the travel modes and the traffic congestion indexes.

2.2.1. Growth of vehicle number in Beijing

The implementation of the license plate lottery program directly slowed down the rapid growth of vehicle ownership in Beijing. According to the Beijing Transport Annual Report 2018, the total number of vehicles in Beijing is 60.8 million in 2018 with an annual increase of 3.0%, while the total number of personal cars is 48.9 million with an annual increase 2.9%. Fig. 1 gives the growth of the vehicles and personal cars in Beijing from 2004 to 2018. The average growth is 7.4% for vehicles and 11.6% for personal cars from 2004 to 2018. It can be observed that the annual growth is very high before 2011, with an average growth of 12.4% for vehicles and 21.3% for personal cars. After the car license plate lottery program was announced at the end of 2010, the growth of vehicles significantly declines. From 201 to 2018, the average growth of vehicles is 3.0% and the average growth of personal cars is 3.2%. In fact, the total growth of vehicles in the following eight years (from 2011 to 2018, about 12.75 million) is even less than that in two years before the car license plate lottery program was announced (from 2008 to 2010, about 13.04 million).Fig. 2.

Although the growth of the vehicles goes down, the demand for vehicles is very high and the lot winning rate for the car license plate keeps declining. In December 2015, the lot winning rate is 0.49% while it is 0.66% in 2014 (Beijing Annual Traffic Analysis Report, 2015). This figure further goes down in recent years. In 2018, the total number of car license plate available declined from 1.5 million to 1.0 million. According to the latest announcement of Beijing Municipal Commission of Transport, the number of personal car plates is 6333 while the number of the effective applicants is 2,796,423 in April 2018 (https://www.bjhjyd.gov.cn/jggb/2018425/1524613996748_1.html, 2018–04-25). Considering the rules of the laddering lottery rate, the winning rate of the lottery is merely 0.05% (China Daily, http://www.chinadaily.com.cn/interface/toutiaonew/1020961/2018–04-26/cd_36094894.html, 2018–04-26).

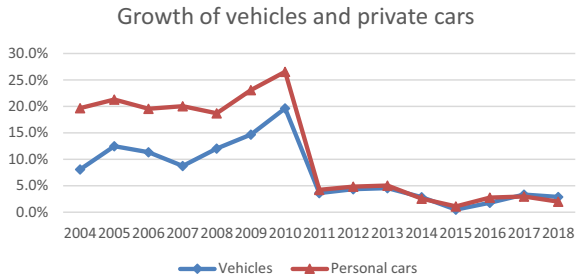

Fig. 1. The vehicle numbers in Beijing from 2008 to 2018 (Beijing Annual Traffic Analysis Report, 2019).

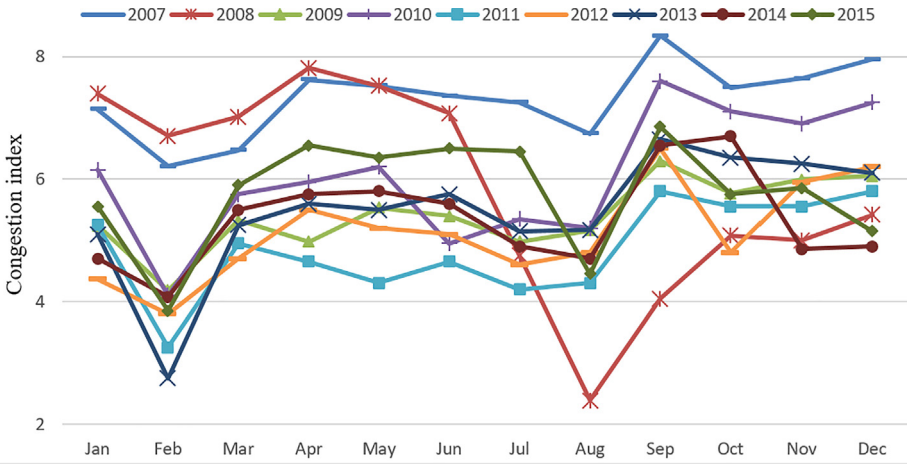

Fig. 2. The monthly congestion index from 2007 to 2015 (Beijing Transport Annual Report 2008–2016).

2.2.2. Traffic congestion situation in Beijing

Based on the above analyses, it seems that the car restriction policies are effective, as the growth of the car ownership slowed down and the share of car trips also declines, which was 31.5% in 2014 while it was 34.2% in 2010. At the same time, the traffic congestion situation seems to be improved. Fig. 3 presents the monthly average congestion index from 2007 to 2015. It can be observed that traffic congestion in winter is more serious, which may be because people prefer to drive by themselves in the cold weather. On the hand other, the traffic situation is better in February and August because of the Chinese Spring Festival holiday and the summer holidays. Traffic congestion in September is usually serious because of the end of the summer holidays, particular in 2007 with a daily congestion index of 8.3[1], which means it was serious congested in the city. The traffic situation was also not good in other months in 2007, with an average congestion index of 7.31, which was caused by the fast growth of travel demand and car ownerships in the past few years.

Congestion got even worse in the first few months in 2008. Then, the odd-and-even license restriction was implemented during the Olympic Game from July to September, which led to a dramatical improvement of traffic situation, particular in August. When the Olympic Game was over, the government continued to implement the "one day per week" car use restriction. Therefore, although the congestion got worse in the next few months in 2008, it was still much better than that in 2007. The effect of this measure lasted in the next two years. The general traffic situation was slightly congested in 2009 and in most of the time in 2010. However, its effect became weak gradually, and congestion became much worse at the end of the 2010.

To avoid the further deterioration of traffic congestion, the government announced the "28 specific measures for congestion mitigation" at the end of 2010. It got effect immediately. In 2011, the average congestion index for working days declined to 4.8. However, it increased slightly in the next few years, which is 5.2 in 2012, 5.5 in 2013 and 2014, and 5.7 in 2015. In fact, the traffic congestion in 2015 was almost as worse as that in 2010. It can be observed that nearly half of the monthly congestion indexes in 2015 are already higher than those in 2010. In addition, the odd-and-even license restric-

[1] The Beijing Municipal Commission of Transport classifies traffic congestion according to a 10-point, 5-level congestion index (as shown in Fig. 3). According to this index, congestion is qualitatively described as "smooth," "basically smooth," "slightly congested," "moderately congested," and "seriously congested". For detail information on the congestion index please refer to the "Congestion index interpretation" issued by the Beijing Transport Institute on their official website (http://www.bjtrc.org.cn/PageLayout/IndexReleased/IndexReader.aspx?menuid=li4).

