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Will a Driving Restriction Policy Reduce Car Trips?

A Case Study of Beijing, China

Lanlan Wang, Jintao Xu, Xinye Zheng, and Ping Qin

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Abstract

A driving restriction policy, as a control-and-command rationing measure, is a politically acceptable policy tool to address traffic congestion and air pollution in some countries and cities. Beijing was the first city in China to implement this policy. A one-day-a-week driving restriction scheme was expected to take 20 percent of cars off the road every weekday. Using household survey and travel diary data, we analyze the short-term effect of the driving restriction policy on individual mode choice. The data also allow us to identify which demographic groups are more likely to break the rules. The estimates reveal that the restriction policy in Beijing does not have a significant influence on individual driving choices, as compared with its influence on public transit. The rule-breaking behavior is constant and pervasive. We found that 47.8 percent of the regulated car owners didn't follow the rules and drove "illegally" to their destinations. On average, car owners who traveled during peak hours or for work trips, and those whose destinations were farther away from the city center or subway stations, were more likely to break the rules.

Key Words: driving restriction policy, Beijing, mode choice, rule breaker

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Lanlan Wang, Jintao Xu, Xinye Zheng and Ping Qin*

Introduction

In preparation for the 2008 Olympics, Beijing imposed rules barring cars from the central city, based on license plate number, in order to control congestion and pollution. These temporary restrictions were followed by similar restrictions that remained in place after the Olympics were over. This study uses individual trip diary data to study the impact of this driving restriction policy on individual travel mode choices and rule breaking behavior in Beijing. When cities in other countries have adopted similar restrictions, their efficiency has been controversial. For Beijing, we find short-term benefits, but also a pattern of rule-breaking and loss of these benefits over time, as residents adapted by changing travel times, buying a second car with a different license plate, or simply violating the rules.

Economists generally believe that congestion pricing is a more efficient strategy than "command and control" rationing to reduce pollution and congestion (see, e.g., Small and Gomez-Ibañez, 1998; Small and Verhoef, 2007). However, the public does not want to pay to use public roads and often regards rationing as more equitable. (Rouwendal and Verhoef, 2006; de Grange and Troncoso, 2011). Driving restrictions have become a more politically acceptable policy tool, in particular favored by policy makers in developing countries. In 2007 and 2008, Beijing introduced temporary odd-even license plate restriction policies to support international sporting events, especially the 2008 Olympics. Evidence of reductions in congestion and mobile source pollution during this period were confirmed (e.g., Wang et al., 2009). The benefits

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seemed so attractive that Beijing soon decided to resume a similar, but less restrictive, one-day-a-week licensing scheme (Wang, 2010). This policy was generally supported by local residents.

We are interested in two research questions. The first is to answer whether the driving restriction policy is effective enough in the short run to justify its implementation. The driving restriction policy in Beijing was expected to take 20 percent of cars off the road on every week day. Did this expectation turn to be true in the real world? Are car owners discouraged from using cars because of this policy? If so, to what degree? Second, if, instead, car owners are motivated to find different ways to circumvent driving restrictions, we want to identify who would be more likely to be the "bad guys" or rule breakers? To our knowledge, this is the first empirical study to investigate rule-breaking behavior in this context. The dataset used in this paper is unique, which gives us a comparative advantage in analyzing the characteristics and determinants of individual choice of transportation mode, and allows us to evaluate the short-term effects of a driving restriction policy in one of the largest cities in China. Given that transportation research in this prominent transitional economy has been under-studied in the literature, this paper can provide preliminary and original evidence to understand how the rationing policy would shape individual travel behavior in a developing country.

The rest of the paper is organized as follows. The second section provides a literature review and empirical evidence on the effectiveness of driving restrictions in general. The third section provides background on driving restrictions in Beijing. The fourth section describes the survey data. The fifth section presents a regression analysis of the efficiency of the driving restriction policy. The sixth section analyzes the characteristics of the rule-breakers. The final section is the conclusion.

Empirical Evidence on Driving Restrictions Worldwide

Early in the 1970s, Buenos Aires, the capital and the largest city of Argentina, banned one-half of automobiles from entering the city center on a given day based on odd or even last digit of the plate number. A similar restriction program was also used in in the 1980s in Caracas, the capital and largest city in Venezuela, and then in Athens between 1985 and 1991 (de Grange and Troncoso, 2011, p. 863). In Mexico City, a one-day-per-week driving restriction from 5:00 a.m. to 10:00 p.m. every weekday was introduced in 1989. Sao Paulo in Brazil, Bogota and Medellin in Colombia, and Santiago in Chile all joined Mexico in introducing driving restrictions to reduce automobile use.

Beijing was the first city in China to implement a driving restriction policy in order to control traffic volume and air pollution. More recently, several Chinese cities from north to south, including Changchun, Lanzhou, Hangzhou, Guiyang, and Chengdu, began to rely on driving restrictions to alleviate traffic congestion.

Economists generally believe that congestion pricing is an effective strategy to reduce car-related problems (e.g., Small and Gomez-Ibañez, 1998; Small and Verhoef, 2007). However, in practice, the public is not willing to pay a higher price to use public roads, even if they would benefit both from reduced congestion and from the transportation-related public goods and services provided with the corresponding revenues (Rouwendal and Verhoef, 2006, p. 106). Meanwhile, the rationing policy is also regarded as a more equitable way than road pricing to reduce traffic congestion (Rouwendal and Verhoef, 2006; de Grange and Troncoso, 2011), as every automobile owner is required to follow the same restrictions. As a consequence, congestion pricing is not readily accepted by the public (Schade and Schlag, 2003; Schuitema, et al., 2010). Instead, rationing, such as driving restriction measures, has become a more politically acceptable policy tool to address congestion problems, and is favored, in particular, by policy makers in developing countries.

However, some theoretical and empirical research has argued against the driving restriction policy, "calling it unjust and inefficient" (de Grange and Troncoso, 2011). It is inefficient due to either non-compliance or compensating responses, such as changing driving times (inter-temporal substitution) or adding a second vehicle with a different license plate. The restrictions do not take into account individual preferences – in other words, different individuals' willingness to pay different amounts to make trips that are personally important to them (de Grange and Troncoso, 2011). In addition, residents who live far away from subway stations or bus stops have less chance than others to find substitutes for car trips. As a result, it is more likely that they might break the rules to make certain trips.

In most developing countries, the public transport system is a very imperfect substitute for cars. This might induce drivers to adapt to the restrictions by purchasing additional cars (Goddard, 1997; 1999). Evidence from Mexico City has shown that wealthy people are able to buy second cars with different license plates to circumvent the ban, and therefore, total car use in Mexico City has, in fact, increased (Eskeland and Feyzioglu, 1997). These additional cars were typically older and generated more pollution, which in turn made air pollution even worse (Eskeland and Feyzioglu, 1997, p. 399-400). Their study also illustrated that "rationing entails welfare costs at least as high as those of a market-based mechanism producing the same reduction in trips" (p. 384). Gallego et al. (2012) found similar results in Mexico and Santiago.

