

Research Article

Control Measures for Automobile Exhaust Emissions in PM_{2.5} Governance

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This paper analyses the correlation between automobile exhaust, PM_{2.5}, and air pollution to explore the rate of contribution of automobile exhaust to PM_{2.5} pollution and the effect of government regulation on automobile exhaust gas. The results show that the atmosphere is hazy and that car exhaust is the main cause of PM_{2.5} pollution. This paper divides the governance strategy into two methods: reducing the number of motor vehicles and reducing the emissions capacity of motor vehicles. It also analyses the effects of congestion control on public car travel and establishes a dynamic game model. To strengthen the influence of supervision on enterprises with regard to purifying devices and restrictions, this study also creates a “prisoner’s dilemma” model. The final results of the study show that restriction measures can effectively relieve road pressure. Additionally, congestion costs can alleviate environmental pressure, but it is difficult to determine the costs, and the difficulty of implementation increases. Increasing enterprises’ installation of purifying devices is not advisable or desirable in the short term. Finally, the paper offers some suggestions for the maintenance of the atmospheric environment and the management of automobile exhaust: (1) improve the national green transport system and environmental protection awareness; (2) advocate public transport as a mode of travel; and (3) reduce the use of buses and popularize new energy vehicles.

1. Introduction

Economic development has led to the simultaneous development of all walks of life, and it has increased energy consumption and ecological damage. However, economic development has shown a trend that runs contrary to environmental care. Data show that China’s total emissions of sulphur dioxide in 2014 reached 174.42 million tons, which was a significant increase over the previous year’s total of 695,000 tons, and China’s consumption remains one of the world’s largest displacements of sulphur dioxide. The serious atmospheric pollution caused by the ecological balance of damage and disease hazards has become increasingly obvious and has slowly affected people’s everyday lives. In recent years, the frequent occurrence of hazy weather, clean air environments, and the number of days necessary to reduce air pollution have garnered more attention; therefore, there is an urgent need to regulate air pollution.

Since 2013, the prevention and control of air pollution in China has achieved remarkable results, and the emissions of major air pollutants have decreased significantly. However, there is still a significant gap between the concentration of PM_{2.5} in most cities and the values guided by the World Health Organization (WHO), and the problem of regional air pollution is still prominent. On the other hand, China’s greenhouse gas emissions have always attracted international attention. In 2020, China proposed to increase national independent contribution, carbon dioxide emissions to reach a peak by 2030, and to achieve the goal of carbon neutralization by 2060. In the face of severe environmental problems, we cannot rely solely on a special period of emergency treatment as a resource to solve environmental problems to achieve the “Asia-Pacific Economic Cooperation (APEC) Blue” level. For better sustainable development, we should not only place strict requirements on heavily polluting enterprises but also analyse pollutants, sources, injuries, and other aspects and

reference-developed countries to measure the effectiveness and feasibility of comprehensive rectification. The government, enterprises, and the public jointly affect the environment; as the macroeconomic level of regulation and control, the government must remedy problems with the ecological balance, in order to improve the credibility of the government and enhance the implementation effect of ecological civilization system. The government can perform two types of actions: it can limit the influence of enterprises that emit atmospheric pollution, and it can limit the large number of people who rely on the environment to survive. Restricting enterprises that contribute to environmental pollution is difficult because of their large contribution to economic growth and because they are the dominant force in economic development. Economic indexes are an important indicator of a region and represent the power of the government, enterprises, and interest relationships with the government. Particularly in the Beijing area, the Twelfth Five-Year Plan adjusted the industrial structure of the policy after its introduction. However, the low-end, standardized management, and noncapital core function of the evacuation of industries do not meet Beijing's environmental indicators for heavily polluting enterprises to back out of the decision to move elsewhere. In this series of measures, to maintain strong economic indicators, there is little room to ease the air pollution of these enterprises. The public is the largest factor in the participation of groups and in many ways affects the state of the environment, primarily through traffic pollution; for example, sources of pollution in Beijing are mainly divided into four categories, including motor vehicle emissions, coal burning, cooking fumes, industrial emissions, and construction dust. Motor vehicle emissions are an important source of air pollution, accounting for about 22% of PM_{2.5}.

Therefore, this paper uses automobile exhaust to assess the effects of different measures taken by the government. A model is created to analyse the environmental changes before and after the measures are adopted to determine the relationship between automobile exhaust gas and PM_{2.5}. This model will help examine the relationship between the atmospheric environment and the measures taken by the government to improve countermeasures. Thus, the subject of this study, air pollution and governance, holds practical significance. In this paper, PM_{2.5} and automobile exhaust, in addition to the source of pollutants, are studied mainly by analysing major pollutants that make the greatest contribution to atmospheric pollution and pollutant exhaust emissions to determine the effect of reducing air pollution. Through scientific data analysis, targeted research, and mathematical analysis of the recommendations for atmospheric environmental remediation, this study evaluates the objective of air pollution control and effective measures to provide a reference for pollution remediation and to enhance the effectiveness of environmental protection.

This paper analyses the data based on game theory and uses a prisoner's dilemma model that restricts the number of motor vehicles controlled by the government. Moreover, the dynamic game model is used to assess government congestion costs and the public's choice of travel mode. A static game model is used to evaluate the installation of

purification devices. This study also analyses the proportion of pollutants, the screening of the main pollutants, and the inflection point of the data model. Analyses of the government's role in automobile exhaust treatment, the environment, and the public, as well as the balance between the indicators of the reasons for contradictions, are conducted using the game model to evaluate the balance between the participants to determine the optimal solution strategy for both sides based on game theory.

2. Literature Review

Since the 1990s, Western developed countries, environmental economics, and management scholars studying the environment, including urban environmental governance, have studied governance problems and published many papers and reports on this topic. Most researchers are in the process of studying urban and rural environmental pollution management and have tentatively begun to study the perspective of "governance" and urban and rural environmental pollution management issues; a few scholars are paying close attention to and studying urban environmental governance issues. Research has been concentrated in two main areas: first, in the early 1990s, research primarily focused on the management perspective when studying environmental problems. During this period, environmental management papers accounted for the vast majority of studies, and there were few papers on environmental governance. Second, in recent years, scholars have begun to transition from a management perspective to a governance perspective while further strengthening the governance perspective of environmental research work; thus, environmental governance research has been thriving. During this period, the number of environmental management papers and environmental governance papers was approximately equivalent. Environmental governance stems from general governance theory; Fioretos and Tallberg [1], Kölliker [2], Williamson [3], and Yazdanpanah et al. [4] analysed and discussed the concept, meaning, characteristics, classification, and content of governance. These theories and their research have further promoted the study of environmental governance.

