The Impact of Carbon Emission Reduction Policies on Commuting Choices of Commuters in Beijing

Qi Wang[a], Ying Liu[b], Linyu Li[c], Huiyu Zhou[d*]

Beijing Jiaotong Univ., School of economics and management, Beijing, 100044, China

[a]21241043@bjtu.edu.cn, [b]21241214@bjtu.edu.cn, [c]21241062@bjtu.edu.cn, [d*]hyzhou@bjtu.edu.cn

Abstract. Policies to reduce carbon emissions in the transport sector are crucial in influencing the public's choice of environmentally friendly travel modes. This paper uses road travel data in Beijing and employs agent-based modelling to analyze and predict the effects of different carbon emission reduction policies on commuters' mode choice in Beijing. The results show that in the short term, strengthening the implementation of vehicle restriction policies and imposing congestion pricing policies have acceptable carbon emission reduction effects. However, in the long term, policy to reduce fuel and electricity consumption has significant potential to reduce total carbon emissions.

Keywords: Carbon emission reduction, Travel mode choice, Agent based method, Policy effects.

1 Introduction

Urban China's carbon emissions are 80% total, with transportation accounting for about one-third, significantly from commuting[1]. Statistics show that commuting trips account for about 40% of daily travel among Chinese residents[2], especially in densely populated megacities where this proportion is even more prominent. Taking Beijing as an example, in 2022, commuting trips in the central urban area accounted for up to 61.5% of the total trips, and the proportion of car trips on weekdays reached 23.9%. There exists a certain contradiction between residents' demand for car travel and carbon emission reduction targets.

To address this challenge, Beijing has issued numerous carbon emission reduction policies to directly or indirectly influence residents' travel choices, such as controlling the total number of motor vehicles, implementing traffic restrictions based on license plate numbers, and accelerating the construction of public transportation systems, aiming to optimize the transportation system and reduce transportation carbon emissions. This has sparked a wave of research on the emission reduction effects of transportation policies. However, due to differences in research methods and evaluation indicators, academic opinions vary on the effectiveness of various policies in reducing carbon emissions. Some researchers argue that car restrictions can only bring minimal

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environmental benefits[3], while others consider it an important means to reduce carbon emissions[4].

To comprehensively explore the carbon emission reduction effects of various policies under the same standard system, this paper constructs a multi-scenario simulation model based on real-world data and theoretical frameworks, utilizing the Agent-based modeling with Netlogo environment to simulate commuting choices of micro-entities under different policy scenarios. We selected three types of carbon emission reduction policies in the transportation sector: technological progress, economic incentives, and administrative orders. By predicting individuals' commuting modes under transportation carbon emission reduction policy scenarios from 2024 to 2035, we analyzed the travel structure and carbon emissions under various scenarios, comprehensively comparing and analyzing the advantages and disadvantages of each policy, providing feasible suggestions for the Beijing Municipal Government.

2 Literature Review

The transportation system, as a complex adaptive system characterized by randomness, dynamism, and adaptability, can be modeled using multi-agent technology. Simulation software such as Netlogo is utilized to mimic the interactions among individuals in a virtual environment, thereby emerging the complex behaviors of the overall transportation system from a bottom-up approach. Current research has applied this method to exploring individual travel characteristics and their responses to various policies[5-6]. However, there is still a lack of comparative analysis on the impact of different carbon reduction policies on commuting choices.

Random utility theory, which takes into account the randomness in decision-making due to incomplete information and cognitive limitations, has been widely used to study travel mode choice. Scholars have established various models[7], including Logit, Probit, and their improved versions, to analyze travelers' probabilities of choosing different modes influenced by subjective perceived costs and other factors. The choice of commuting mode is influenced by multiple factors, including time cost, economic cost, environmental awareness, and personal preferences, often involving randomness[8-11].

Scenario analysis, by constructing different scenarios, helps explore the potential impacts of various factors on future carbon emission trends under different policies and economic conditions[12-13]. This article aims to conduct a simulation study on residents' travel mode choices under different carbon emission reduction policies in Beijing, based on random utility theory and scenario analysis, to discover emergent patterns from micro-individual behaviors to macro-social travel phenomena.

