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Effect analysis of air pollution control in Beijing based on an odd-and-even license plate model

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ABSTRACT

Nowadays, air pollution has become a major challenge in urban management despite rapid economic development. Meanwhile, vehicle exhaust has gradually turned into the main source of air pollution in the city. To reduce air pollution, many measures have been taken including the odd-and-even license plate rule in some cities. However, it is difficult to evaluate the effectiveness of those measures. In view of this, based on the Davis method, this article has taken Beijing as its subject and built an odd-and-even license plate model by a probabilistic modelling method and the analysis of means, thus to quantify the pollution caused by vehicle exhaust emissions and the actual effect of the license plate limitation rule. This paper also examines the relationship between the license plate limitation rule and urban air pollution control and to see whether, or not, the rule exerts a positive influence on air pollution control. The results showed that the odd-and-even license plate rule has positive impacts on air pollution control in the short-term; however, the influence of the limitation policy gradually diminishes and disappears as the overall number of cars increases. Therefore, it is suggested to tackle air pollution in a broader and more effective way.

1. Introduction

The general public's quality of life has been greatly improved in pace with the rapid development of China's economy, therefore, there is a higher demand for a more convenient and comfortable transportation modes. Naturally, a private car is the first choice for many. It is under this background that the number of private cars has exploded in the last two decades. As we all know, the boom in private car use does not only increase traffic congestion but also aggravates air pollution. Taking Beijing as an example, its number of vehicles has exceeded 5.1 million in August 2012 and the number of drivers has exceeded 7.2 million. Besides, over 40% of major air pollutants such as NO_x arise from vehicles (Zhao et al., 2010a). Beijing has adopted an odd-and-even license plate policy since 2008 with the initial aim being to alleviate traffic pressure and reduce urban environmental pollution during the preparation for the Beijing Olympics in 2008. Nevertheless, Beijing, and other municipal governments, have listed the license plate limitation rule as a key move in controlling urban air pollution and maintaining sustainable social development. Of particular note, the feasibility and effectiveness of this rule have been hotspots for academic and public discussion ever since its unveiling.

Current studies of odd-and-even license plate rules are mainly concentrated around their origins, purpose, effectiveness, and so on. Most of them discuss the impacts of the policy on improving air quality. Among them, Wang et al. (2009) started from the obvious improvement in Beijing's air quality during the Beijing Olympic Games. By analysing the odd-and-even license plate rule's origin, purpose, and effect, they discussed the possibility and related issues, pros and cons, in institutionalising the policy; by using qualitative methods, Zhu (2012) focused on analysing the effects that traffic congestion has on socio-economic factors such as population, employment, GDP, energy consumption, land utilisation, environmental pollution, travel cost, and travel time. He combined a top-down system dynamics model and a bottom-up cellular automata model and started from the perspective of macro-socio-economics and a micro-traffic model. Zhu combined the advantages that the system dynamics model has in scenario simulation and macro-driving factors together with the advantages of cellular automata models in microscopic traffic flow simulation. To explore the socio-economic impacts of urban traffic congestion, he built the

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system dynamics model of the interactive relationship between urban traffic and the social economy, as well as the cellular automata model of urban traffic congestion's micro-economic costs; Chen et al. (2011) studied the Beijing Olympic Games 2008 when the odd-and-even license plate rule was one of the policies that the government implemented to improve air quality. They found that this policy brought benefits to air quality by reducing 24.9% of air pollution indices compared with the same period in 2007. Nevertheless, there are more studies pointing out the limitations of the policy, per se, and its explicit, hidden risks. Cao et al. (2014) and several other researchers studied the effects of the license plate limitation rule after Beijing's Olympics in 2008. They tracked the change of air pollution index, inhalable particles, nitrogen dioxide, and sulphur dioxide and adopted a breakpoint regression method to solve its endogenous problem. They concluded that, although the air quality in Beijing was improved during the Olympic Games, it was not as an outcome of the license plate limitation rule. Enderle et al. analysed the factors affecting traffic congestion. From an economic perspective, they pointed out that, using the odd-and-even license plate rule would only bring short-term benefits and it would not do any good to the long-term and stable development of urban economy through the analysis of urban residential demand for cars, parking lots, and the impact on the automobile industry (Enderle et al., 2012; Zhang et al., 2013). Shen et al. (2014) introduced Harbin's car ownership situation in recent years. They analysed car ownership and its exhaust components by statistical methods. It turned out that the vehicle exhaust emissions have little effect on air pollution in Harbin; but, as car ownership rises, it would also have negative impacts on air quality. Besides Beijing, the odd-and-even license plate rule has been implemented in many cities in China. Yet as it turns out, the policy does not live up to popular expectations. Taking the Guangzhou Asian Games for example, the policy has been adopted but its effectiveness is limited (Huang et al., 2012). Another case in point is Chengdu, on the whole, the limitation policy did not work as expected since its inception in 2012 (Xu and Hou, 2015). The study of this policy has led to some achievements, which will inspire our follow-up studies, however, there are still some deficiencies. First of all, a lot of studies are only conducted in a qualitative way, failing to quantify the extent of the impact of the policy. Secondly, as the air quality will be affected by the type of regional climate, studies of other cities, except Beijing, cannot be a good explanation of the merits of Beijing's odd-and-even license plate rule. Lastly, many studies use mathematical tools to analyse the policy, but most of them just compare the before, and after, effects of carrying out the odd-and-even license plate rule, or simply analyse the effects of various factors on air quality, and there is lack of predictions of air quality in the future although it is a predictable condition. In view of this, this paper attempts to use a probabilistic modelling method and analysis of means to build up an odd-and-even license plate rule simulation and analyse the change of means in this model. This paper explores the effects degree of vehicles on urban air pollution and thereby discusses the degree of improvement of the rule quantitatively.