Another representative view is the "regional synergy governance model." Research on regional collaborative governance and intergovernmental cooperation, which first originated in Europe, the United States, and other developed countries, is based on regional economics combined with environmental public policy theory, collaborative governance development theory, and other perspectives. It focuses on regional governmental cooperation between causes and laws. This model has four perspectives. First, intereconomic exchanges and cooperation are the basis of political coordination; therefore, successful technical cooperation lays the groundwork for subsequent cooperation. One particular function of technical cooperation is to enter the political field and to even subsume the political field. Second, there are spillovers. Spillovers effect refers to regional expansion into another region. The basis of spillovers is the measure of the interests of various regions of the main body and, ultimately, the transition from economic integration to the

development of political integration. Third, there is market push. Market forces can drive the domestic or international community into a core area and create several peripheral areas around the centre. American scholar Balassa's "market + system" theory is similar to this view [5]. Fourth, there is resource dependence. Pfeffer et al. argue that the need for resources can cause an organization to interact with and impact the surrounding environment and other subjects [6].

In the "Establishment of an Intercommunity Air Pollution Control Program" in 1962, George et al. proposed that due to the proliferation of air pollution, which relates to the environmental, economic, and human health interests of a region and the interests of other relevant areas, combating air pollution should be a joint effort that uses multilateral measures through legislation to build a shelter forest to ease air pollution [7]. In 1967, in the "Importance of Public Education in Air Pollution Control," Irwin and Flieger proposed that the public should pay more attention to air pollution and education on air pollution so that members of the public understand the current atmospheric environment, long- and short-term effects, and what measures can be taken to reduce pollution, allowing the public to participate more in pollution prevention and control [8]. In 1972, in "Evaluating Local Air Pollution Control Administration Effectiveness," Wiel and McMahon proposed the current government measures on atmospheric pollution to improve three aspects of the government's administrative measures regarding air pollution [9]. In 2009, in "The Social Distribution of Neighbourhood-Scale Air Pollution and Monitoring Protection," Amy et al. noted that poor individuals and people living in suburbs were more harmed by air pollution than urban populations [10]. Thus, the government should strengthen the supervision of suburban sewage enterprises to achieve multiagent cooperation and to reduce the level of air pollution.

Xue et al. used the emission factor method to quantitatively determine the air pollutant emissions from the transportation sector [11]. The emission intensity of different modes of transportation was estimated, and measures are proposed to prevent and control air pollutants emitted from the transportation sector. Xu et al. decompose factors affecting China's energy-related air pollutant (NO_x, PM_{2.5}, and SO₂) emission changes into different effects using structural decomposition analysis (SDA), and some policies arising from our study results are discussed [12]. Wu et al. present the overall haze situation in China and explore the determinants of PM_{2.5} using a random-effects model, as well as a set of OLS regressions [13]. Zhang et al. constructed a regional-scale environmental impact assessment model that includes pollution sources, pollution stress, and evaluation results and evaluated the environmental impact of SO₂, NO₂, CO, PM₁₀, and PM_{2.5} from three perspectives: regional integration, different energy consumption sectors, and different cities [14]. Gao et al. enrich existing literature on air pollution control and provide a novel scientific tool for design and formulation of air pollution control policies by innovatively integrating commonly used evaluation models and deep learning forecast methods [15].

Wang et al. investigate the effects of the temporary strengthening of air quality assurance controlling measures and find that effective control of primary gaseous pollutants and volatile organic compounds (VOCs) will be very significant for further lowering the concentration of PM_{2.5} in Beijing in normal time [16]. Liu et al. take a city's reasonable five-year treatment plan for PM_{2.5} as an example to calculate possible annual average governance indicators. It has certain practical significance for guiding PM_{2.5} control plan [17]. Lian et al. introduced the correlation between the PM_{2.5} concentration and the total concentration of the other five elements in the Air Quality Index (AQI) [18]. A three-dimensional concentration distribution model was established. Under appropriate constraint conditions, a comprehensive nonlinear programming model is established. The final management program is obtained through Lingo simulation. Ye et al. study the spatial distribution and evolution of PM_{2.5}, which is the basis for regional cooperative governance, attempt to propose a new multiscale framework based on spatiotemporal integration, define and divide the space affected by PM_{2.5} into four categories, point out the path of space diffusion, and finally propose methods for regional cooperation and environmental governance [19].

Mao et al. researched air pollutants and pollution incidents in four cities. The results show that PM_{2.5} is the main pollutant in each city, followed by O₃, PM₁₀, and NO₂ [20]. Gao et al. [15] take the Chengdu-Chongqing region of China as the research object, evaluate the monthly air quality of these cities during the study period, and put forward relevant policy recommendations for air pollution control in the Chengdu-Chongqing area [21]. According to the research results, the effectiveness of air pollution control in various cities has shown a clear improvement trend. Jules et al. emphasize the system view of the city system, propose a new method of smart city system integration, and find that the air pollution emitted by vehicles can be eliminated by considering information related to reducing air pollution [22]. Ding et al. used LMDI decomposition method to establish a factor decomposition model of carbon emissions from China's transportation industry. On this basis, the influencing factors of China's transport carbon emissions from 1991 to 2008 are quantitatively analysed, and three influencing factors of transport energy efficiency, transport structure, and transport development are determined. They found that the impact of transport development on transport carbon emissions is a pull effect. In addition, the impact of transportation structure on transportation carbon emission shows a promoting effect on the whole, but its promoting effect on carbon emission decreases year by year [23].

3. Research Methodology

3.1. Theoretical Basis

3.1.1. Composition and Sources of Air Pollution. In the process of treating air pollution, it is necessary to analyse the composition and sources of air pollution. The atmosphere is composed of a certain proportion of gases, water vapour, and suspended matter. Air pollution means that the

concentration of gaseous substances in the components of the atmosphere has exceeded the general levels, there is no trace of the original material, or the concentration of suspended particle content is too high, meaning that people, animals, and plants may experience adverse effects. The presence of different pollutants in the atmosphere comes from different sources, and when the concentration of pollutants reaches a certain value, it is possible that they will cause serious damage to the ecosystem. According to the results of current research, atmospheric pollutants mainly include harmful gases and particulates, for example, carbon dioxide, nitrogen oxides, hydrocarbons, photochemical smog, and halogen elements, such as dust and acid fog.

Air pollutants come from both natural and man-made sources. As many as 100 types of pollutants have been recorded, and human factors are the main underlying cause. The main pollution sources are industrial production, transportation, and coal fuel combustion. And with the rapid development of urbanization and industrialization, agriculture, industry, commerce, and transportation continue to discharge pollutants into the atmosphere, air quality drops sharply, and the term “haze weather” appears more and more frequently in front of the public. Haze is a new type of compound air pollution, and its essence is ultrafine particle pollution associated with photochemical pollution, including all kinds of dust (sand dust, wind dust, construction dust, road dust, etc.), crustal elements, carbon black produced by combustion and industrial processes, elemental carbon, as well as organic particles, sulfates, nitrates, ammonium salts produced by secondary conversion of gaseous pollutants, as well as a small amount of metal elements (lead, mercury), bioaerosols, and radionuclides.

Industrial pollution results from the production and manufacturing of waste gases, photochemical smog, and construction site dust. Transportation pollution results from the waste gas produced by the use of fuel, such as petroleum, which accounts for the majority of automobile exhaust. Pollution from coal fuel combustion is associated with the main energy source of stoves, heating boilers, and enterprises.