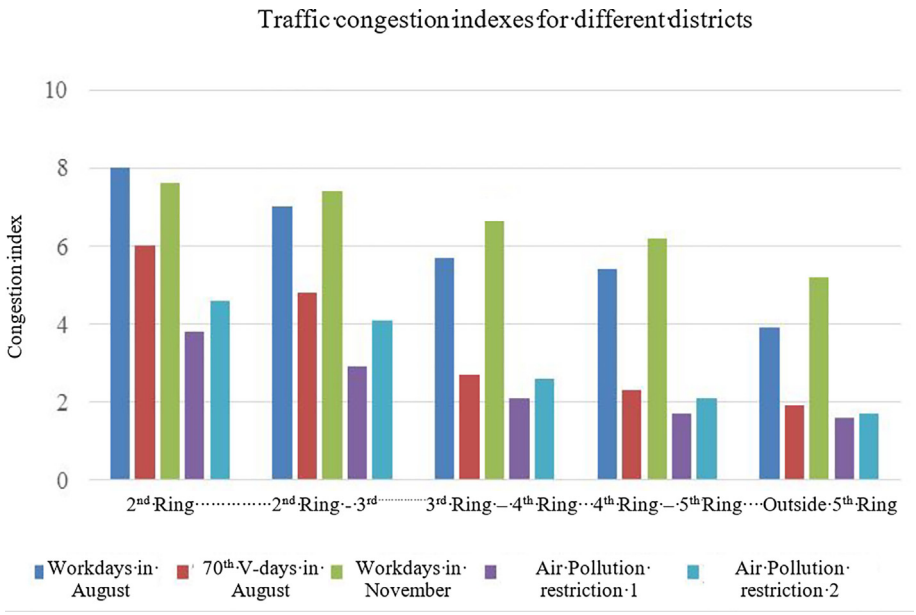

Fig. 3. The congestion indexes for different districts (Beijing Annual Traffic Analysis Report, 2015).

tion was adopted for some workdays in August and December. Although the average congestion index level is still slightly below that in 2010, whether this effect will last for long time is still not sure yet. After 2015, more congestion mitigation measures were taken, such as the development of sharing bicycles. As a result, the traffic situation in the next few years slightly improved with an average congestion index of 5.6 in both 2016 and 2017 (Beijing Transport Annual Report, 2018).

Although the long-term effect is not clear yet, the license plate restriction, especially the odd-and-even license restriction, can alleviate congestion immediately. The odd-and-even license restriction was implemented three times in 2015, one in August due to the celebration activities for the 70th anniversary of the victory of World War II and two in December due to the serious air pollution. During these periods, the traffic congestion index was between 2 and 3, with the peak value less than 4.0. In contrast, the traffic congestion index on workdays without any restrictions was between 4 and 6, with the peak value about 8.0. Fig. 4 presents the congestion indexes for different districts during the odd-and-even license restriction periods. The Second-Ring was still the most congested area, but the congestion indexed had been declined a lot to "slightly congested" or "moderately slightly" traffic situation. On the other hand, the traffic situation outside the Third-Ring was significantly improved, and almost no congestion existed. Although the traffic congestion was still serious inside the Second-Ring, the traffic efficiency was significantly improved. The average traffic speed inside the Second-Ring reached 35 km/h, which raised by 43% in contrast with that on the workdays in November. At the same time, the total traffic flows declined in the whole network while the flow during peak hours increased on the arterial roads. As for the travel modes, the travel by taxi increased the most with an increase ratio of 15.1% while the ratio of bus increased by 3.4%.

In summary, the growth of the vehicle population in Beijing has been effectively controlled due to the car license plate lottery program. The other regulation measures are also effective, especially the car use restrictions, which resulted in a sharp decline of congestion index. The share of car trips has also declined, which was about 27% in 2018. However, it should be noticed that the car use restrictions usually take effect immediately, but their effect decreases year by year, which is consistent with the finding in literature (e.g., Gallego, Montero, & Salas, 2013). Without further regulation, they will lose their effect in a few years. In addition, these measures also impose restrictions on individuals' mobility freedom, especially the car license plate rationing and the "one day per week" car use restriction.

3. Survey design and data collection

3.1. Credit based measures for travel demand management

The concept of tradable credits is actually not new. The pioneer study of credits can be tracked back to the work of Coase (1960) on external costs, followed by that of Dales (1969) on tackling water pollution, and the formalization of pollution permit markets by Montgomery (1972). Tradable credits provides a variety of instruments that combine the conventional regulation and the competitive markets, They can minimize the total cost of achieving a given emissions reduction objective (Baumol & Oates, 1988), as well as giving agents the freedom to choose. In addition, the initial allocation of credits does

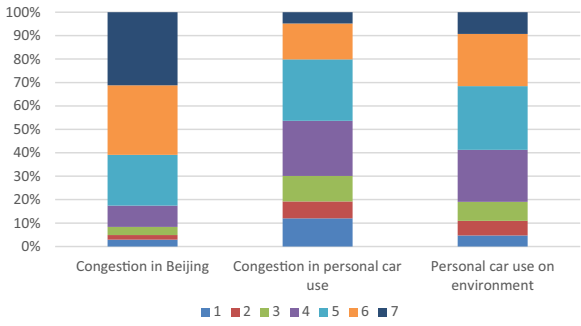

Fig. 4. Respondents' attitudes toward congestion and environment situation.

not affect the effectiveness of emissions reduction, which means the issues of efficiency and equity are separated in these instruments.

In the context of transport, the features of TDC make it particularly attractive for the mobility management. Under the TDC, drivers receive a certain amount of credits for free at the beginning of every period (e.g., every month) that can be used on the roads. Compared to road pricing, drivers do not need to pay money "out of pocket" unless they spend more than their allowance, which gives them a limited amount of free access to public roads. In contrast to rationing, drivers have the freedom to choose where and when to drive. In addition, the fact that drivers can sell their extra credits for tangible benefits encourage them to limit their travel demand, and thus, leads to the improvement of traffic condition.