Based on hourly concentration records of carbon monoxide, their results "show that policies that may appear effective in the short run can be highly detrimental in the long run, i.e., after households have adjusted their stock of vehicles" (p. 1). Even if no one bought extra cars and everyone fully abided by the license plate restriction, as one reviewer pointed out, the reduced traffic in the short run would increase travel speed, thus encouraging more travel by those who are legally allowed to drive on a particular day. The principle of "trip convergence" would then guarantee that any strategy not based on pricing will eventually lead to the same congestion levels as before and thus be quite ineffective (Downs, 2004).

Beijing is not an exception to the unintended consequences of a driving restriction policy. People have a natural preference for fast and convenient transportation and will find ways to circumvent rationing programs of this sort (Davis, 2008). In Beijing, people have invented "surprising" ways to circumvent the driving restriction program. For example, they covered plates, or borrowed plates or cars from others on the days their cars were banned. Some of them set out earlier in the morning to beat the 7:00 a.m. cutoff. Or they simply ignored the restriction rules. In a cross-country comparative study that included Beijing, Lin et al. (2011) found that, when driving restrictions are effective only during certain weekday hours, people are likely to change the times at which they drive. According to the Beijing Transportation Research Center (Legal Evening Paper[1], 2011), the congestion index in Beijing decreased from 7.95 in 2007 (the year before the restriction was formally implemented) to 5.93 in 2009 (the year after). However, this index value quickly jumped back to 7.80 in 2010. Possible reasons might include both non-compliance and the purchase of more vehicles. One survey found that 50% of families with one car planned to purchase a second car to circumvent this policy. Data from the second-hand car market also show that sales of cheap used cars, valued at less than 80,000 RMB, doubled after the restriction policy, and their price increased by at least 15%. Nevertheless, it has been reported in other cities that driving restriction policies were effective in controlling car trips in the short term, although non-compliance was near universal (de Grange and Troncoso, 2011, p. 864).

Development of the Driving Restriction Policy in Beijing

As the capital city of China, Beijing has experienced explosive growth during the last three decades. Between 1990 and 2010, total population in Beijing increased from 6.995 million

[1] http://auto.163.com/11/0120/08/6QR0PQS300084IKO.html

to 11.87 million. The developed area in the city proper increased from 397 square kilometers to 1,186 square kilometers, and GDP per capita grew from 4,653 RMB to 78,047 RMB during the same period[2]. Market reforms, increased population and rising wealth have fuelled strong demand for mobility, which in turn has reshaped the lifestyle of residents. The total number of automobiles[3] in Beijing jumped sharply from 2.583 million in 2005 to 4.809 million in 2010, of which about 3.207 million were owned by individual households. The annual growth rates for automobiles and private automobiles reached 13.2 percent and 19 percent respectively. The total number of daily trips made by the residents inside the 6th ring road[4] of Beijing was 41.30 million in 2010, of which 9.93 million (24 percent) were made by automobiles, and 11.53 million by public transit (27 percent) (Beijing Transportation Research Center[5], 2011a).

However, this rapid increase in mobility comes at a high price. Beijing is already one of the world's most polluted cities in terms of air quality, and vehicular emissions contribute heavily to levels of hazardous local air pollutants, such as carbon monoxide (CO), oxides of nitrogen (NOx), and volatile organic compounds (VOCs). The city has been named the most congested in the world by numerous international organizations. According to a city-wide travel survey, average travel speed on workdays in Beijing in 2010 was 11.70 kilometers per hour for all travel modes, and 18.67 kilometers per hour for automobiles (Beijing Transportation Research Center[6], 2011b). These average speeds were far below the average travel speed in New York State in 2009, which is 42 kilometers per hour[7]. The extensive economic costs of this severe congestion and its negative externalities have also been well-documented. For example, one study conducted by Creutzig and He (2009) estimated that, in Beijing, the annual social costs

[2] China Economic Information Network, 2010, City Census Data.

[3] Automobiles include automobiles owned by private individuals, as well as automobiles owned by companies or institutions. In 2010, about 33 percent of automobiles registered in Beijing were owned by companies or institutions. The rest of the automobiles were owned by individuals or families (Beijing Transportation Research Center, 2011a, p. 17).

[4] Beijing is one of the very few cities to possess multiple ring roads, or "beltways" (Wikipedia). It is now served by six circumferential or loop routes which encircle the city center. The loop route nearest to the city center is the 2nd ring road, and the ring road furthest away from the city center is the 6th ring road, as shown Figure 1 in this paper.

[5] Beijing Transportation Research Center, 2011a, *The Fourth Comprehensive Transportation Survey in Beijing*.

[6] Beijing Transportation Research Center, 2011b, *Analysis of Travel Behavior of the Residents in Beijing*.

[7] https://www.dot.ny.gov/divisions/policy-and-strategy/darb/dai-unit/ttss/repository/ComparisonRpt09-95-011107.pdf

of congestion in terms of value of time were 22.8 billion RMB8 for car drivers, while the value of time lost in bus transportation amounted to 5.8 billion RMB annually. The Xinhua news reported that annual congestion costs in Beijing reached 72 billion RMB, 5% of regional GDP9.

All this raises the question of what to do about the congestion. In answer to this question, the Beijing Municipal Government has adopted a series of policy instruments in an attempt to reduce the negative transport externalities so apparent in the city. From the supply side, the municipal government invested a total 240.5 billion RMB over 4 years (from 2006 to 2010) to build five new subways (Beijing Transport Annual Report, 2012), with a total length of 130 kilometers. Yet, this enormous investment and rapid expansion of public transportation facilities are still unable to keep pace with the travel needs of the residents. From the demand management side, the municipal government implemented both regulatory and market based policy instruments. The objective of these policies is to reduce traffic volume by controlling automobile ownership (lottery policy[10]), restricting car use (driving restriction policies), or increasing the cost of private transport (such as parking fees and fuel taxes) to push residents to switch from private automobiles to public transit. In 2007, the Beijing municipal government reduced the regular bus fare by 60% and set the subway price at 2 RMB for a trip, with unlimited transfers among almost all subway lines except for the airport express line. This policy was intended to make the bus or subway economically more attractive to travelers and to make public transit more affordable to low-income people. However, there is little evidence that the policy has had any substantial effect on bus ridership (Qin et al., 2013). In 2011, Beijing started to charge higher parking fees in non-residential areas in order to divert cars away from commercial districts and busy routes. Parking fees for roadside parking are now set for 10 RMB for the first hour and 15 RMB for each additional hour. Underground parking now costs 6 RMB per hour, and off-street parking costs 8 RMB per hour. The government data shows that the short term effect of this parking policy is substantial. The congestion index during peak hours was reduced to 4.4 within one month after the implementation of this policy, a 26.9% decrease over the same period in

[8] US$ 1 = Yuan 6.83, at the 2009 exchange rate; US$ 1 = Yuan 6.77, at the 2010 exchange rate.