3.1.2. The Composition and Sources of PM_{2.5}. PM_{2.5}, also known as fine particles, refers to atmospheric particles with a diameter of less than or equal to 2.5 μm . Because the diameter of such particles is so small, they are also known as lung particles. They are composed of chemicals including sulfates, nitrates, and carbon. Because of the small size of PM_{2.5}, its strong activity, and its strong adsorption, it attaches more easily to toxic and harmful substances, such as heavy metals and microorganisms. Fine particles remain in the atmosphere for a relatively long time; they are a more harmful type of atmospheric environmental pollution.

According to current research, it is impossible to clarify the specific composition of PM_{2.5}, but its sources can be determined, including natural sources, anthropogenic sources, and atmospheric reactions that constitute secondary pollution sources. Research on PM_{2.5} has analysed its origin and shown that anthropogenic sources are more

hazardous, including exhaust gases from fuel combustion emissions from industrial processes and coal, fuel, and mobile sources operating from stationary sources. In addition to the primary particles discharged into the environment, gaseous pollutants are exposed to the atmosphere, and through a series of complex chemical reactions, gaseous pollutants generate secondary particles; thus, when studying PM_{2.5}, gaseous pollutants cannot be ignored. The main gaseous air pollutants are sulphides, nitrogen oxides, and hydrocarbons.

3.1.3. The Main Components of Automobile Exhaust. Motor vehicle exhaust gas is a major source of atmospheric pollution and PM_{2.5}. Its emissions include harmful pollutants, such as solid suspended particles, carbon monoxide (CO), nitrogen oxide (NO_x), sulphur oxides (SO_x), and hydrocarbons (HC_s). In ultraviolet light catalysis, nitrogen oxides (NO_x) and hydrocarbons (HC_s) produce photochemical smog, which endangers human health, specifically by damaging the eyes and upper respiratory mucosal tract. According to the 2014 annual environmental statistics published by the Environmental Protection Department, the total discharge of four motor vehicle pollutants was 54,573,000 tons, down 0.5% compared to the 2013 level. The specific pollutant emissions are shown in Table 1 and Figure 1.

3.1.4. The Relationship between Automobile Exhaust and PM_{2.5}. In 2013, the Institute of Atmospheric Physics researcher Wang recorded a decade of data on the rate of contribution of automobile exhaust to PM_{2.5} [24]. These data show that the proportion of automobile exhaust gas is increasing. When the air is relatively clean, cars contribute 10% of their gas emissions to PM_{2.5}. When air pollution is relatively serious, the rate of contribution of automobile exhaust to PM_{2.5} is 40%. The main reason for this phenomenon is that when pollution is serious, haze forms around the Beijing area, reducing the city’s environmental capacity; thus, car exhaust pollution cannot be dissipated, resulting in a more serious impact. Therefore, automobile exhaust gas pollution significantly influences all air pollution; hence, regulating automobile exhaust can better control the degree of air pollution. Figure 2 shows haze day in Beijing in January 2013.

3.1.5. PM_{2.5} Hazards

(1) Harm to the Human Body. Living in a polluted environment for a long period of time will cause the body to produce a physiological response: symptoms of chronic poisoning. Beijing’s continuous hazy weather results in a high incidence of respiratory tract infections. Because of the major pollution in this city in China, the incidence of lung cancer is positively correlated with contamination. Longer periods of exposure will damage the body, resulting in physical abnormalities in newborn children, mutations, and induced cancer, thus decreasing people’s

TABLE 1: Motor vehicle pollutant emissions.

| | CO | HCs | NOx | PM |
|-------------------------------|--------|-------|-------|------|
| Cars | 2942.7 | 351.7 | 578.8 | 55.0 |
| Low-speed cars | 13.7 | 14.1 | 38.9 | 2.4 |
| Motorcycles | 477.3 | 62.5 | 10.0 | 0.2 |
| Total emissions (10,000 tons) | 3433.7 | 428.4 | 627.8 | 57.4 |

Unit: 10,000 tons. Source: Ministry of Environmental Protection of the People's Republic of China.

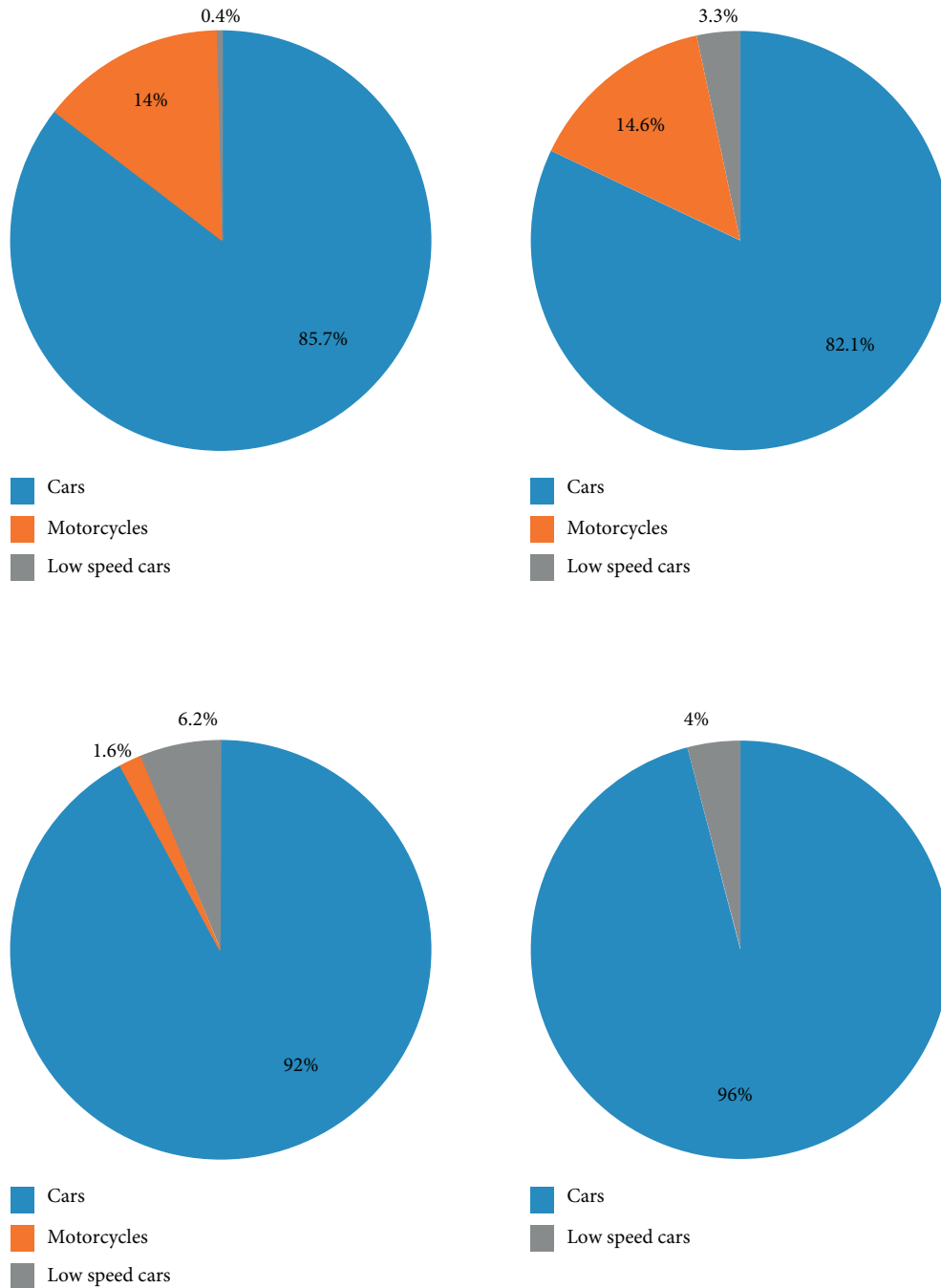


FIGURE 1: Motor vehicle pollutant discharge.