Although there are many studies on the modelling and the economics analyses of tradable credits (see e.g. Grant-Muller and Meng (2014) and Lessan and Fu (2019)), the empirical studies are still rare, as concluded in Dogterom et al. (2016). Considering the potential application of TDC in the near future, the response and attitude of the public are important. Although a powerful government can push an instrument if they think it should do, a broad understanding and agreement among the public is required for its success. Dogterom, Bao, Xu, and Ettema (2018) and Dogterom and Ettema (2018) compared drivers' acceptability of TDC and their willingness to change between the Netherlands and Beijing. In this research, we try to get a broad understanding of the public's attitudes to the current traffic condition and the possible TDC measure through an experiment investigating drivers' responses to these issues.

3.2. Questionnaire survey

The experiment was conducted in Beijing, in which a survey on drivers' car trips under hypothetical TDC schemes was given, and participants' attitudes towards the current traffic situations and the implemented restriction policies are also provided. The survey used a stated adaptation approach and investigated participants' reactions to different TDC scenarios by means of questionnaire (a reliability and validity test of the questionnaire is given in Appendix A). Only drivers who frequently commute by car were recruited to participate in the experiment. Most respondents are invited to complete the online questionnaires through email while the others are approached face to face. In total, 660 usable questionnaires were collected, including 600 online questionnaires and 60 paper-based questionnaires. The questionnaire included the questions described in the following:

Characteristics of the respondents

The questionnaire included some fundamental information about respondents, i.e. gender, family size, educational level, income per month and car numbers owned. These characteristics are summarized in Table 1.

Participants' car trip information over a full week

Participants are first required to given information about their travel in the past seven days. Questions like how many car trips they made for work & study, social activities and recreation activities, and how many kilometers they drove for these activities are given. Then, they are asked to compare whether they made more or less trips, drove more or less kilometers in the past seven days than their normal levels. In this way, we hope participants can fully recall their car trips information and their travel demand. Thus, they can make reasonable travel choices when they are given different TDC schemes later. A seven-day period is chosen because a week is one of the most desirable experiment periods, which on one hand can provide insights on participants' travel behaviors under the TDC scheme and on the other hand will not put too much burden on participants.

Participants' reactions to different TDC scenarios

In the experiment, we investigated people's travel behavior change under a distance-based TDC scheme. Participants must pay one credit for driving one kilometer. They are given different number of credits under different scenarios. For the first scenario, participants received 50 km more credits than their demand and for the second scenario, they received 50 km less credits than their demand. Based on their travel demand in last week, participants received different sized budgets. By doing so, we could investigate participants' reactions given different credit shortages and credit surpluses. Credits

Table 1
Sample characteristics.

Gender	Male	337	51,1%
	Female	323	48,9%
Educational level	University, master/doctor	74	11,2%
	University, bachelor	440	66,7%
	College	123	18,6%
	High school	20	3,0%
	Middle school and below	3	0,5%
Income	Less than 6000¥	302	45,8%
	More than 6000¥	358	54,2%
Family size	1	12	1,8%
	2	117	17,7%
	3	417	63,2%
	4	66	10,0%
	More than 4	48	7,3%
Car numbers owned	1	601	91,1%
	More than 1	59	8,8%

can be traded in the market. Three different price levels: ¥0.50, ¥0.8 and ¥1.0 per credit (i.e., per kilometer) were assigned to participants.

Participants' attitudes toward traffic condition and personal car use

The last part of the questionnaire includes questions about participants' attitudes. Respondents are asked to give their attitudes in the following aspects: the congestion and environment issue caused by car use in Beijing; the status and pleasure they can derive from their car and car driving; the possibility to switch to other travel modes and whether they think another congestion mitigation policy (TDC) can perform better than the existing policy (i.e. the "one day per week" car use restriction for Beijing); their attitudes toward the new congestion mitigation policy (TDC). About the congestion and environment, respondents are asked to choose to what extent congestion is a problem in the city, in their personal car use and to what extent car use is a problem in environment. A 7-point scale is used to measure the degree of the problem with "1" means "not a problem at all", "7" means "a very serious problem", and "4" means the respondents' attitudes are neutral. Some other questions are also measured by a 7-point scale. Questions on "personal cars represent status", "driving brings pleasure" and "TDC can perform better than existing policies" are measured with an increasing degree of agreement. The possibility to switch to other modes is measured with an increasing degree of possibility and the participants' attitudes toward TDC is measured with increasing degree of acceptance.

4. Respondent's attitudes toward traffic congestion and personal car use

Although detailed investigation on the effectiveness of these policies has been carried out, it is still too early to decide the long-term effects. Thus, it is better to look at the question from the perspective of the vehicle drivers. As the users of the public roads, they have intuitive appreciation about the congestion situation and are aware of their own adaption behaviors to avoiding the car restrictions (Yang et al., 2014). As the traffic flows are the aggregate results of individuals' travel, their behavior change under these policies are essential to the effect of these policies. Therefore, they are aware whether the congestion and environment can be improved by these policies as it largely depends on whether and how they change their behaviors. From their responses, we can better understand the current situation, i.e., if the current policies are effective and if it is necessary to adopt new instrument. Therefore, we investigate drivers' attitudes toward congestion, personal car use and TDC in our survey.

As we mentioned in last section, one of the main parts of the questionnaire is participants' attitudes toward traffic condition and personal car use. Fig. 4 shows how they perceive the general traffic congestion situation in Beijing, the congestion problem in their personal car use and the impact of personal car use on environment. For the first question, more than 30% of respondents in Beijing think congestion is a very serious problem and choose the highest degree "7″. This ratio rises to nearly 60% when the second highest degree "6" is include. In contrast, less than 5% of participants think congestion is a very serious problem (the highest degree "7") in their personal car use, and there are 20% of participants who think congestion is a serious problem ("6" and "7") in their personal car use. This implies that the negative effect of congestion on the general traffic condition is much more serious than that on the personal car use. Given the serious congestion problem in Beijing, it may explain why the share of car trips is still so high. In term of environment issue, near 60% of respondents think personal car use is a problem on environment while less than 20% of participants think it is not. This is also consistent with the serious air pollution situation in Beijing.