3 Agent Based Modeling

This study employs a multinomial logit model and real-world data to build a simulation system using Agent based approach with Netlogo Platform, which aims to simulate the commuting mode choices of Beijing residents. The system structure is illustrated in Figure 1.

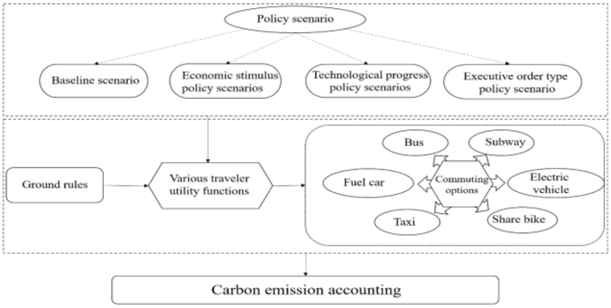

Fig. 1. Model structure

3.1 Scenario Introduction

Baseline Scenario. Considering the existing traffic policy guidelines in Beijing, the model assumes that the total annual increase in small and micro passenger cars will not exceed 2% of the previous year's figure. Among them, fueled vehicles will account for no more than 20% of the newly added cars, while pure electric vehicles will make up no more than 80%. The annual trend of passenger volume changes in public transportation and the subway, the total carrying capacity of buses and subways is set to increase by 1% each year, with the proportion of subway carrying capacity to the total carrying capacity increasing by 1% annually.

Based on industry reports on ride-hailing services and regulations for shared bicycles, it is assumed that the total number of taxis, ride-hailing vehicles, and shared bicycles will remain unchanged.

In accordance with the existing restrictions on fueled vehicles, 1/5 of such vehicles are assumed to be restricted during peak hours on weekdays. Regarding the policy of exempting new energy vehicles from purchase tax, it is assumed that new energy vehicles will be exempted from vehicle purchase tax up to 30,000 yuan until the end of 2025; and from 2026 to 2027, the exemption will apply to vehicles with a purchase tax of up to 15,000 yuan.

Emission Reduction Scenario.

Reduction in Energy Consumption. The technological advancement policy emission reduction scenario assumes a gradual and linear reduction in the average fuel consumption of fueled vehicles from 8.24 liters per 100 kilometers in 2022 to 5 units in 2035 and the figure for new energy vehicles is expected to decline linearly from 13.5 kWh per 100 kilometers in 2022 to 80 units in 2035.

Reduction in Battery Costs. The battery of a new energy vehicle accounts for 30% to 40% of the total cost of the vehicle[14], with the price of new energy vehicles reduces.

Subsidies for Vehicle Replacement. Travelers (Agents) who replace their fueled vehicles with new energy vehicles will receive a subsidy of 10,000 yuan.

Charging Subsidies. It is proposed to provide a subsidy of 0.4 yuan per kWh to travelers who charge their vehicles at public charging stations.

Charging pricing. Each trip would be subject to a fee equivalent to 1% to 5% of the average daily wage in Beijing. Additionally, there would be a maximum of three charges per day to avoid excessive fees for frequent travelers[15].

Enhanced License Plate Restriction and Total Vehicle Control Policies. It is proposed that 30% of fuel-powered vehicles will be restricted from driving during peak hours on weekdays.

Total Control of Fueled Vehicles. It is proposed that all the vehicle purchase quotas or license plate quotas for fueled vehicles will be transferred to new energy vehicles.

3.2 Decision-Making Rules

The traveler agents in our model are assumed to have bounded rationality and make travel mode choices based on a multinomial logit model. This model takes into account both the objective factors such as travel costs and subjective factors in determining the mode of transportation. Additionally, the carrying capacity limits of each mode of transportation and the availability of private vehicles are also considered. In the initial year, the vehicle ownership status is set based on actual data. Future intentions to replace or purchase a new vehicle depend on the traveler agent's considerations of purchase cost, travel cost, and subjective factors. However, the actual replacement or purchase is constrained by the annual quota for small and micro passenger vehicles. The decision-making process for travel choices follows a similar logic. The rules of conduct for travelers is shown in Figure 2.