quality of life. For example, methyl isocyanate (C_3H_7NO) leaked in a pesticide plant in Pauer, India, killing 2,500 people and injuring more than 100,000. Clearly, if the

concentration of pollutants (toxic gases, etc.) reaches a certain value, serious poisoning of the human body poses a threat to life.

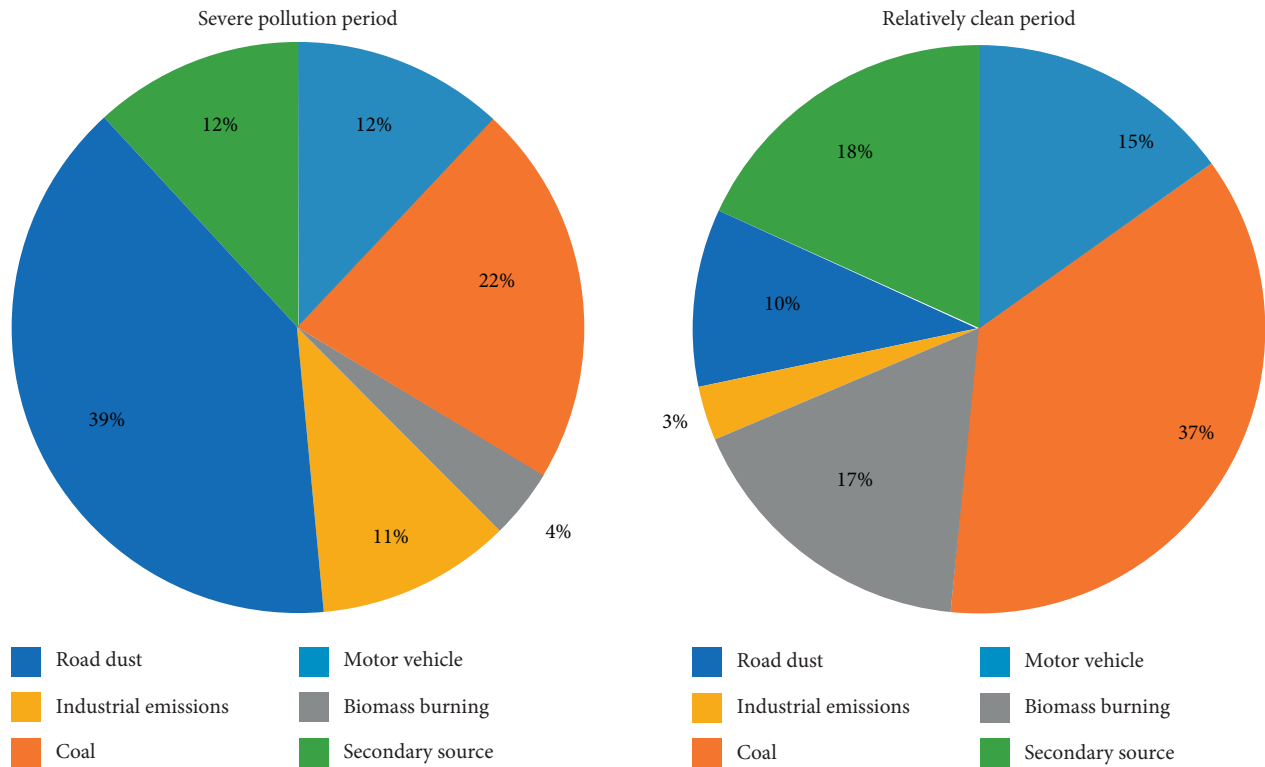


FIGURE 2: January 2013 Beijing haze days.

(2) *Harm to Animals and Plants.* Acid rain due to air pollution causes a series of physiological and chemical reactions within plants that affect their physiological and metabolic activities. Acid rain infiltrates the soil and water, causing toxic soil and water acidification and thus poisoning animals and plants. Serious pollution can even lead to biological extinction and damage the environment.

(3) *Harm to the Economy.* Through the corrosion of industrial facilities and equipment damage, air pollution can directly impact the service life of a facility, increase the costs of maintenance and repair, pollute the soil and water, and harm human health, increasing indirect costs; this harm results in human, financial, and material losses.

3.2. *Research Model.* The government can adopt a limited number of measures, such as increasing congestion costs and installing purification plant measures, to regulate automobile manufacturing enterprise. These measures between the government and citizens and between the government and enterprises, respectively, can be assessed in a game model to analyse the effect of these measures.

3.2.1. *Game between People: The Choice of Travel after Limits Have Been Implemented.* In Beijing, office workers and students account for 70% of all residents. Travel time is concentrated in the morning between 7:00 and 9:30 and in the evening between 17:00 and 19:30. Limit measures are implemented in those peak times so that through a

comprehensive consideration of the travel distance and other factors, people choose whether to use car travel.

After reaching the limit, car owners will measure the cost of transport and the actual limit of the circumstances, and they will thus choose a reasonable travel method rather than the preferred method of car travel. The government's decision-making policy is based on road traffic, environmental quality, and social benefits; thus, the traffic capacity and environmental and socioeconomic factors all influence the government's decision regarding travel in this noncooperative game.

Urban road traffic is influenced by traffic capacity, environmental quality, and economic factors. The relationships of these factors between travellers, between the government and travellers, and between travellers and the environment all focus on benefits, and all pursue the maximum benefit. In this paper, game theory is used to solve the problem in this system to optimally allocate road resources.

(1) The basic elements of the game model

Participants: Travellers (divided into car owners, bus travellers, or other green travellers).

Strategy: Travellers, based on the purpose of travel and distance, select travel tools and routes to maximize their own benefits. The main travel options are cars or buses.

(2) Model establishment

Travellers can choose a different mode of transport; thus, the static game in the "prisoner's dilemma" model can be used for analysis based on the following assumptions:

City roads are limited, and the options of travellers are independent.

The total number of travellers in the model is the same, and it is divided into two main actors, A and B.

The participants are rational.

The travellers travel only in a car or via public transportation (without considering bicycles, walking, etc.), in which public transportation represents a green trip and is assessed as follows:

The strategy of the main mode of travel is $S\{1, 2\} = \{\text{car, public transport}\}$.