Fig. 5 shows respondents' attitudes toward other issues, such as the symbolic character of personal cars, the pleasure of driving and so on. Nearly 50% of respondents think their cars can provide them status and prestige. On the other hand, about 60% of the respondents think driving can bring pleasure. Respondents' alternatives for car use and their attitudes toward other traffic instruments are also presented in Fig. 5. The third bar shows whether it is easy for respondents to choose other

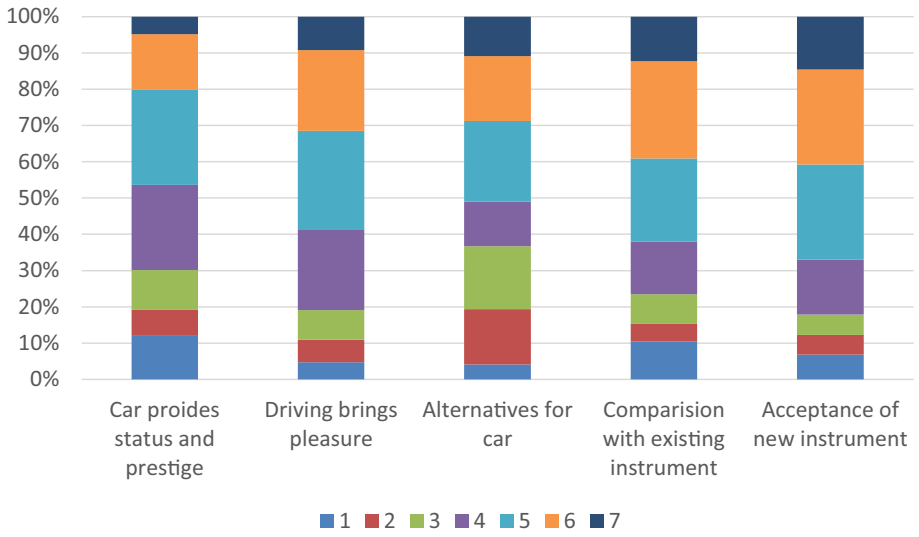

Fig. 5. Respondents' attitudes toward other questions.

travel modes, with "1″ means "very hard" and "7" means "very easy". The percentage of respondents who think it is easy for them to use other traffic modes is about 50%. This can be explained by the development of public transportation in Beijing. The fourth bar gives the comparison between TDC and the current policy. Respondents are asked to answer whether they think TDC can perform better than the plate number restriction. About 60% of the respondents believe the new instrument can perform better than plate number restriction. It is also interesting to notice that nearly 70% of the respondents think that the new instrument is generally acceptable. This may be caused by the difference of the congestion situation in Beijing, and some respondents think a new instrument is acceptable even it may not necessary to perform better than the existing instrument.

In sum, most respondents in Beijing think congestion and the environment issue caused by car use are very serious while much less of them believe the inconvenience caused by congestion in their personal car use is less serious. This indicates the cost caused by the congestion on the general traffic condition is larger than that on personal car use, which means negative externality exists for personal car use. In Beijing, personal cars are still a kind of symbol of individuals' status and prestige for a large proportion of people. Therefore, it may be hard to reduce the share of car trips even the development of public transportation provides convenient alternatives for personal cars. At the same time, most respondents in Beijing are open to new congestion mitigation instrument, mainly because of the serious congestion situation in Beijing. Thus, we will further analyze respondents' attitudes toward the new traffic instrument, TDC, and its potential effectiveness in the next section.

5. The potential effectiveness of TDC

From Fig. 5, we know that respondents in Beijing have a very high acceptance of the new traffic instrument, TDC. According to the results in Section 2 and Section 4, the effectiveness of the current vehicle restriction policies in long terms are unsatisfactory, and most respondents have negative attitudes to traffic situation and the effectiveness of the existing traffic measures. Respondents' high acceptance of the new instrument also verifies the seriousness of the problem and the urgent need for more effective congestion mitigation measures. Although nearly 70% of respondents think that TDC scheme is acceptable and nearly the same number of respondents believe that it can perform better than the current vehicle restriction policies, respondents' attitudes toward the effectiveness and the related equity issues reflected from this survey should draw our attention.

Fig. 6 illustrates respondents' attitudes toward the effectiveness and equity of the TDC scheme and its effect on personal benefits, which are also measured in a 7-point scale with an increasing degree. Generally, most respondents are positive about the effectiveness of TDC. About 60% of respondents believe TDC can reduce traffic congestion effectively, and almost the same number of respondents think TDC can reduce the impacts of personal car use on environment. Given the extremely congested situation in Beijing, these results are not surprising. As to the equity issue, nearly 65% of respondents think TDC is fair, and about 70% of respondents think it is fairer than the current vehicle restriction policy in Beijing. However, more than half of respondents think they will be worse off under the TDC scheme. In addition, nearly 60% of respondents perceive the TDC scheme as an infringement in their personal mobility. Theoretically, a proper design of TDC scheme can balance the efficiency and equity issues. Personal benefits and mobility freedom can also be ensured as drivers can easily trade their extra credits in the credit market. Therefore, it is as expected that respondents believe TDC is effective and fair. However, their doubts about the impact of the TDC scheme on personal benefit and mobility freedom need to be paid attention to.

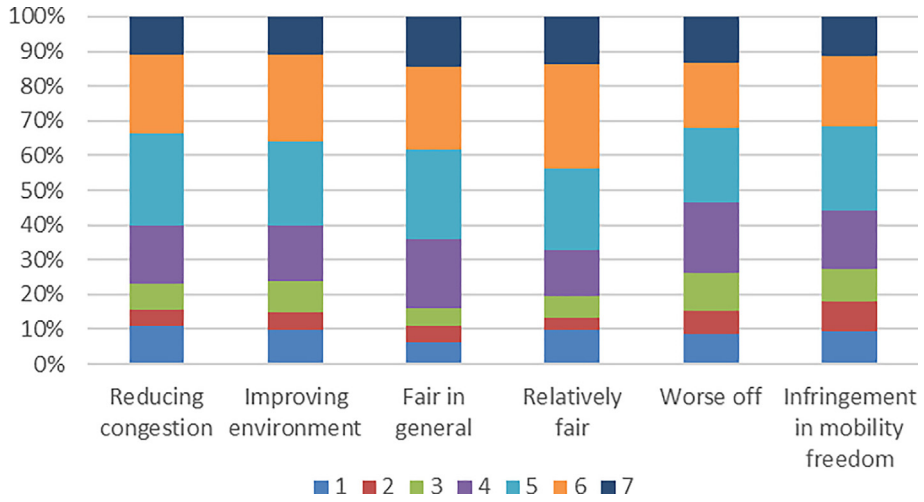

Fig. 6. Respondents' attitudes toward TDC scheme.