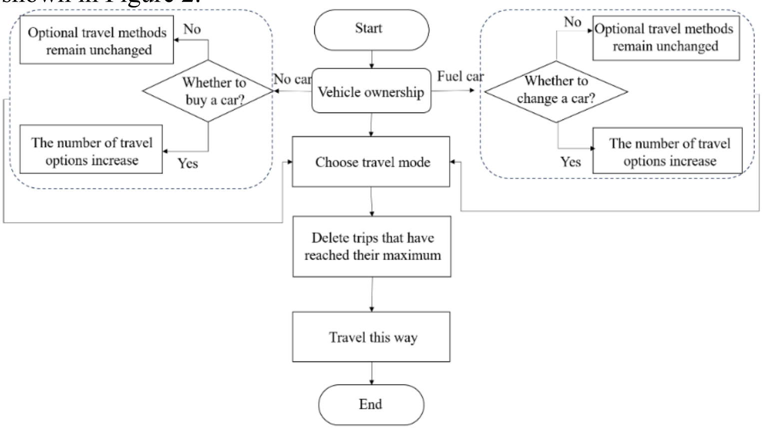

Fig. 2. Rules of conduct for travelers

Logit Model.

The decision-making process for travel, car replacement, and car purchase is conducted simultaneously. Agents who successfully purchase or replace a car will make travel choices again for the current month, while those who fail will exclude the car purchase or replacement option for that month. Options that reach their carrying capacity limit in real-time are excluded from selection. Based on these considerations, a real-time list of available options is generated for each agent. The probability of selecting each option is calculated as follows:

$$U_i = beta * \cos t_i \quad (1)$$

$$P_i = \frac{\exp(\cos t_i * beta)}{\sum_{\cos t_i \epsilon A} \exp(\cos t_i * beta)} \quad (2)$$

Based on relevant literature and the cost magnitude of this study, the beta parameter, representing the degree of individual rationality, is set to -0.001. A negative value indicates that a smaller cost leads to a greater utility. The smaller numerical value of beta represents the more rational individual.

4 Result Analysis

4.1 Model Testing

To verify the rationality of the logic and parameters, a sensitivity test was conducted on the key parameters α, B, and γ. The results in Figure 3 showed that the coefficients had a significant impact on the selection, and the current selection was relatively optimal.

Moreover, we assess the fitting effect of the model parameters in 2023. It can be seen in Figure 4 that the errors between the simulated and actual values for travel mode choice in each year are below 7.5%, and the errors for carbon emissions are below 9.5%. Therefore, we consider the travel mode choice process and the core parameters of the traveler agent in the model to be reliable.