[9] http://news.xinhuanet.com/local/2010-10/15/c_12664091.htm

[10] The lottery policy requires potential automobile buyers to participate in a lottery in order to obtain new purchase permits and license plates. The Beijing municipal government introduced this regulation at the end of 2010 to curb the growth of new vehicle sales by limiting the number of license plates issued each year.

2010. In addition, average daily transit ridership was increased by 3.3%[11]. Nevertheless, among all of these transportation policies, the driving restriction policy and lottery policy stand out as the two most prominent instruments favored by the Beijing municipal government.

In Beijing, the driving policy was first introduced on August 17, 2007. It lasted four days as a trial run for the 2008 Olympic Games. The program restricted automobiles to be driven on alternate days from 6:00 a.m. until midnight, depending on whether the last number of the license plate was even or odd. This restriction was enforced in the entire city of Beijing (including suburban areas and the countryside), and the drivers who broke this rule were fined 100 RMB per day and required to drive back to their place of origin. It was estimated that this four-day experimental restriction took about 1.30 million automobiles off the roads[12].

From July 20 to August 27, 2008, the same driving restriction rules were used again to control traffic and air pollution in support of the Olympics. But the restriction time was extended from 3:00 a.m. to midnight. After the Olympics, evidence of reductions in congestion and mobile source pollution encouraged the municipal government to continue with a similar but less restrictive program. From August 28 to September 20, 2008, the driving restriction boundary area was redefined as the 5th ring road. This suggests that the program was only applied to the urban areas inside, and including, the 5th ring road. With this program, it was predicted that 70 percent of about 300,000 cars registered in Beijing would be taken off the roads during the two-month restriction period[13].

On September 28, 2008, Beijing officials announced a new driving restriction measure to be enforced from October 11, 2008 to April 10, 2009. This new measure put last digit numbers of the license plates into five groups: 1 and 6, 2 and 7, 3 and 8, 4 and 9, and 5 and 0. Private automobiles with the last digit numbers in each group were forbidden from using the road inside, but excluding, the 5th ring road on a designated week day from 6:00 a.m. to 9:00 p.m. The assignment of these pairs to weekdays was rotated every month. In addition, the new measure banned 30 percent of government and corporate vehicles on each weekday. Emergency vehicles, mass transit vehicles, and public service vehicles were exempted from these restrictions, but they were few in number.

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[11] http://auto.ifeng.com/usecar/traffic/20110510/607017.shtml

[12] http://news.xinhuanet.com/newscenter/2008-07/23/content_8756737.htm

[13] http://www.nytimes.com/2008/06/21/world/asia/21china.html

On April 5, 2009, Beijing announced that driving restrictions would continue for another year, with minor changes in the restriction time and rotation period. The restriction time was changed to 7:00 a.m. to 8:00 p.m., a reduction of two hours, and the rotation period was extended from every month to every 13 weeks. The Transportation Research Committee estimated that the new rules would take 930,000 of the city's 3.6 million vehicles off the road each weekday[14]. In 2010, 2011 and 2012, the Beijing municipal government continued these measures to restrict all automobiles from driving one day per week based on the license plate number. After January 9, 2011, the government revised the restriction to charge a 100 RMB fine each time if two consecutive violations were committed more than three hours apart by the same person. In other words, the punishment was no longer limited to one fine per day. With this measure, supported by more than 2,000 surveillance cameras all over the city and frequent patrols, the driving restriction policy in Beijing was expected to take one fifth of the city's 4.2 million cars off the road each weekday. Table 1 summarizes the history of driving restriction policies implemented in Beijing. Figure 1 describes the coverage change of the restricted driving zone.

Figure 2 illustrates how congestion in Beijing spread out across its road network over time. In year 2007, congestion occurred in major commercial districts and on major arterial roads. With the driving restriction policy, the congestion index was reduced substantially after two years, reaching a low level of 5.93 in September 2009, even though the vehicle population increased by 26% over 2007. However, the effect did not last very long. One year later, in 2010, the congestion index jumped back to 7.80, with total vehicle population reaching 4.5 million.

Drivers in Beijing have invented various ways to circumvent the driving restriction policy. They purchase multiple cars with different license plate numbers, cover or borrow license plates, etc. The Beijing municipal government is aware of these "innovations." In 2010, it initiated two major policies in an attempt to fill the holes in driving restriction policy. Starting in January 2011, the city government levied a much heavier penalty for the rule breakers. The fine for violating driving restriction policy was no longer limited to 100 RMB per day. Drivers who are fined once and who fail to take remedial action will be liable to being fined again after three hours of their previous rule-breaking action.

In addition, on December 31, 2010 the Beijing municipal government finally decided to implement a lottery program to control automobile ownership. This is another example of a

[14] http://www.chinadaily.com.cn/bizchina/2009-04/06/content_7651378.htm

command and control policy. License plates in Beijing are now issued by lottery. Only 240,000 license plates were issued in 2011, compared with 700,000 in the previous year. By limiting the number of license plates, the city government tried to use this policy to regulate the increasing number of private cars.

Data and Descriptive Analysis

In this study, we use household travel survey data to analyze whether the driving restriction measure implemented in Beijing was effective enough to re-shape individual mode choice. In the transportation research field, mode choice has been regarded as one of the main causes of urban congestion.

The data are from the Beijing Household Travel Survey (BHTS). This survey was conducted in September and October in 2010 by the Beijing Transportation Research Center (BTRC)[15]. In order to develop a representative sample, the survey used a multistage cluster sampling strategy to select a sample of elements from the target population. In the survey, the study area was first divided into 388 communities and 1,911 neighborhoods, from which 233 communities were randomly selected. Then 1,085 neighborhoods in these 233 communities were randomly selected based on the list provided by the municipal government. In each neighborhood, 10 to 50 households were randomly selected according to the size of the neighborhood. The final sample size was 46,900 households, with a total of 116,142 respondents, all in the Beijing Municipal Area. The households surveyed accounted for 0.59 percent of total households in Beijing in 2010 (Beijing Transportation Research Center, 2011b, p. 6). All respondents in the sample were interviewed face-to-face at their homes and were asked to report individual/family information, as well as their travel, in a one-day trip diary. This data can be analyzed at a district, neighborhood and community level.

To analyze the effects of the driving restriction policy, we used a simple tour as the research object. A simple tour is defined as a round trip through which an individual starts from home as an anchor and visits another place with a single purpose on a single day[16]. BHTS data

[15] Holiday periods (Sept. 22 to Sept. 24, and Oct. 1 to Oct. 7) in those two months were excluded from the survey.