To further verify its effectiveness, respondents were given two TDC scenarios, and were asked to make travel choices under these scenarios. All the respondents were first given more credits than their demand, and then less credit than their demand. Respondents were asked to choose if they would increase/decrease car use, or make no change. When they were given more credits than demand, about 23% of respondents increased car use, about 37% of respondents reduced car use, and 40% of respondents did not change; when they were given less credit than demand, about 12% of respondents increased car use, 46% of respondents reduced car use, and 42% of respondents kept unchanged. Therefore, there are in total 60% of respondents making changes when they were given more credit than demand while 54% of respondents made changes when they were given less credit than demand. What's more, quite a few of respondents increased their car use even they received less credits than their demand.

Fig. 7 illustrates the relationship between respondents' willingness to change and their social-economic characters. The impacts of respondents' gender and income level on their willingness to change are marginal. When they are given less credits than their demand, the ratio of male respondents choosing "increasing car use" is lower than that of female respondents, while more male respondents chose "decreasing car use" than female respondents. Most of the respondents with high income (income greater than 6000 ¥) chose "making no change" in both scenarios. The ratio of respondents with high income choosing "increasing car use" is lower than that of respondents with low income in both scenarios. Both education and household size have larger impacts on respondents' willingness to change. The percentage of respondents with university education is very large (77.9%) in the sample. Removing this effect, the ratio of respondents with university education chose "increasing car use" is still very high in both scenarios, while the ratio of respondents without university education is very high in "making no change". On the other hand, the percentage of respondents with big household (family size greater than 2) is also very large (80.5%). Considering this, the ratios of respondents with small household choosing "make no change" are high in both scenarios, while the ratios of respondents with big household are high in both "increasing car use" and "decreasing car use" when they are given less credits.

Fig. 8 illustrates the relationship between respondents' willingness to change and their attitudes towards personal car use. Most of the respondents choosing "increasing car use" believe in the symbolic meaning of personal cars (more than two thirds), i.e., cars provide status and prestige, and driving brings pleasure. About a third of the respondents choosing "making no change" think personal cars provide status and prestige. In contrast, about half of the respondents choosing "making no change" think driving gives them pleasure. The impact of the alternative travel modes on respondents' willingness to change is small, especially when they are given more credits than demand. About half of the respondents think it is easy to use other modes in all the cases for both scenarios.

To find out the underlying causes of people's choices, we further analyze the influencing factors of respondents' behavior change with TDC, and hope the results can provide insights about the effectiveness of the traffic policy. The analyses are based on respondents' attitudes towards congestion, personal car use, and the effectiveness and equity of the TDC. Besides the questions we talked about in last section, respondents are given some other questions related to TDC. About the effectiveness of the instrument, respondents are asked "Do you think TDC will reduce congestion?" and "Do you think TDC will reduce the impact of car use on environment?"; about the equity, they are asked "Compared to plate number restriction/per kilometer charge, do you think TDC is fairer?" and "In general, do you think TDC is fair"; and about personal benefits, "Do you think you will in general be worse off with TDC?" and "Do you perceive TDC as an infringement in your personal mobility freedom?". Every problem is measured in a 7-point scale. We use the "making no change" as the base outcome in the two TDC scenarios. Besides respondents' attitudes toward congestion, TDC and personal car use, their socio-economic character-

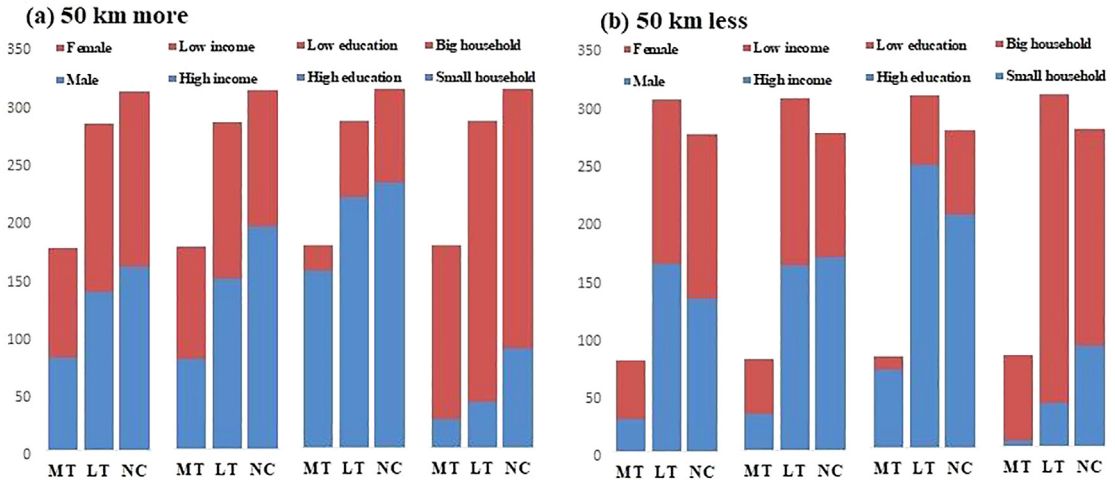

Fig. 7. Respondents' willingness to change under TDC scheme and their social-economic characters ("MT": increasing car use, "LT": decreasing car use, "NC": making no changes).