The travellers' goal is to have the lowest comprehensive travel cost and to spend the least time travelling, whereas the government's goal is to pursue the overall (travellers' maximum utility and environmental utility) most effective method.

If main actors A and B select bus travel, U_1 represents the effectiveness of a single car traveller; if main actors A and B selected bus travel, U_2 represents the effectiveness of a single bus trip; if main actors A and B choose car travel and bus travel, respectively, U_3 represents the benefits of car travel, and U_4 represents the benefits of bus travel, in which $U_3 > U_1 > U_2 > U_4$ (otherwise, game theory is not established).

The implementation of the limit before the benefit matrix is shown in Table 2.

The above table shows that the Nash equilibrium crossings (U_1, U_1) are the best strategies for travel subjects A and B; that is, car travel should be chosen in those circumstances. Under limited urban road resources, the possibility of traffic congestion is very high, and the emergence of congestion may make car travel unfavourable for each participant. Although each participant chooses the strategy to maximize his or her own benefits, after the collective selection of adverse effects, the final overall results are unfavourable, and the overall efficiency is not optimal.

Therefore, the government implements limit measures. α indicates that the government creates a limit policy brought about by changes in the benefits of choosing car travel, and β indicates that the government creates bus travel subsidies to change the benefits of α , in which $\beta > 0$.

Consider the limit after the benefit matrix, as shown in Table 3.

As shown in Table 2, since $U_3 > U_1 > U_2 > U_4$, $U_3 - \alpha > U_1 - \alpha$, $U_2 + \beta > U_4 + \beta$. However, because of α , the β specific size is unknown, and the magnitude of $U_1 - \alpha$, $U_2 + \beta$ cannot be determined.

3.2.2. Game between the Government and People: Increased Congestion Costs. With the economy and improved living standards, car ownership remains high. Although the government has taken measures, more than 2 million vehicles are used in Beijing on a daily basis, causing serious traffic congestion. Pollution control must consider several travel factors caused by road congestion problems. With the increase in vehicle congestion, motor vehicle idling will

TABLE 2: The implementation of the limit.

| | | B | |
|---|---------|--------------|--------------|
| | | 1 car | 2 buses |
| A | 1 car | (U_1, U_1) | (U_3, U_4) |
| | 2 buses | (U_4, U_3) | (U_2, U_2) |

TABLE 3: Benefits matrix after limit implementation.

| | | B | |
|---|---------|--------------------------------|-------------------------------|
| | | 1 car | 2 buses |
| A | 1 car | $(U_1 - \alpha, U_1 - \alpha)$ | $(U_3 - \alpha, U_4 + \beta)$ |
| | 2 buses | $(U_4 + \beta, U_3 - \alpha)$ | $(U_2 + \beta, U_2 + \beta)$ |

increase, and the fuel efficiency of motor vehicles will be reduced, thereby significantly increasing the emissions of motor vehicle exhaust pollution and increasing the PM2.5 problem. It is difficult for the government to create effective control and regulatory management measures that affect the personal use of motor vehicles.

To reduce the PM2.5 index, the government controls the number of motor vehicles to control automobile exhaust pollution. This article assesses how to improve the cost of motor vehicle travel (i.e., to reduce congestion problems) so that the public will use public transportation. Based on an analysis of congestion costs, the government will increase the costs of using motor vehicle travel, thus forcing the public to consider travel costs when making travel decisions.

(1) The basic elements of the game model

Participants: the government and people (car owners, public transport passengers, and pedestrians).

Strategy: By controlling congestion rates, the government will increase congestion costs, reduce road congestion, and maximize overall benefits. Based on the congestion rate and the purpose of their trips, people must consider the travel mode and determine when to travel by car to maximize their benefits.

The analysis of the government's role in congestion costs and the use of motor vehicles during this process of change shows that as the government increases congestion costs, the costs of urban travel increase, making people consider whether they will travel by motor vehicle. Thus, the number of motor vehicle trips is affected by the government changing congestion costs, and therefore, the government can determine the congestion costs based on the number of people who choose motor vehicle travel, that is, the road congestion decision. Thus, there is a game between people and the government. To analyse congestion costs and public car travel and to create a balance between the government and the public, this study builds a dynamic perfect game model based on the following assumptions:

(2) Model establishment

The government first determines the congestion rate, and people decide whether to drive a motor vehicle.

$U(w, L)$ indicates the utility function of the government, in which w is the ratio of the government in affecting congestion costs and L is the number of people who choose to travel.

Assume that $U(w, L)$ is an increasing function of (w, L) . Thus, the higher the number of people who choose to travel (L), the higher the congestion rate (the absolute value of w slope), and the higher the amount of government regulation that is necessary to achieve a better effect.

$R(L)$ is a concave function, that is, $R'(L) < 0$, $R''(L) < 0$. With the increase in the number of L , the congestion rate w is higher; thus, fewer people will choose car travel. The utility of the public's use of cars is $\pi(w, L) = R(L) - wL$, where wL is the cost. The benefits of car travel under the effect of congestion rates, with the number of car travel changes, are shown in Figure 3.

The government and the people are rational
 People are a community of interests
 Road resources are limited, and the traffic load is fixed
 By controlling congestion rates, the government aims to maximize comprehensive benefits
 By determining the number of cars and pursuing the lowest travel costs, people maximize their benefits
 The government-people game model expands $T = \{N, H, P, u\}$ as follows:
 Participation in the game model: $N = \{\text{government, people}\}$;
 Decision set: $S = \{w, L\}$;
 Participant function: $P(o) = \text{government}$, $P(w) = \text{public}$;
 Preference: The functions of the government and the public are utility functions $U(w, L)$ and $\pi(w, L) = R(L) - wL$, which the government uses to collect congestion costs.

The inverse equilibrium method is used to solve the subgame perfect equilibrium of the dynamic game.

First, under the given government congestion rate, people choose $L(w)$ to maximize utility: $\pi(w, L) = \text{Max}R(L) - wL$

The first-order condition is $R'(L^*) - w^* = 0$.

Since $R(L)$ is a concave function, the above equation must be solved, and the first-order condition is also sufficient. Using the inverse function of the first-order condition, we obtain $L(w)$, which shows how the population chooses L based on congestion rate w under the maximization of the public effect. According to Figure 3, when $L > L^*$, $R'(L) - w^* > 0$. When L remains the same, the congestion rate increases, which will increase the cost to people, and benefits are reduced. When $L < L^*$, $R'(L) - w^* < 0$, reducing the congestion rate will reduce the cost to people, and benefits will increase. Thus, the public benefits curve is an inverted U shape. $L(w)$ must be the highest point of the yield curve, and the lower yield curve represents a higher level of utility, as shown in Figure 4.

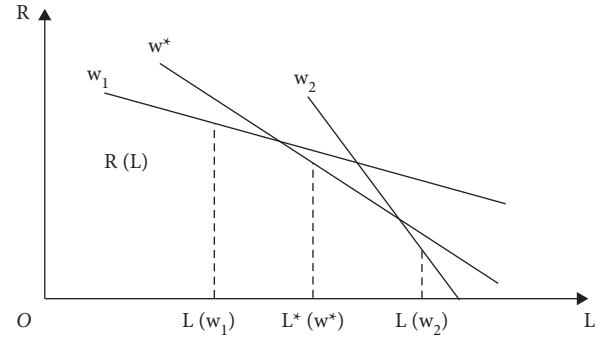


FIGURE 3: The curve of the public's benefits.