[16] It is much more complicated to define a "multi-chain tour." This would also make our analysis and model construction more complicated. To simplify the analysis, this study only focuses on simple tour data. Certainly we realize that travelers may have higher probabilities of using cars for multi-chain tours, and breaking the driving restriction policy is likely to be more prevalent in the case of trip chaining. Therefore, our estimation may present the lower bound of probabilities of breaking the driving restriction policy.

had a total of 54,134 simple tours. The total valid observations which have complete trip information are 37,167, which belong to 25,607 families. These are the observations used in the analysis. Meanwhile, we classified the mode alternatives into seven categories: walk, car, bicycle, powered two-wheelers (which include electric bicycles and motorcycles), bus, subway, and other[17]. Among the surveyed households, about 24.7 percent owned automobiles; 65.3 percent owned bicycles; only 14.9 percent and 2.8 percent of households owned electric bicycles and motorcycles, respectively. In all of the simple tours, 31.7 percent were made by bus. Subway had a smaller share of 12.2 percent. The second largest share of the mode choice was car, accounting for 17.1 percent of the total simple tours. And 15.5 percent of the simple tours relied on walking. The rest of the tours (about 23.5 percent) were shared by bicycle, powered two wheelers and other modes. Table 2 shows the descriptive statistics of the sample used in the analysis.

The survey started on September 8, 2010, and ended on October 31, 2010. During this period, the driving restriction rule was defined as follows. Before October 9, the five groups of last digit numbers of license plates, 5 and 0, 1 and 6, 2 and 7, 3 and 8, and 4 and 9, were assigned to Monday through Friday, respectively. In other words, cars with a last digit license plate number of 5 or 0 were not allowed to use a road inside the 5th ring road on Monday from 7:00 a.m. to 8:00 p.m.; 1 or 6 were not allowed on Tuesday, and so on. From October 10, the assignment of these five groups was 4 and 9, 5 and 0, 1 and 6, 2 and 7, 3 and 8 from Monday to Friday, respectively. The restrictions were not applied to weekends and holidays.

Based on these restriction rules, the last digit of the license plate numbers collected in the survey, and the location of the origination or destination places (inside the 5th ring road), we identified 730 cars that were subject to the restriction rules. In other words, these 730 cars were not allowed to use the road system surrounded by the 5th ring road between 7:00 a.m. and 8:00 p.m.[18] on a given date. If any of these 730 cars were used at any time between 7:00 a.m. and 8:00 p.m., and the origination or destination place of its trip was located inside the 5th ring road (so that at least part of the trip was taking place in the area surrounded by the 5th ring road), we would define this car trip as an "illegal" trip. Correspondingly, its car owner would be regarded

[17] "Other" includes vans, trucks, taxis, cooperation shuttles, school shuttles, illegal taxis, and other. The total number of these modes is 1,954, accounting for 5.26 percent of total 37,167 valid observations. The cooperation shuttles took the largest share (about 66 percent) of the modes in "other" category.

[18] Rule-obeyers refer to those who beat the restriction time by leaving home earlier than 7:00 a.m. and/or going home after 8:00 p.m., or those who did not use a car at all on the restricted day.

as a rule-breaker. Note that each of these 730 cars was used by its major user and owned by his or her family. If the household owned more than one car, each car was then associated with its major user in the household. Therefore, the analysis below is based on individual travelers rather than households. The data showed that 349 car owners or car trips, or about 47.8 percent of the regulated car users[19], broke the driving restriction rules. This high rate of driving violations corroborates the 58 percent violation rate found by Chen (2012)[20].

In order to investigate the differences between rule-breakers and rule-obeyers, we conducted a statistical analysis of these two groups (Table 3). The t-test shows that there are statistical differences in terms of age, whether the trip was made during peak hours, and distance from destination to the city center (Tian-An-Men). We found that rule-breakers were relatively younger, and that drivers were more likely to disobey the restriction if the trip took place during peak hours. The results also show that the location of the destination seems to be related to the car owner's choice of whether to break the driving restriction rules.

In terms of spatial distribution of these rule breakers, Figure 3 displays where they lived and where their destinations were in Beijing. We can see from this figure that, for the majority of rule breakers, either the origin or the destination was located within the 5th ring road, even though the public transit system is better within that area. The data also showed that, for trips between home and work place, there were more inbound illegal car trips (43.6 percent of total

[19] We found that 92 car owners (about 12.6 percent of regulated car owners), who were subject to driving restrictions on the dates, left home between 6:00 a.m. and 7:00 a.m. We suspect some of these "early birds" chose to leave early in order to avoid the driving restrictions. In addition, due to lack of information, we were not able to identify how the drivers broke the rules: disobeying the restriction, covering the plate, borrowing a plate or car, etc.

[20] According to the study by Chen (2012), trip observations should satisfy two conditions: 1) both the origin and destination of each trip should be located inside of the 5th ring road; 2) each trip should take place during morning peak hours (7:00-9:00 a.m.) on workdays. However, the trip observations used in this study were spread throughout the whole metropolitan area of Beijing, through the whole day, and 7 days per week. Yet, this high violation rate is still surprising. We speculate that this could have happened for two reasons. First, the data were collected before and after two major holidays in China (the Moon Festival and the National Day Holiday). Travel demand in a holiday season is usually stronger than in a non-holiday season, which, in turn, may induce higher probabilities of breaking the rules. On the other hand, according to the Beijing Transportation Research Center, the impact from holidays on travel demand was carefully considered when the survey was originally designed. To minimize this impact, the holidays, as well as one day before the holidays, were excluded from the survey (Beijing Transportation Research Center, 2011b, p. 5). Second, 100 RMB per day as a violation penalty is not very high for wealthy households in Beijing. As a comparison, the fine in Bogota (Colombia) is $125 when a driver is caught driving when it is prohibited.

illegal trips), while the outbound[21] share of illegal car trips was 34.1 percent. The concentration of the jobs in the city center could be one reason for this inbound-outbound discrepancy[22] (Sun et al., 2012).

Driving Restriction and Travel Mode Choice

To identify whether and to what degree driving restrictions would change individual mode choice, we used a Nested Logit model (NL, hereafter [23]). The observations included in the final analysis are one direction of a simple tour, namely, a simple trip from home to a non-home destination. In the model, we control for four types of variables that may be correlated with mode choice. The first one is related to the traveler's social and economic information, including age, gender, per capita income, education level, occupation, and whether she owns an automobile. The second type is related to trip information. The variables we consider are travel distance, trip purpose, travel time, travel cost, whether the trip was made on a weekday or weekend, and whether the trip was made during peak hours or non-peak hours. The third type of variables are spatial factors related to places of origin and destination; these include distance to city center, represented by Tian-An-Men, distance to the nearest subway station, distance to the nearest entry/exit of a ring road[24], and number of bus stops within 1,000 meters of the trip origin or destination. We assume that the longer the distance to the city center, or the less accessibility to the subway or bus systems, the less likely it is that a traveler will take public transit. The last type of variables are district dummy variables to capture district-level characteristics that may have influence on individual mode choices but are difficult to quantify, such as transportation-related policies, etc.

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[21] Inbound means "toward city center," outbound is "away from city center." As there are more jobs located in the city center, there would be more home-to-work trips in the inbound direction, and therefore higher probabilities of observing illegal trips in this direction.

[22] The survey data showed that 71.5 percent of simple trips were commuting trips. As most jobs in Beijing were concentrated in central city, home-to-work commuting trips would be more likely to be directed toward the city center.