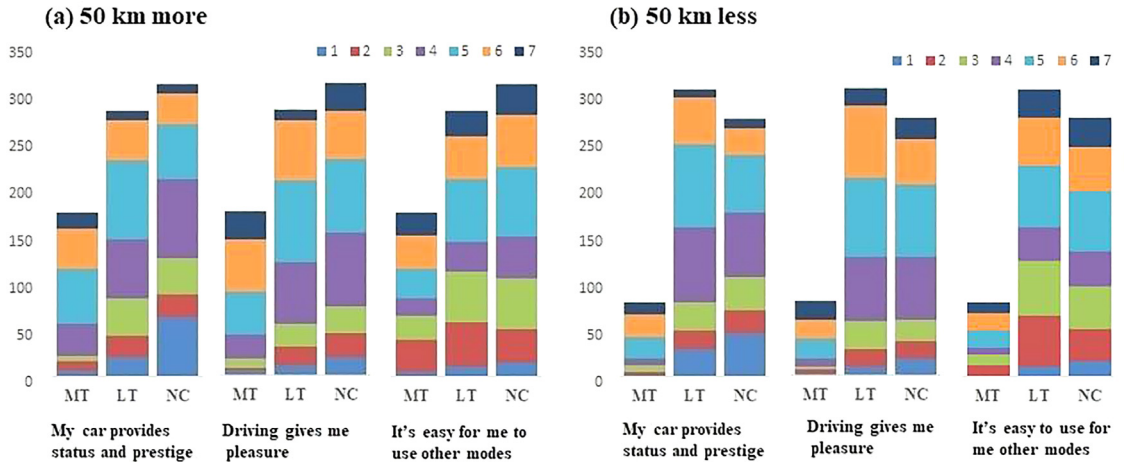

Fig. 8. Respondents' willingness to change under TDC scheme and their attitudes towards personal car use ("MT": increasing car use, "LT": decreasing car use, "NC": making no changes).

istics are also incorporated into the regression analysis. The estimation results of respondents' behavior change under TDC is presented in Table 2.

From Table 2, participants' social-economic characters, such as income level, education level and family sizes all have significant effect on their behaviors in the TDC scenarios. As some of the questionnaires are online and some of them are collected on street, we first test the impact of the data collection method. The result shows that collected online has no significant effect on the respondents' behavior change. We now further analyze the impacts of respondents' social-economic characters. When respondents are given less credit than their demand, male respondents are more likely to reduce car use. Higher income level has negative effect on the increase of car use in the first scenario, i.e., when there are given 50 km more credit than their demand. In other words, people with higher income level has lower willingness to increase their car use because of receiving more credit. This may be because these people have already driven enough kilometers in their previous travel pattern, and thus feel unnecessary to further increase car use.

On the other hand, big household size also has positive effect on respondents' behavior change in both scenarios. Big family usually means the presence of children and the elder. It is as expect that it has positive impact on the increase of car use. However, it is quite strange that it also has positive impact on the reduction of car use when respondents are given less credit than their demand. To explain this, we test the interactions between big household size and other variables. It turns out there are interaction effect between big household size and high income. Compared to low income and small household size, low income and big household size has positive effect on the reduction of car use in both scenarios. This may be because that bigger families usually have much more car use in their daily life, and thus have more room to reduce. Given the same low-income level, participants with bigger household size thus tend to reduce car use to get the profits (reduce the costs)

Table 2
The estimation results for respondents' car use change under TDC scheme.

	50 km more		50 km less	
Variables	Increase	Reduction	Increase	Reduction
Data collection method				
Collected online	0.0221	0.424	1.132	0.177
Social-economic characters				
Male	0.0538	0.0313	−0.194	0.311*
Income>¥6000	−1.051*	0.524	−0.859	0.463
Household larger than 2 persons	0.860*	0.436	2.005**	0.706**
Income<¥6000 # Household larger than 2 persons [a]	−0.0763	1.060**	0.156	1.068**
University education (bachelor and graduate)	1.173***	0.273	0.910**	0.497**
More than one car	0.465	−0.0657	−0.0611	−0.0151
Personal attitudes				
Congestion is a serious problem in Beijing	−0.0631	0.00193	−0.0805	0.00306
Congestion is a serious problem in personal car use	0.104	0.0288	0.112	0.123
Car use is a serious problem in environment	−0.183*	−0.159*	−0.315**	−0.134
TDC can reduce congestion	0.106	0.0609	−0.136	0.165
TDC can reduce car use impact on environment	−0.0732	0.192*	0.0721	0.0593
TDC can better reduce congestion than car plate restriction	−0.000407	0.159	−0.0269	−0.103
TDC is fairer than car plate restriction	0.00876	0.0451	0.0975	0.0426
I will be worse off with TDC	−0.0529	0.00971	−0.0463	−0.0488
TDC is an infringement in my mobility freedom	−0.0838	0.00526	0.0682	0.0639
TDC is fair in general	0.0727	0.139	−0.135	−0.0247
TDC is acceptable in general	0.0486	−0.186*	0.294*	0.0673
It's easy to use other modes	−0.0948	−0.0953	0.0629	−0.0635
My car provides status and prestige	0.448***	0.178**	0.510***	0.152**
Driving gives me pleasure	0.171*	−0.171**	0.0277	−0.0679
Credit price	0.322**	0.266**	0.231	0.0734
Constant	−4.037***	−2.999***	−6.792***	−2.915***
Observations	660	660	660	660

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

[a] 'Income<¥6000 # Household no more than 2 persons' is the base outcome; other categories ('Income>¥6000 # Household no more than 2 persons', 'Income>¥6000 # Household larger than 2 persons') are omitted because of collinearity.

of selling (buying) extra credit. University education level has positive effect on the increase of car use in both scenarios, which is not surprising. However, it also has positive effect on the reduction of car use when respondents are given less credit than demand. Given the large percentage of respondents with university education (77.9%) in this survey, more research should be done about the impact of high education. The number of car owned have no significant effect on respondents' behavior change.