Finally, in the analysis of the government utility maximization problem, the first stage of the problem is based on the decision of people $L(w)$, and the congestion rate is selected based on the government utility maximization function: $\max_w U(w, L(w))$.

Since we do not know the specific form of the utility function, we use the government's indifference curve instead of maximizing the above formula. According to microeconomic knowledge, when the indifference curve is tangent to the budget line, the combination represented by the tangent point will maximize efficiency. In the above analysis, $L(w)$ in Figure 4 is the budget line facing the government because the pursuit of utility maximization will inevitably lead to this result.

In Figure 5, the government's best choice is to make its indifference curve tangent to the $L(w)$ curve. Thus, (w^*, L^*) is the perfect balance between the government and people.

3.2.3. Game between the Government and Businesses: Installation of Purification Equipment. A purification device is physically installed on a vehicle's exhaust filter. Through a chemical reaction, toxic gases can be converted into non-toxic gases; thus, the automobile exhaust gas generated by the second aerosol control reduces atmospheric environmental pollution.

A filter device will result in a motor vehicle power system that is not as good as that of a car without a filter. Enterprises considering the installation of filter devices will experience increased costs, but this increase will also affect sales by reducing market competitiveness; thus, there is conflict or speculation regarding whether to install filter purification devices or whether installing such devices is effective.

(1) The basic elements of the game model

Participants: the government and automobile manufacturing enterprises.

Strategy: the government maximizes overall benefits by determining whether to conduct spot checks and whether regulations should be strict or lax. Automobile manufacturers maximize their own benefits by determining whether to install filters.

The government regulates and controls automobile manufacturers' installation of automobile filters by developing a method to control the installation of

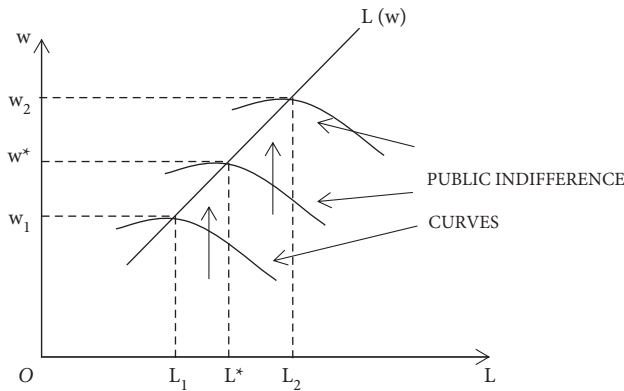


FIGURE 4: Public indifference curves.

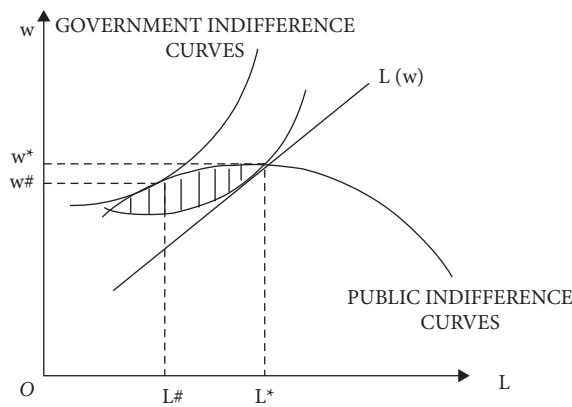


FIGURE 5: Optimal decision selection.

such filters. Simultaneously, when deciding to install the filters, automobile enterprises will determine whether they affect product quality and their own sales rate and whether they increase the cost of the actual manufacturing process. Thus, because the objective functions of car manufacturers the government differ, their behavioural strategies are different. Companies are concerned about the fines that must be paid for the installation of purifiers, the cost of installing purifiers, and the financial benefits that the government can provide; they also do not want their social reputation to be affected by the failure to comply. The government is concerned about the costs of regulating enterprises, the economic subsidy costs, and the economic and environmental benefits of the supply of filters, the most important of which is whether regulating the automobile industry is conducive to environmental improvement. When an enterprise pays a penalty higher than the cost of installing purifiers and sales are impacted, the car manufacturer will choose to install purifiers. Conversely, when companies choose not to install filters, the government, based on corporate decision-making behaviour, will make the appropriate adjustments, such as increased punishment and notification criticism. Enterprises will then

determine whether to install filters, and these two decision-making entities will ultimately achieve a balanced game. This paper analyses the static game model and makes the following assumptions:

- (1) Assume that there is only one government in an area, and the automobile manufacturers are considered a group. Both the government and the manufacturers are the main bodies of the game. The effect function of automobile manufacturers is denoted by E , and the utility function of the government is expressed by G ; it is assumed that both sides are rational. Automobile manufacturers aim to maximize their own pursuit of efficiency, whereas the government pursues the interests of the public and the environment to maximize the integration of the purpose of the decision between the two sides to determine the opposition between behaviour and decision-making.
- (2) Assume that C_{11} is the installation cost of automobile manufacturing enterprises, C_{12} is the cost of purification equipment installation (the quality cost is different based on the degree of purification of the purifier), and R_1 is the income of installing automobile manufacturing enterprises.
- (3) Suppose that C_{21} is the government's cost of providing subsidies to firms. C_{22} is the government's cost of conducting corporate regulation (the government's costs for corporate supervision and the impact of the purification pass rate). R_2 is the cost for enterprises to install purifiers to result in environmental benefits. R_2 must be $> (C_{21} + C_{22})$; otherwise, the government does not need to supervise businesses. P indicates that an enterprise does not install filters and is checked and supervised. The government's fines for enterprises must be $P > (C_{11} + C_{12})$; otherwise, a company will not choose to install purifiers, assuming that $(C_{11} + C_{12}) > (C_{21} + C_{22})$.

(2) Model establishment

The analysis can be used to determine different decision-making utility combinations for the government. The utility function is shown in Table 4.

Assume that x represents the probability of the installation of the purifier, $1 - x$ indicates the probability that purifiers are not installed, y represents the probability of government sampling, and $1 - y$ indicates the probability that the government will not conduct spot checks. If x is 0, subsequent game behaviour does not occur. However, in reality, x will not be 0; thus, there will be a balance between enterprises and the government to continue game behaviour. If $y > 1 - y$, companies will be more likely to choose to install purifiers, that is, $x > 1 - x$. Conversely, if a firm chooses not to install purifiers, then $x < 1 - x$, and game theory is present between the enterprise and the government, which adversely affects the environment. Therefore,

TABLE 4: The game utility matrix of automobile manufacturing enterprises and the government with regard to installing purifiers.

| Enterprise | Government | |
|---------------|--|--------------------------------|
| | Spot checks | No spot checks |
| Installation | $(R_1 - C_{11} - C_{12}, R_2 - C_{21} - C_{22})$ | $(R_1 - C_{11} - C_{12}, R_2)$ |
| Not installed | $(-P, P - C_{21} - C_{22})$ | $(0, 0)$ |

the game matrix in Table 4 shows that the attitude towards governmental supervision and spot checks have strong control and authority in the effectiveness of environmental protection.