[23] We tried Multinomial Logit model (MNL thereafter). However, the Small-Hsiao tests show that the IIA assumption is violated in the MNL model. We thus present only NL model results.

[24] To calculate real travel distance requires a road network GIS file. Unfortunately, it is extremely difficult to get this kind of information in China. We therefore decided to use Euclidean distance. In transportation literature, existing studies take Euclidean distance as one acceptable alternative (see; e.g., Mozolin et al., 2000; Bowers et al., 2004; Chainey et al., 2008).

We need to explain how to calculate travel cost and travel time for the alternative transport modes. The travel cost refers to the out-of-pocket monetary cost. We set the monetary cost of a trip to be zero for biking and walking, and 2 RMB for taking the subway (a uniform price for all subway patrons, except for the express line to the airport). The bus fee is set by the public transport authority at 0.2 yuan for students, 0 for elderly people holding a Senior Citizen Certificate, 0.4 yuan for people with public transportation cards, and 1 yuan for people without public transportation cards. Fuel cost is a major component of the monetary cost associated with the use of cars. It is calculated based on a uniform average speed of 20km/hour and travel distance. We use 0.075 liter/km as average fuel consumption per unit of distance, and 6.87 yuan/liter as fuel price in 2010 (Song et al., 2008). The fuel cost is then equivalent to commuting distance multiplied by 0.515 RMB/km[25]. For the travel time, if the individual used a specific transport mode, the travel time reported by her would be used for that particular mode. The travel time for alternative modes is based on "average journey time." Average journey time is based on the survey observations of how long it took, on average, to use each alternative mode to travel between each origin-destination pair. This is calculated at the neighborhood, community, or district level. Table 4 provides a detailed description for each variable used in the analysis.

For the Nested Logit model, the top level of the set of transportation modes is partitioned into three subsets or nests, which are "automobile," "public transit" (which includes bus and subway) and "green mode" (which includes walking and bicycles). The bottom level is the most specific choice set, which distinguishes further among automobile, bus, subway, walking, and bicycles. In the structure specified for the Nested Logit model, individual characteristics, household characteristics, and spatial characteristics are the key factors that shape individual choice for the first stage (or top level) choice among automobile, public transit and green mode. At the bottom level, travel time and travel cost influence the choice of specific mode[26]. We did a multicollinearity test and likelihood-ratio tests for independent variables, including the interactive terms. The variables which failed these two tests were dropped out of the regressions.

Table 5 reports the Nested Logit regression results, with public transit taken as the reference alternative. Note that the LR test indicates that we can reject the null hypothesis that all

[25] We did not include powered two-wheelers and "other" modes in our analysis due to the small number of observations.

[26] The "other" and "powered two-wheelers" are excluded from the NL analysis.

of the log-sum coefficients are 1. Hence, the Nested Logit model is considered to be more appropriate than a standard logit model. It is true that this particular test of IIA depends on how we specify the decision tree. Yet, the Small-Hsiao tests further confirm that the IIA assumption is violated in MNL model. Therefore, we chose to use the NL model.

In general, the model performs well. The coefficients on "travel time" and "travel cost" are both negative and significant. This is in line with our expectation, and indicates that a traveler is less likely to take a particular mode if it takes more time or costs more money. The coefficient that we are most interested in - "subject to traffic control restriction" - is negative but insignificant. Here, we are comparing the effect of the driving restriction on both driving and green modes of transit (walking and bicycling) to the effect of the driving restriction on public transit. Compared to the effect of the restriction on public transit, we find a negative coefficient for driving and a positive coefficient for green modes, but neither effect is significant. The lack of significance might indicate that the driving restriction policy is not effective enough to change individual mode choice. In addition, the interactive term between driving restriction policy and work trip produces a positive and slightly significant coefficient, which indicates that male car owners who broke the restriction rules are more likely to drive to work.

There are some other interesting results from NL model. For instance, compared with male travelers, female travelers are more likely to drive than to take public transit, but are less likely to ride bicycles than to take public transit. We don't have concrete evidence to interpret this result. The possible reason could be that women tend to have a higher value of time than men, as documented by existing studies (Brownstone and Small, 2005; Hanson and Pratt, 1995), which in turn may induce higher probabilities for women to use cars. Table 5 also reveals that people with higher education levels are more likely to drive cars and are less likely to use green modes to their destinations than people with lower education levels. Income level is negatively and significantly associated with the probability of driving a car, which is against our hypothesis. For this variable, we don't have enough information to explain this relationship given by the NL regression. As for occupations, self-employed, private business workers, and social workers had a higher probability than other types of occupations of driving cars. The coefficient of "own automobile" is positive and significant. This suggests that car owners have very strong and significant preferences to depend on cars rather than on public transit to satisfy their travel demands.

Shopping, social, entertainment, or personal trips were more likely to rely on the use of automobiles than on public transit. The results also show that the preference for cars is not

significantly different between weekdays and weekends. Yet we can see from Table 5 that travelers during peak hours are more likely to use public transit than automobiles.

For the spatial factors, Table 5 shows that, if the place of origin is closer to the city center, or if the destination is further away from the city center, a traveler would be more likely to a drive car.

Who is More Likely to Violate the Restrictions?

Next, we will try to identify which demographic groups are more likely to break the rules. In this study, we use automobile owners who were subject to driving restrictions on specific days (total 730 observations, as discussed in the third section) to answer this question. The results of the Logit regression are presented in the Table 6:

Table 6 shows that there are only a few significant variables. Age has a positive effect on the probability of breaking the driving restriction rules, until a turning point is reached, which is around age 38 in the study. Car owners are more likely to break driving restriction rules if they need to meet friends, go to a party, pick up or drop off friends, etc., compared to going on shopping trips.

Rule breakers also tend to drive cars during peak hours rather than non-peak hours. Compared to non-peak hour trips, peak hour travel increases the log odds of breaking restriction rules by 0.78, holding all other predictors constant. In other words, peak hour travel could increase the odds of breaking driving restriction rules by a factor of 2.17. Compared with non-peak hours, morning rush hours in Beijing often mean heavily congested roads as well as overcrowded buses or subways for the car owners who need to travel. Strong demand for travel, excessive crowding on public transit during rush hours, and the moderate fine charged to rule breakers work together as potential reasons that car owners in Beijing have a higher probability of breaking the driving restriction rules during morning rush hours. Because the driving restriction policy was originally designed to reduce traffic congestion, this evidence of violation of the policy, especially during peak hours, may indicate that the policy itself is not as effective as it was supposed to be.

The results in Table 6 also show that the probability of breaking driving restriction rules is higher if the trip destination is further away from the city center. This is probably because places which are farther away from the city center in Beijing are not as well served by public transit and are equipped with fewer surveillance cameras or police patrols. Driving to these places “illegally” may involve smaller probabilities of being caught. However, the results also

reveal that neither trip distance nor accessibility to the bus or subway stations showed any significant influence on individual choices to break or obey the driving restriction rules. If the driving restriction policy was intended to encourage car owners to use public transit, this intention might be not achieved, because accessibility of public transit, either at the place of origination or destination, is not attractive enough to reduce the probability of breaking the driving restriction rules.