It can be observed that the traffic congestion condition in the city and on personal car use have no effect on respondents' willingness to change. However, the impact of car use on environment has subtle effect on their behavior change. It has negative impact on the increase of car use in both scenarios, which implies that would like to restrain the increase of car use for the environment. But when respondents have more budget than demand, it also has negative impact on the reduction of car use. Given the poor air quality in Beijing, this may be because respondents prefer to stay in their car when they have adequate credit budget. When they are given more credit than demand, the belief that TDC can reduce the impact of car use on environment has a positive effect on the reduction of car use when they are given more credit than demand. On the other hand, the belief that TDC scheme is acceptable in general has a positive effect on respondents' increase of car use when they are given less credits than demand, and has a negative effect on their reduction of car use when they are given more credits than demand. However, respondents' attitudes toward the effectiveness and the fairness of the TDC scheme have no significant effect on their behavior change. Further, respondents' welfare and mobility freedom with the TDC scheme do not affect their behavior significantly, either.

The symbolic meaning of personal cars also has positive effect on respondents' behavior change. Respondents who think car can provide status and prestige are more likely to increase car use, which is not surprising. However, it is unexpected that the belief that car provides status and prestige also has positive effect on people's willingness to reduce car use, although the effect is not as significant as that on the increase of car use. This may be because respondents who believe in the symbolic meaning of personal cars usually drive more frequently and have more unnecessary car use, and thus have more room to reduce. At the same time, respondents who think driving brings them pleasure are more likely to increase car use, and are much less likely to reduce car use when they are given more credit than demand, which are as expected. But when respondents receive less credit than demand, this variable does not have significant effect on their behavior change, which is not surprising either. Respondents' behavior change is sensitive to credit price when they receive more credit than demand. But when they get less credit than demand, credit price has no significant effect on their behavior change. When they receive more credit than demand, credit price has a positive effect on the increase of car use as well as on the reduction of car use, which is strange.

Based on the above analyses, respondents' behavior change in TDC scenarios is mainly affected by people's social-economic characters and the symbolic meaning of personal cars. High income level has negative effect on the increase of car use when respondents have more credit than demand. Big house size has positive effect on the increase of car use in both scenarios. However, it also has positive effect on the reduction of car use when respondents have less credit than demand. This is because there is interaction effect between income and household size. Respondents with bigger household size and low income are more likely to reduce car use when they get less credit than demand. Whether personal cars provide status and prestige is also an important influencing factor in their behavior change. It has positive impact on both the increase and the decrease of car use. One reason for its effect on the reduction is that these respondents may have more unnecessary car use in their daily life, and thus have more room to reduce. On the other hand, the belief that driving brings pleasure has positive effect on the increase of car use, and negative effect on the reduction of car use in the scenario of receiving more credit than demand. The impact of car use on environment and the effectiveness of TDC on improving environment condition have weak effects on their behavior change. However, the general congestion situation, the effectiveness and fairness of the TDC measure, and respondents' benefits change under the measure have no significant effect.

6. Conclusions

The effectiveness of existing traffic regulation measures in Beijing has reviewed based on the available reports from the authorities. It has shown that the car ownership restriction has effectively limited the vehicle population in Beijing, while the car use restriction got effect immediately but cannot last long. Given the numerous traffic regulation measures in Beijing, the traffic situation is under control now. Based on the Beijing Annual Traffic Analysis Report, the traffic in Beijing was slightly congested in recent years, with an average congestion index of 5.6 in both 2016 and 2017. However, respondents' feeling about congestion is much more serious in the survey on drivers' attitudes towards congestion and traffic regulation measures in Beijing. Nearly 60% of respondents chose "serious" and "very serious" when they were asked about the congestion situation in Beijing.

We also find that the negative effect of congestion on the general traffic condition is much more serious than that on the personal car use. Although most respondents believe that the traffic congestion in Beijing is serious, only 20% of the respondents think congestion is a serious problem in their personal car use. Given the serious congestion situation in Beijing, it may explain why the share of car trips is still so high. In addition, personal cars are regarded as a kind of symbol of individuals' status and prestige for a large proportion of people in Beijing, and more than half of the respondents think driving brings them pleasures. This indicates that it may be difficult to further reduce the share of car trips even the public transportation provides convenient alternatives for personal cars, which is confirmed by traffic data in recent years. Given the rapid development of public transportation, the share of Green Travel only had very slight increase in the last three years.

Due to the serious congestion situation in Beijing, most respondents in Beijing are open to new congestion mitigation instruments. About 60% of respondents think TDC can help reduce congestion and improve environment. The influencing factors of respondents' behaviour change with TDC are analysed. Generally, individuals' social-economic characters such as income level and family size have significant effect on respondents' behavior change under TDC scheme. However, the general congestion condition, the effectiveness and equity of TDC, and the individuals' benefits change under TDC have no effect on the issue. The symbolic meaning of personal cars is also an important influencing factor in their behavior change. The impact of car use on environment and the effectiveness of TDC in improving environment condition have weak effects on their behavior change.

Given the fact that the traffic congestion is still very severe, more effective congestion mitigation measures are in urgent need in Beijing. This is further supported by respondents' high acceptance of the new instrument. As the negative effect of congestion on the general traffic condition is much more serious than that on the personal car use, new instruments should improve the private travel cost of personal car use. At the same time, it is helpful to improve the public's awareness about environment issues caused by traffic congestion, and emphasize the effectiveness of the new instruments on improving environment. As shown in the analyses, these two terms have positive effects on improving people's willingness to change under TDC. In addition, the symbolic meaning of personal cars plays an important role in people's willingness to change in Beijing. Therefore, it is important to advocate the positive effects of taking green transport, such as public transportation and cycling. Furthermore, the design of new instruments should also take into account of the social-economic attributes of drivers, such as income level, education level and household size.

Acknowledgments

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Appendix A. The reliability and validity of the questionnaire

To test the reliability of the questionnaire, Table 3 presents the Cronbach's Alpha of the questionnaire and the Cronbach's Alpha if one item is deleted. It can be observed that the value of the Cronbach's Alpha is above 0.8, which suggests that it has

Table 3
Reliability analysis of the questionnaire.