Nash equilibrium does not occur under the pure strategy of the game between firms and the government. Therefore, the probability distribution of Nash equilibrium under the mixed strategy can only be analysed. Based on the assumption that a firm's strategy is $S_1 = (x, 1 - x)$, the government's strategy is $S_2 = (y, 1 - y)$ based on the assumption of the firm's regulated checks and unregulated checks. The expected benefit function of firms and the government based on the utility of different strategies and combinations of firms and the government is calculated in Table 4. $E(S_1, S_2)$ represents the desired function of firms, and $G(S_1, S_2)$ represents the government's expected benefit function:

$$E(S_1, S_2) = x[-P_y + 0] + (1 - x)[(R_1 - (C_{11} + C_{12}))y + (R_1 - (C_{11} + C_{12}))(1 - y)] \\ = x((C_{11} + C_{12}) - R_1) + R_1 - (C_{11} + C_{12}) - P_{xy}, \quad (1)$$

$$G(S_1, S_2) = y[x(-C_{21} + C_{22}) + P] + (1 - x)(R_2 - (C_{21} + C_{22})) + (1 - y)[0 + (1 - x)R_2] \\ = P_{xy} - (C_{21} + C_{22})y + R_2 - R_{2xy} - R_{2x}. \quad (2)$$

The Nash equilibrium shows that after S_2 is determined, the probability that an enterprise will install filters is calculated, which maximizes formula; thus, the derivative of x in the formula is 0, and the derivative is available:

$$P_y = (C_{11} + C_{12}) - R_1. \quad (3)$$

The left-hand side of formula (2) represents the expected benefits of enterprises, and the right-hand side represents the expected benefits of enterprises with the installation of purification devices. The formula shows that, to achieve Nash equilibrium, the government's hybrid strategy must make enterprises determine whether the selection or installation is effective, as a result of which enterprises will not engage in pollution control: $y = ((C_{11} + C_{12}) - R_1)/p$.

Similarly, for formula (2) in the y -direction to be effective, the derivative must be 0:

$$(P + R_2)x = (C_{21} + C_{22}). \quad (4)$$

The left-hand side of formula (4) represents the expected benefits of the government, and the right-hand side represents the expected benefits of the government when performing supervision checks. The formula shows that, to achieve Nash equilibrium, the mixed strategy of enterprises must make the government choose whether supervised spot checks are effective, which will cause the government to relax its supervision of pollution control:

$$x = \frac{(C_{21} + C_{22})}{P + (R_2)}. \quad (5)$$

Based on the calculated expected benefit functions of enterprises and the government, we can obtain the mixed strategy of enterprises and the government:

$$S_1 = (x, 1 - x) = \left[\frac{(C_{21} + C_{22})}{P + (R_2)}, 1 - \frac{(C_{21} + C_{22})}{P + (R_2)} \right], \\ S_2 = (y, 1 - y) = \left[\frac{((C_{11} + C_{12}) - R_1)}{p}, 1 - \frac{((C_{11} + C_{12}) - R_1)}{p} \right]. \quad (6)$$

The solution of the mixed strategy is as follows:

$$(S_1, S_2) = \left(\left[\frac{(C_{21} + C_{22})}{P + (R_2)}, 1 - \frac{(C_{21} + C_{22})}{P + (R_2)} \right], \left[\frac{((C_{11} + C_{12}) - R_1)}{p}, 1 - \frac{((C_{11} + C_{12}) - R_1)}{p} \right] \right). \quad (7)$$

Therefore, enterprises and the government arrive at equilibrium when they arrive at the following:

$$G(S_1, S_2) = P_{xy} - (C_{21} + C_{22})y + R_2 - R_{2xy} - R_{2x} = R_2 - \frac{(C_{21} + C_{22})}{P + (R_2)}. \quad (8)$$

In the process of PM2.5 governance, the government and business games of R_2 , C_{21} , C_{22} , and P are related. When R_2 , C_{21} , and C_{22} are determined, increasing P will increase the government's expected benefits. Based on the government's expected benefits model, strict implementation of the government's supervision and control on the right-hand side indicates that not installing purification measures leads to increased penalties, thus guaranteeing the government's expected benefits.

Although increasing the penalties when enterprises fail to implement purifiers can improve the PM2.5 treatment effect, the duration of this improvement must be tested.

In Figure 6, y represents the government's regulatory sampling probability. $0 < y < 1$, $1 - y$ is the probability that the government does not conduct spot checks. The vertical axis shows the probability that governmental monitoring via spot checks does not result in the expected benefits of purification installation. Line $M1$ represents the probability, when the fine is $P1$, that enterprises do not receive the expected benefits of the purification equipment with supervision via government checks. $M1$ and the horizontal axis of the intersection of $y1$ for enterprises and the government of the equilibrium point show that when the government's control sampling probability is $y1$, the expected benefits of enterprises are 0.

From the analysis of the previous formulas (5)–(8), we see that the larger the value of P is, the greater the expected return of the government. Assume that the government will increase fines from $P1$ to $P2$; thus, the expected benefits for enterprises that do not install purification equipment will be moved from $M1$ to the left. If the government's strategic model remains the same, the expected benefits of firms will change from 0 to $-e$, with $e > 0$, which shows that the results are unfavourable for enterprises that do not install purification equipment. Thus, they will choose to install purifiers. This figure also shows that the government's act of increasing penalties is effective. In reality, the government will not strictly supervise enterprises; over time, it will relax its supervision, and the government's regulatory sampling probability will shift from $y1$ to $y2$. At this time, enterprises will choose to not install purification equipment because the expected benefits will decrease from e to 0 (or if they do install purification equipment, although the purification process is simple and the effect accounts for the power system, the effect is not obviously achieved through governmental supervision and sampling standards).

4. Results and Discussion

4.1. Analysis of the Game Results

4.1.1. Game Analysis between People. According to the game between people, travel choices after the implementation of restrictions can be concluded as follows.

Conclusion 1. When $U_1 - \alpha > U_2 + \beta$, the Nash equilibrium cross-point $(U_1 - \alpha, U_1 - \alpha)$ is the best strategy for main actors A and B, but then, $\alpha + \beta < U_1 - U_2$. That is, if the government implements a limit line of punishment and punishment $<$ choosing car travel and bus travel is poor, the limit line does not change how people travel, and the limit line has no effect.

Conclusion 2. When $U_1 - \alpha = U_2 + \beta$, the Nash equilibrium intersection is $(U_1 - \alpha, U_1 - \alpha)$, $(U_2 + \beta, U_2 + \beta)$. That is, when the government creates a limit in which the incentive punishment = the choice of car travel and bus travel is poor; in other words, when car travel and bus travel have the same benefits, the limit line has no significant effect.