Meanwhile, gender and income both have a fairly significant relationship to the probability of violating the driving restriction, at the 12% and 13% level of significance, respectively. Female car owners are less likely to break the driving restriction rules than male car owners. And car owners with higher income levels tend to have higher probabilities of driving cars in violation of driving restrictions.

Conclusion

As an international metropolitan area under rapid development, Beijing is facing a sharp rise in its vehicle population. While its residents have enjoyed great benefits from this increase in mobility, Beijing is one of the world's most polluted cities and is one of the most gridlocked cities in the world. Driving restrictions, as one of the command-and-control policy instruments, have been regarded as a silver bullet by the governments in a dozen countries and regions to mitigate congestion problem. Beijing is one of them. However, the extremely rapid growth and its unique political status and power as the nation's capital city, as well as its sheer size, suggest that Beijing could be different from its Third World counterparts. This study adds new findings showing that, even from a short run perspective, the driving restriction policy is not as effective as intended in controlling car trips. The findings are consistent with those in cities in some other countries; because of unintended consequences, a driving restriction policy results in only short-time effects in achieving the intended goals. Rule-breaking behavior is constant and pervasive, as has been observed in other regions. In particular, the public is more likely to break the rules at peak hours. Our results show that peak hour travel increases the odds of breaking driving restriction rules by a factor of 2.[17].

Even without driving at "illegal" times, drivers in Beijing have circumvented the driving restriction policy by purchasing multiple cars with different license plate numbers, covering or borrowing license plates, etc. The government of Beijing has responded to these "innovations" by increasing the penalty for the rule breakers and restricting automobile ownership through a license plate policy.

Put in place together, the driving restrictions and the license plate policy seem to have been effective in curbing air pollution and traffic congestion, according to Beijing Municipal Commission of Transportation[27]. Yet, it has been reported that these command-and-control restrictions policies have driven license plate prices record high[28] and increased demand[29], thus creating more problems, including heralding the birth of new black market. In our view, these command-and-control policies can only alleviate the negative externalities generated by travel demand for a very short period of time, but they are unable to attack the root causes. In the long run, the driving restriction policy or license plate lottery policy can hardly constitute the silver bullet necessary to reduce traffic congestion or air pollution. Beijing probably needs more market-oriented transportation policies and a more comprehensive policy package (e.g., a combination of congestion tolls, expansion of the subway system, parking fees, fuel taxes, high-speed transit facilities, etc.) to relieve this city from these negative externalities.

[27] People's Daily Online, "Beijing's Congestion Control Measures Pay Off", April 18 2011. Available from http://english.peopledaily.com.cn/90001/98649/7353674.html (accessed on September 1, 2013).

[28] http://blog.ce.cn/html/14/115014-1631375.html, in Chinese, accessed on September 1, 2013.

[29] http://www.ibtimes.com/want-drive-shanghai-thatll-be-10000-license-plate-852500, accessed on September 1, 2013.

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Tables and Figures

Table 1. Driving Restriction Policy in Beijing, 2007–2012

Period	Restriction scheme	Restricted time	Restricted Area	Violation Penalty
August 17 to August 20, 2007	Odd-even number driving restriction scheme	6:00 am to midnight	Entire Beijing	100 RMB per day
July 20 to August 27, 2008	Odd-even number driving restriction scheme	3:00 am to midnight	Entire Beijing	100 RMB per day
August 28 to September 20, 2008	Odd-even number driving restriction scheme	3:00 am to midnight	Inside (including) 5^{th} ring road	100 RMB per day
October 11, 2008 to April 10, 2009	One-day-a-week driving licensing scheme	6:00 am to 9:00 pm	Inside (excluding) 5^{th} ring road	100 RMB per day
April 5, 2009- January 8, 2012	One-day-a-week driving licensing scheme	7:00 am to 8:00 pm	Inside (excluding) 5^{th} ring road	100 RMB per day
January 9, 2012-till now	One-day-a-week driving licensing scheme	7:00 am to 8:00 pm	Inside (excluding) 5^{th} ring road	100 RMB per time

Table 2. Descriptive Statistics for Simple Tour Samples

Variable	Mean	Std. Dev.	Min	Max
Age	41.90	12.64	19	69
Gender (1 = Female, 0 = Male)	0.50	0.50	0	1
Education (1=college and higher, 0=otherwise)	0.32	0.47	0	1
Income per capita (annual income, log value)	10.11	0.48	9.21	12.68
Family size (no. of people)	2.79	0.99	1	5
If own automobile (by individual) (1=yes, 0=no)	0.18	0.38	0	1
Trip time (minute)	50.13	34.55	1	260
Trip distance (km)	7.37	8.16	0	92.91
Mode				
Walk	0.16	0.37	0	1
Automobile	0.17	0.38	0	1
Bus	0.32	0.47	0	1
Subway	0.12	0.33	0	1
Bicycle	0.14	0.35	0	1
Powered two-wheelers	0.04	0.19	0	1
Others (including van, truck, taxi, cooperation or school shuttles, illegal taxi, and other)	0.05	0.22	0	1
Total observations	37,167			

Table 3. Descriptive Statistics for Rule-Breakers and Rule-Obeyers

	Subject to Driving Restrictions		t-test
	Rule-Obeyer	Rule-Breaker	
Age	42.28	40.75	2.05*
Gender (1 = Female, 0 = Male)	0.28	0.24	1.41
Income per capita (annual income, log value)	10.28	10.34	-1.31
Education (1=college and more, 0=otherwise)	0.47	0.51	-1.23
Trip distance (km)	9.20	9.53	-0.56
Peak hour[30] trip (1 = yes, 0 = no)	0.86	0.91	-1.77*
Distance from origination to Tian-An-Men (km)	9.71	9.42	0.68
Distance from origination to the nearest subway station (km)	2.05	1.88	0.92
Distance from origination to the nearest ring road entry/exit (km)	1.11	1.06	0.79
No. of bus stops in 1000 meters of origination	92.90	93.62	-0.20
Distance from destination to Tian-An-Men (km)	8.20	9.50	-2.59*
Distance from destination to the nearest subway station (km)	1.97	2.50	-1.64
Distance from destination to the nearest ring road entry/exit (km)	1.02	1.12	-0.62
No. of bus stops in 1000 meters of destination	104.50	101.21	0.85
Total observations	381	349	

Note: The degree of freedom is 728 for t-test.

[30] According to the Beijing Transportation Research Center, morning peak hour is defined as 7:00-9:00 a.m. In our data analysis, we only use one segment (from home to destination) of a simple trip, which usually happened in the morning.