2. Models

There are a large number of qualitative studies, both domestic and overseas, of the odd-and-even license plate rule: many successful cases that have offered detailed analyses of the effects of the rule. Among them, the most exemplary is the Air Pollution Index (API) explanatory model proposed by Lucas and Davis (2008). This model took the Hoy No Circula (HNC, literally “Don't drive today”, a vehicle limitation rule) initiated by the Mexican Government in 1989 as its object of study. Davis utilised high-frequency metrical data from the monitoring station and explored the relevance between the limitation rule and air pollution by mathematical model. To be specific, Davis used the HNC's influence *1(HNC)* and a timeline covariant x_t to explain the change of log(API). In the meantime, Davis employed a large number of data relating to number of cars and air pollution to analyse the change in pollutants such as sulphur dioxide, nitrous oxide, and ozone on a daily or annual basis. Furthermore, he also observed petrol use, automobile growth, and public traffic mode choice: based thereon, Davis concluded that the limitation rule did not generate a significant improvement in air quality. Besides, he added that this rule will engender a growth in automobile numbers to a certain extent. Davis's explanatory model for Mexican air pollution is as shown by the following formula (1):

$$\log(API)_{Mexico} = \eta_0 + \eta_1 l(HNC) + \eta_2 x_t + \mu_t \quad (1)$$

In (1), *1(HNC)* is the observable variable after the implementation of odd-and-even license plate rule, coefficient η_1 is the influential factor that HNC has on air pollution. $\boldsymbol{X_t}$ is a timeline coefficient which includes the indicator variable of every month, day, and hour.

So to speak, Davis' analysis and argument are quiet creative and foresighted in their partial explanation for the limitation rule's failure. Nevertheless, the model's general applicability remains open to question. For example, Davis's model cannot be applied directly to explain and judge whether, or not, Beijing's vehicle limitation rule is effective in improving air quality for several reasons. Firstly, China's air pollution is closely related to seasonal and environmental factors such as temperature, humidity, rainfall, and wind speed. Beijing has a typical temperate and monsoonal climate with four clearly distinct seasons (Li et al., 2012; Zhou et al., 2014). Therefore, seasonal factors should be critical in describing Beijing's air pollution. Secondly, Davis's study emphasis on the comparison between air qualities before and after the limitation rule, thus does not give full play to its explanatory function. Besides, Davis' model does not simulate the petrol use, vehicle growth, and public traffic before the implementation of the limitation rule. (Viard and Fu, 2015). Thirdly, Davis worked out that the license plate limitation rule has greatly boosted automobile purchases in Mexico. Yet obviously, this conclusion does not fit Beijing. Though the number of automobiles in Beijing is soaring, the limitation rule cannot strongly promote automobile purchases given citizens' income levels in Beijing.

2.1. The establishment of an air pollution model

As a matter of fact, those doubts over Davis' model have not denied the model totally, but only to point out that this model is restricted. In other words, if we take full consideration of a certain area's specific conditions and transform Davis' model properly, the adapted model would still have strong explanatory power. It is under this construct that this paper has designed a model. To elaborate thereon, this paper has constructed a suitable mathematical model to explain Beijing's air pollution by taking full consideration of Beijing's conditions and introducing environmental variables such as automobile numbers, rainfall, temperature, wind speed, and so on.

API, as an index measuring air quality, cannot be predicted for a specific future value since its numerical value is a random number. We get the API data for Beijing from the Ministry of Environmental Protection of the People's Republic of China (MEP). For example, the API's logarithms from 1 June 2006 to 31 May 2007 are distributed as shown in Fig. 1.

It is worth noting that, the variation of air quality and the variety of factors affecting the air quality have the feature of a long time

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