Conclusion 3. When $U_2 + \beta > U_1 - \alpha$, the Nash equilibrium intersection $(U_2 + \beta, U_2 + \beta)$ is the best travel strategy for main actors A and B. When $(\alpha + \beta) > (U_1, U_2)$, that is forced government to limit the rewards, and the punishment $>$ selection of car travel and bus travel efficiency is poor; thus, main actors A and B choose bus travel. In this case, the government has implemented a policy limit to change the participants' method of travel, with effective results.

In summary, the government uses several methods to reduce the number of cars to meet the conditions of $(\alpha + \beta) > (U_1 - U_2)$. That is, the outcomes of increasing the number of car travel penalties or increasing the convenience of bus travel must be better than the benefits of bus travel so that traffic congestion is eased under conditions of limited urban road resources to maximize overall efficiency.

If the government does not take any traffic control measures and travellers prefer using a car, traffic pressure will increase, which will result in urban traffic chaos. When roads carry more than the maximum degree of traffic, they will be paralyzed, affecting the environment, the economy, and quality of life.

When the government implements a policy of car license

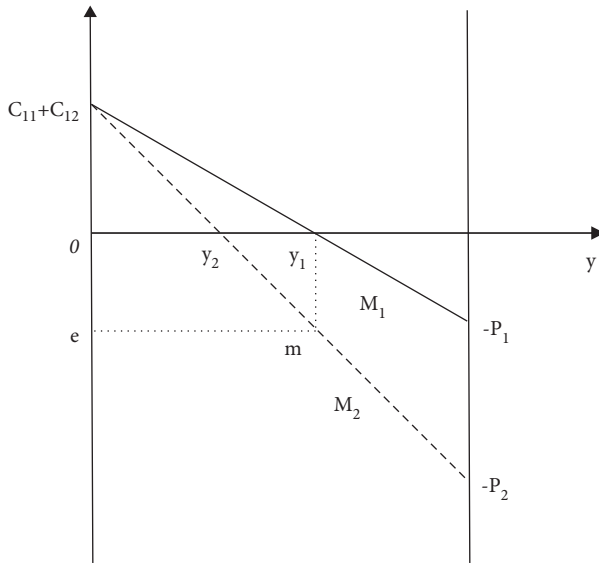


FIGURE 6: Analysis of the mixed strategy model.

plate number restriction, it is impossible to control the traffic flow on roads in line with bus subsidies (including improving bus lines, increasing the number of buses, increasing the convenience of bus trips, and reducing the cost of bus trips). The reward and punishment efforts must be higher than the benefits of bus travel to make travellers prefer bus travel to reduce car travel, ease traffic pressure, and improve the overall effectiveness.

4.1.2. Game Analysis between Government and People. According to the game between the government and the public, increasing the cost of congestion can be concluded as follows.

The results of the analysis in Figure 5 show that if w and L are in the shadow of the case, there is a balance between the government's environmental improvement and the population's travel costs within an acceptable range. In the collection of congestion costs, people and the government exist in a balance, and PM2.5 emissions are controlled.

4.1.3. Game Analysis between Government and Enterprises. According to the game between the government and enterprises, installation of purification equipment can draw the following conclusions:

The results in Figure 6 show that the government's increased penalties are effective in the short term, achieving short-term equilibrium; however, in the long run, they are not the best option. To combat car exhaust, the government must determine other effective measures after the transition period during which strict regulatory measures for enterprises are effective.

4.2. Discussion. Pollution sources have been easier to confirm in foreign studies on PM2.5. For example, the United Kingdom has attempted to control PM2.5 twice through coal and motor vehicle exhaust pollution sources. After

determining the pollution source, targeted measures for coal and motor vehicle exhaust emissions were implemented to control pollution. However, China's pollution problem is caused by multiple sources of pollution, and the cross-reaction of these pollutants causes secondary pollution. Thus, it is necessary to fully implement remediation, but full implementation will result in the decentralization of government efforts.

Notably, in the United States, the United Kingdom, and other countries, there are as many cars on the road as in China, but the amount of PM2.5 pollution is very small. Therefore, good environmental quality and a high number of cars can coexist. Comparative studies have found that the construction of roads, the convenience of traffic, fuel quality, and national environmental awareness are much higher in other countries than in China. Thus, the proposed measures for China's automobile exhaust treatment are as follows.

4.2.1. Improve the National Green Transport System and Environmental Protection Awareness. PM2.5 pollution affects everyone's quality of life and health; thus, to protect the atmosphere, active participation is required. The public should cooperate with the government on vehicle exhaust remediation based on standard annual vehicle inspections, and the public should increase the use of green travel. When purchasing vehicles, people should choose clean energy models.

4.2.2. Advocate Public Transport as a Mode of Travel. Public transport is a sustainable method of transportation that reduces environmental pollution, fuel consumption, and the per capita road occupied area to achieve the rational use of urban road resources and to reduce road congestion. In areas prone to traffic congestion, bus lanes should be reasonably created to improve the speed of public transport. Bus stations and routes should also be planned based on the layout of cities, accounting for the traffic volume and traffic concentration of local bus stations to plan the best bus lines. The government should improve the level of public transport services, improve the density of the public transport network, increase the bus travel ratio, enhance the convenience of bus travel, and encourage more people to choose bus travel.

4.2.3. Reduce the Use of Buses and Popularize New Energy Vehicles. Bus reform, such as transitioning buses from traditional fuel vehicles to new energy vehicles, plays a role in promoting clean energy vehicles and is at the cutting edge in the implementation of green travel. By constructing many new transport systems, the government can promote the use of new energy trams and promote the public's preference for clean energy trams.

5. Conclusion

Due to the lack of more data about PM2.5 in the atmosphere, this paper is unable to summarize the vehicle exhaust

emission control measures in PM2.5 control in the atmosphere more comprehensively. In addition, the dynamic game model is adopted in this paper, but there are still many game subjects in real life. It is impossible to include all subjects in this paper, so the game has limitations to some extent. By analysing the correlation between automobile exhaust, PM2.5, and air pollution, this paper discusses the contribution rate of automobile exhaust to PM2.5 pollution and the influence of government regulation on automobile exhaust. The results show that the atmosphere is haze, and automobile exhaust is the main cause of PM2.5 pollution. On the basis of dynamic game model, a prisoner's dilemma model is created. In terms of purification devices and restrictions, the impact of supervision on enterprises is strengthened. The final results of the study show that, among the measures taken by the government, the "car lottery" method can effectively control the number of vehicles. Limiting the mode of travel can effectively alleviate traffic congestion, thus reducing the impact of automobile exhaust pollution on the environment. Implementation costs can reduce the number of vehicles on the road, but it is difficult to limit how such reductions are accepted. Strengthening the monitoring of enterprise installation of purifiers can effectively reduce vehicle emissions, but it is only short-term, the cost is difficult to determine, and the implementation will become more difficult. Therefore, improve the national green transportation system and environmental awareness; advocate public transportation as a means of transportation; and measures such as reducing the use of buses and promoting new energy vehicles are necessary to reduce PM2.5 in the atmosphere.

Data Availability

The dataset used in this paper is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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