Table 4. Variable Description

Category	Variable Description	Note
Dependent Variable	Mode	1= Walk, 2 = Car, 3=Bus, 4=Subway, 5=Bicycle
Subject to traffic control restriction		1=yes, 0=no
Traveler Related Variables	Age	
	Gender	1=female, 0=male
	Per capita income	Annual income per person, log value
	Education	1=college and more, 0=otherwise
	Occupation	1: Laborers in mining, construction, manufacturing and transport; Agricultural, forestry and fishery laborers
		2. Clerical support workers; Service and sales workers
		3. Civil servants in government agencies or SOEs[31]; Armed forces occupations
		4. Teaching professionals; health professionals
		5. Social workers, Self-employed; Private businessmen, and other
	Own automobile (by individual)	1=yes, 0=no
Trip Related Variables	Trip distance (km)	Euclidean distance from trip origination to destination
	Trip purpose	1=Work; 2=School; 3=Shopping; 4=Personal (banking or seeing doctors);
		5=Social (Visiting friends, partying, picking up or dropping off friends, etc.);
		6= Entertainment (gym, entertainment, take a rest)
	Trip on weekend or not	1=yes, 0=no
	Travel time (minute)	
	Travel cost (RMB)	
	whether traveled in peak hour	1=yes, 0=no
Spatial Factors	Distance from Origination to Tian-An-Men (km)	
	Distance from Origination to the Nearest Subway Station (km)	
	Distance from Origination to the Nearest Ring Road Entry/Exit (km)	
	No. of Bus Stops in 1000 Meters of Origination	
	Distance from Destination to Tian-An-Men (km)	
	Distance from Destination to the Nearest Subway Station (km)	
	Distance from Destination to the nearest Ring Road Entry/Exit (km)	
	No. of Bus Stops in 1000 Meters of Destination	
District Factor	Dummy variable for district	

[31] SOE is the abbreviation of State Owned Enterprise.

Table 5. Results of the Nested Logit Model for Mode Choice

		Automobile	Green mode
Travel time	-0.0113***		
	(0.0007)		
Travel cost	-0.6689***		
	(0.0674)		
Subject to traffic control restriction (1=yes, 0=no)		-0.8330	2.0042
		(0.7059)	(1.0937)
Age		0.0014	0.1052***
		(0.0147)	(0.0134)
Age*Age		0.0002	-0.0008***
		(0.0002)	(0.0002)
Gender (1=female, 0=male)		0.1340**	-0.5240***
		(0.0501)	(0.0448)
Per capita income		-0.1992***	-0.0477
		(0.0305)	(0.0286)
Education (1=college and higher education, otherwise=0)		0.2551***	-0.2932***
		(0.0502)	(0.0492)
Clerical support workers; Service and sales workers (1=yes, 0=no)		-0.1662	-0.5201***
		(0.0922)	(0.0806)
Civil servants in government agencies or SOEs;		0.0887	-0.2932**
Armed forces occupations (1=yes, 0=no)		(0.1043)	(0.0934)
Teaching professionals; health professionals (1=yes, 0=no)		-0.2105	-0.4020***
		(0.1229)	(0.1070)
Social workers, Self-employed; Private businessmen,		0.6732***	-0.3721***
and other. (1=yes, 0=no)		(0.1083)	(0.1010)
Own automobile (by individual) (1=yes, 0=no)		3.8629***	-0.1042
		(0.0544)	(0.0758)
Trip distance		0.3020***	-0.6414***
		(0.0342)	(0.0109)
School purpose (1=yes, 0=no)		0.2155	0.1243
		(0.3660)	(0.3374)
Shopping purpose (1=yes, 0=no)		0.4785**	0.3725**
		(0.1521)	(0.1246)
Personal trip purpose (1=yes, 0=no)		0.4908*	-0.6506*
		(0.2207)	(0.2550)
Social trip purpose (1=yes, 0=no)		1.3219***	-0.4031
		(0.1493)	(0.2070)
Entertainment purpose (1=yes, 0=no)		0.9560***	0.7196**
		(0.2503)	(0.2500)
Other trip purpose (1=yes, 0=no)		1.2115***	-0.5795**

	(0.1643)	(0.2108)
Weekend (1=yes, 0=no)	-0.0778	-0.1408**
	(0.0531)	(0.0497)
Peak hour (1=yes, 0=no)	-0.5572***	-0.3637***
	(0.0725)	(0.0650)
Distance from origination to Tian-An-Men	-0.0150**	0.0265**
	(0.0057)	(0.0102)
Distance from destination to Tian-An-Men	0.0346***	-0.0010
	(0.0032)	(0.0090)
Restriction * Age	-0.0136	-0.0404*
	(0.0109)	(0.0190)
Restriction * Gender	-0.4157	0.1141
	(0.2258)	(0.4093)
Restriction * Work trip purpose	1.0731*	-0.4647
	(0.5412)	(0.7919)
dissimilarity parameters		
Automobile_tau	1	
Public transit_tau	1.324	
	(0.135)	
Green_mode_tau	0.273	
	(0.0197)	
Number of cases	25,804	
LR test for IIA (tau = 1):	chi2(3) = 751.89	Prob > chi2 = 0.0000

Notes:

1. Standard errors are in parentheses.

2. *<10%, **<5%, ***<1%

3. District-level variables were controlled in the regression, but they were not listed in this table.

Table 6. Who is More Likely to Violate Driving Restrictions? (Logit Analysis)

Variable	Coefficient	Standard errors
Age	0.227***	(0.0791)
Age*Age	-0.003***	(0.0009)
Gender	-0.297	(0.1906)
Per Capita Income	0.230	(0.1535)
Trip distance	-0.017	(0.0156)
Work trip	-0.030	(0.8044)
Personal trip purpose	-0.517	(1.110)
Social purpose	2.799**	(1.450)
Other purpose	-0.265	(1.020)
Clerical support workers; Service and sales workers	0.141	(0.4115)
Civil servants in government agencies or SOEs; Armed forces occupations	-0.235	(0.4311)
Teaching professionals; health professionals	-0.586	(0.5247)
Social workers, Self-employed; Private businessmen,	0.348	(0.4518)
Peak hour trip or not	0.775**	(0.3106)
Distance from origination to Tian-An-Men	-0.010	(0.0236)
Distance from origination to the nearest subway station	-0.019	(0.0426)
Distance from origination to the nearest ring road entry/exit	-0.084	(0.1215)
No. of bus stops in 1000 meters of origination	-0.001	(0.0020)
Distance from destination to Tian-An-Men	0.056**	(0.0260)
Distance from destination to the nearest subway station	0.003	(0.0452)
Distance from destination to the nearest ring road entry/exit	-0.072	(0.0837)
No. of bus stops in 1000 meters of destination	0.003	(0.0020)
Constant	-7.694***	(2.2701)
N	672	
pseudo R-sq	0.053	
LR chi2(24)	51.26	
Prob > chi2	0.001	

Note: *<10%, **<5%, ***<1%.