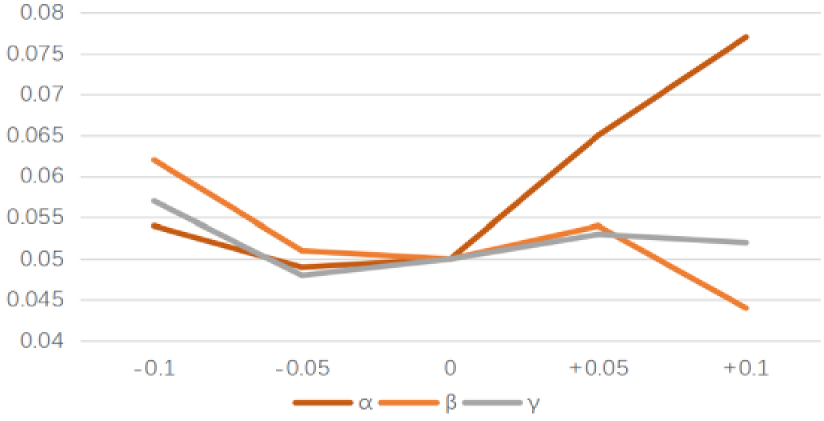

Fig. 3. Sensitivity analysis of the weight coefficient

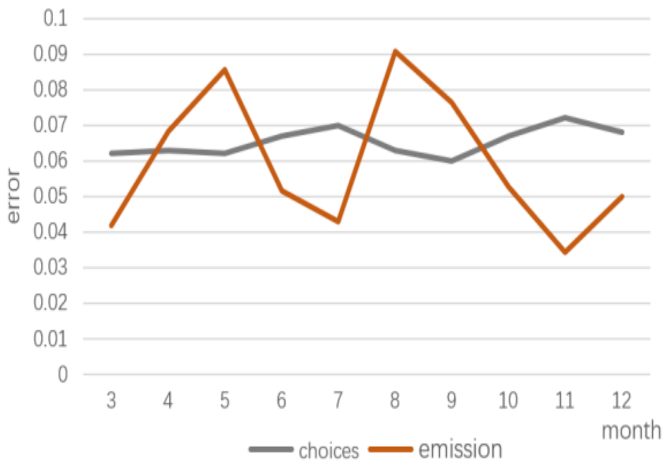

Fig. 4. Systematic error test

4.2 Analysis of Results

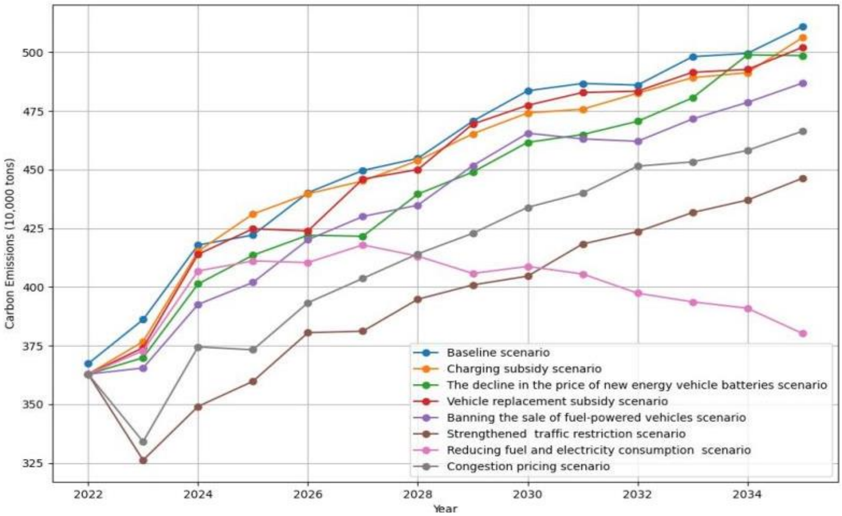

Fig. 5. Single policy predicts outcomes

As shown in Figure 5, except for the scenario of the policy of reducing fuel and electricity consumption, the total carbon emissions under other policies generally show an upward trend. Compared to the baseline scenario, the carbon emissions have all decreased. Among them, strengthened traffic restriction scenarios has the most significant carbon emission reduction effect, followed by the congestion pricing policy. In the scenario of the policy of reducing fuel and electricity consumption, the total carbon emissions first increase and then decrease.

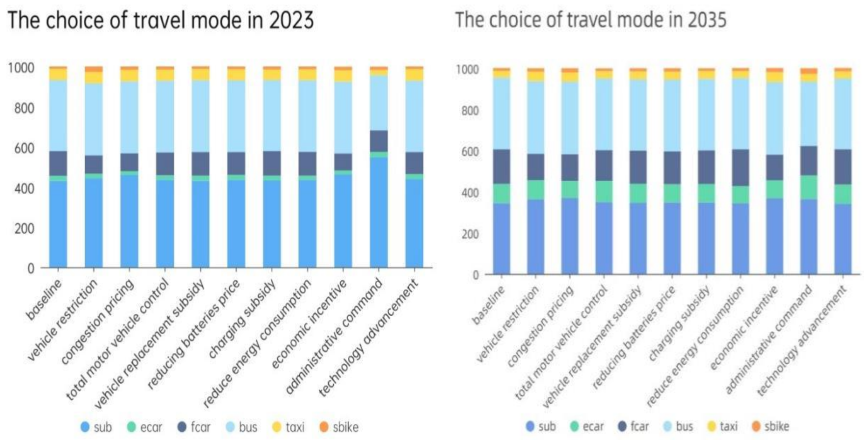

Fig. 6. Changes in the travel structure of Beijing

Figure 6 illustrates the travel structure under different policies. It is evident that by 2035, the policies that are effective in improving transportation and travel structure remain congestion pricing policy and vehicle restriction policy.

5 Conclusion

In the short term, due to their directness and compulsory, enhancing the implementation intensity of administrative command policies such as strengthened traffic restriction scenarios and total motor vehicle control policy can play a prominent role. Meanwhile, implementing congestion pricing policy will yield better carbon emission reduction results, while the policy of reducing fuel and electricity consumption will have greater potential in reducing overall carbon emissions in the long term.

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