Reliability Statistics	
Cronbach's Alpha	Number of Items
,806	22

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
You will get 50 km more credits than your demand. How will you arrange your car trips?	74,82	178,243	-,185	,816
You will get 50 km less credits than your demand. How will you arrange your car trips?	74,70	177,631	-,172	,814
Congestion is a serious problem in Beijing	71,00	167,910	,173	,807
Congestion is a serious problem in personal car use	71,44	160,223	,401	,797
Car use is a serious problem in environment	71,41	156,494	,457	,793
TDC can reduce congestion	72,45	140,891	,742	,773
TDC can reduce car use impact on environment	72,41	141,535	,730	,774
TDC can better reduce congestion than car plate restriction	72,36	140,618	,732	,773
TDC is fairer than car plate restriction	72,18	144,307	,654	,779
I will be worse off with TDC	72,51	161,646	,230	,808
TDC is an infringement in my mobility freedom?	72,56	157,868	,312	,803
TDC is fair in general	72,16	148,067	,617	,783
TDC is acceptable in general	72,14	146,286	,643	,780
It's easy for me to use other modes	72,69	162,697	,212	,809
My car provides status and prestige	72,90	154,212	,435	,794
Driving gives me pleasure	72,35	158,300	,374	,798
Income>¥6000	76,45	175,304	-,041	,810
University education (bachelor and graduate)	76,22	174,073	,070	,808
Household larger than 2 persons	76,19	174,489	,035	,808
Male	76,51	175,495	-,055	,810
More than one car	76,48	170,699	,311	,803
	75,00	173,586	,035	,810

a high internal consistency of the questionnaire, and also, the questionnaire is reliable for the purpose of collecting data. For all items, the values of the Cronbach's Alpha if item is deleted are all around 0.806, which suggests all of them should be included in the questionnaire.

Table 4 gives the results of the factor analysis of the questionnaire. It can be observed that the KMO value is 0.792, and the observed significant level of the Bartlett's test is 0.000. It is concluded that the strength of the relationship among variables is strong. Therefore, we can proceed for factor analysis of the data. Among the 21 items, there are seven main factors, and they account for more than 70% of the total variance, which suggests that these seven main factors can sufficiently extract and explain the information of the variables. According to the Rotated Component Matrix, each item mainly contributes to only one main factor, which suggests it is valid to include all the items in the questionnaire.

Table 4
Exploratory factor analysis of the questionnaire.

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		,791
Bartlett's Test of Sphericity	Approx. Chi-Square	6598,497
	df	231
	Sig.	,000

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5,449	24,769	24,769	5,449	24,769	24,769	4,607	20,940	20,940
2	2,010	9,134	33,903	2,010	9,134	33,903	2,008	9,127	30,067
3	1,828	8,310	42,213	1,828	8,310	42,213	1,897	8,621	38,688
4	1,786	8,119	50,332	1,786	8,119	50,332	1,844	8,384	47,071
5	1,550	7,047	57,378	1,550	7,047	57,378	1,753	7,968	55,039
6	1,231	5,595	62,973	1,231	5,595	62,973	1,506	6,845	61,885
7	1,106	5,029	68,002	1,106	5,029	68,002	1,273	5,788	67,673
8	1,005	4,570	72,571	1,005	4,570	72,571	1,078	4,898	72,571
9	0,907	4,122	76,693						
10	0,820	3,726	80,419						

(*continued on next page*)

Table 4 (*continued*)

Total Variance Explained			
11	0,719	3,269	83,689
12	0,660	3,000	86,688
13	0,524	2,382	89,070
14	0,441	2,006	91,077
15	0,416	1,889	92,965
16	0,400	1,820	94,785
17	0,289	1,315	96,100
18	0,224	1,017	97,117
19	0,203	0,924	98,041
20	0,159	0,721	98,762
21	0,149	0,676	99,438
22	0,124	0,562	100,000

Extraction Method: Principal Component Analysis.

Rotated Component Matrix[a]

	Component							
	1	2	3	4	5	6	7	8
You will get 50 km more credits than your demand. How will you arrange your car trips?	−0,133	0,040	0,020	−0,004	**0,755**	−0,192	0,014	−0,193
You will get 50 km less credits than your demand. How will you arrange your car trips?	−0,111	0,033	−0,036	−0,048	**0,817**	−0,103	0,049	−0,056
Congestion is a serious problem in Beijing	0,002	**0,801**	0,009	0,004	0,031	−0,126	0,138	−0,004
Congestion is a serious problem in personal car use	0,190	**0,799**	0,056	0,147	−0,035	0,026	−0,014	−0,014
Car use is a serious problem in environment	0,298	**0,759**	0,081	−0,016	0,010	0,131	−0,009	−0,006
TDC can reduce congestion	**0,854**	0,166	0,056	0,056	−0,089	0,119	−0,059	0,013
TDC can reduce car use impact on environment	**0,841**	0,136	0,056	0,070	−0,048	0,167	−0,101	0,042
TDC can better reduce congestion than car plate restriction	**0,885**	0,086	0,068	0,023	−0,042	0,129	−0,038	0,057
TDC is fairer than car plate restriction	**0,873**	0,051	0,020	−0,085	−0,063	0,109	−0,004	0,045
I will be worse off with TDC	0,011	0,102	−0,010	**0,919**	0,022	0,057	−0,032	0,052
TDC is an infringement in my mobility freedom?	0,126	0,026	0,003	**0,908**	−0,024	0,100	−0,034	−0,005
TDC is fair in general	**0,758**	0,073	0,028	0,141	−0,076	−0,002	0,085	−0,032
TDC is acceptable in general	**0,827**	0,068	0,050	0,024	−0,084	0,030	0,031	−0,059
It's easy for me to use other modes	0,079	0,084	**0,953**	−0,013	0,020	0,073	−0,001	−0,017
My car provides status and prestige	0,321	−0,020	0,078	0,204	−0,194	**0,723**	0,027	−0,040
Driving gives me pleasure	0,251	−0,069	0,141	0,148	−0,099	**0,718**	0,171	−0,132
Income>¥6000	−0,030	−0,006	−0,078	−0,067	0,236	0,040	**0,792**	−0,069
University education (bachelor and graduate)	−0,034	0,165	0,104	−0,013	−0,232	0,003	**0,683**	0,206
Household larger than 2 persons	0,057	0,080	−0,080	−0,063	**−0,564**	−0,124	0,046	−0,338
Male	0,061	−0,151	0,032	0,201	−0,059	**−0,523**	0,302	−0,292
More than one car	0,109	0,046	**0,954**	0,008	0,018	0,072	0,017	0,008

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Rotation converged in 6 iterations.

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