Figure 1. The Coverage of the Restricted Driving Zone in Beijing

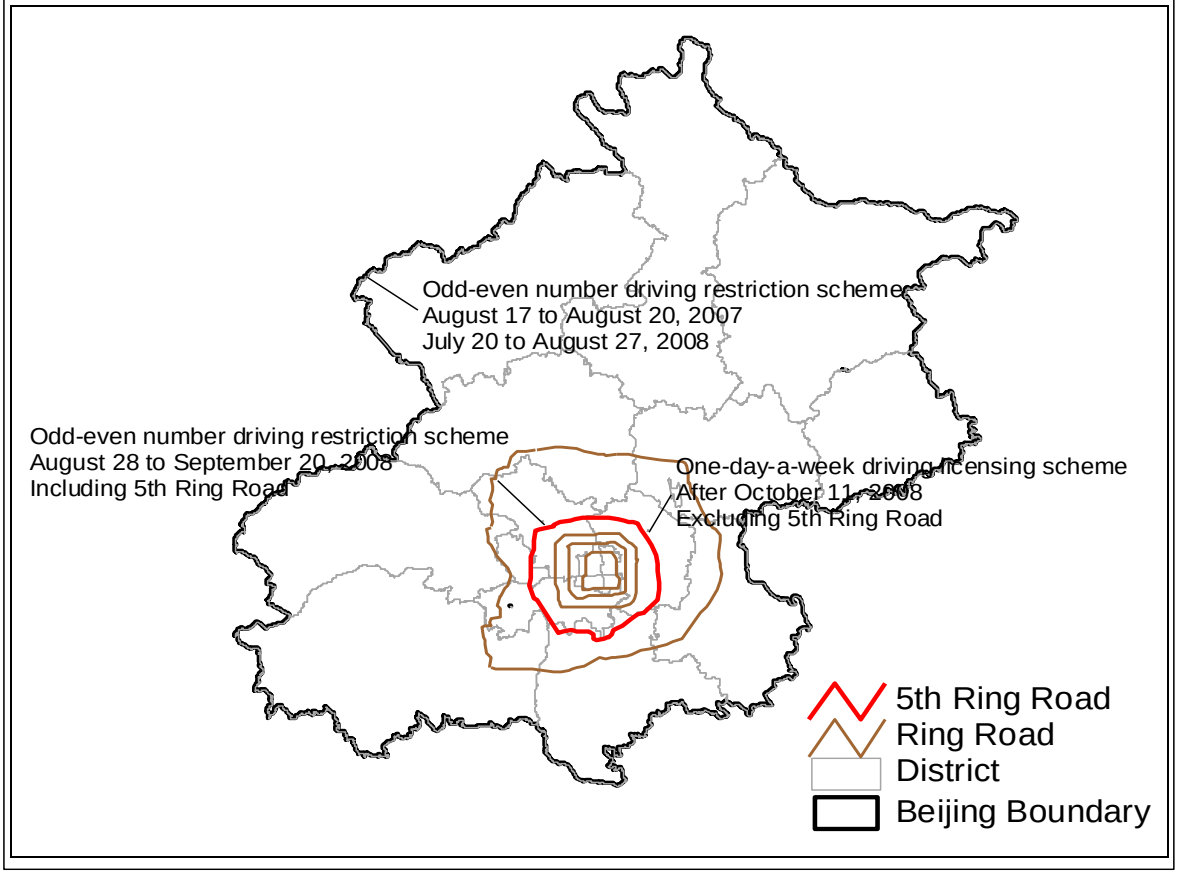

Figure 2. Congestion Level Change with 5th Ring Road from 2007-2010 (Sources: Beijing Transportation Research Center)

2007.9
（3.06 million，without restriction policy）
Congestion index：7.95

2009.9
（3.87 million，with restriction policy）
Congestion index：5.93

2010. 9
（4.51 million，with restriction policy）
Congestion index：7.80

2010.9.17
Congestion index：9.70
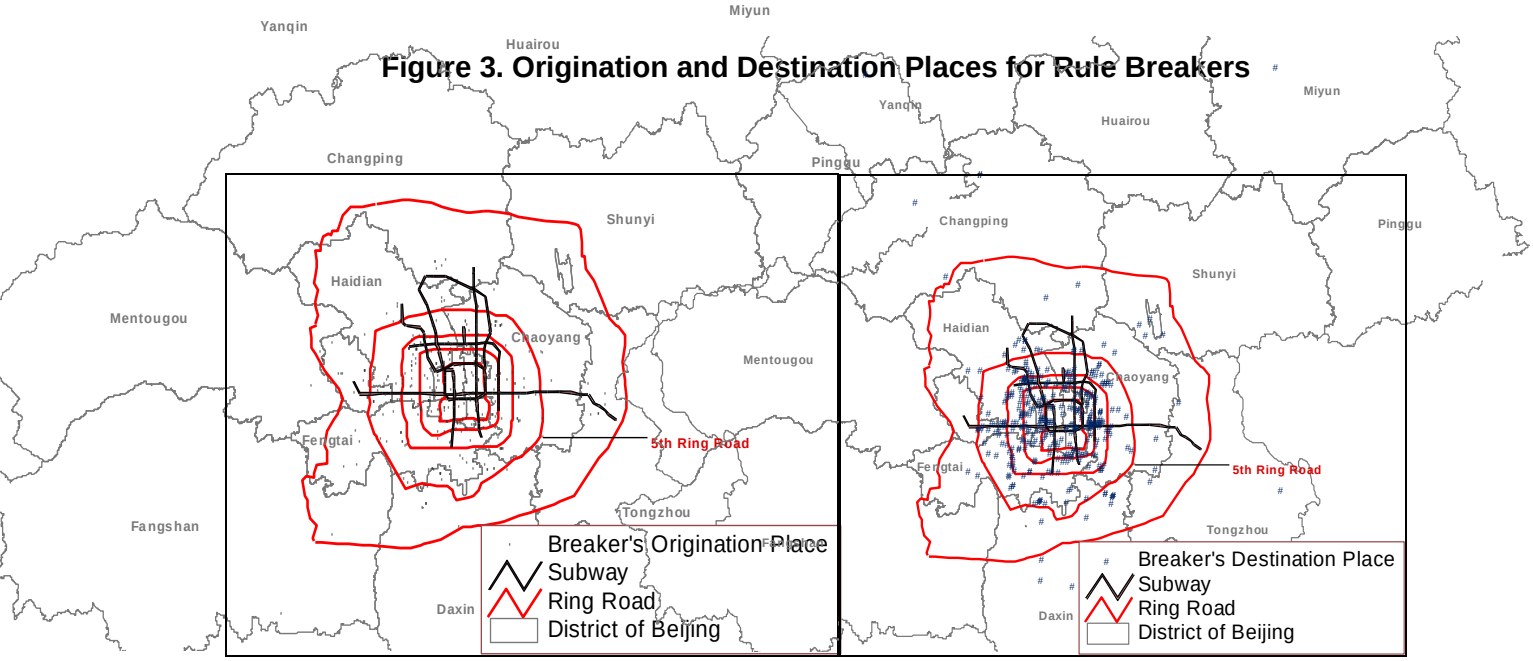
Figure 3. Origination and Destination Places for Rule Breakers