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Modeling the CO_2 emissions and energy saved from new energy vehicles based on the logistic-curve

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HIGHLIGHTS

- ▸ This paper predicted the number of vehicles in China.
- ▸ This paper used a logistic-curve to predict the market share of NEVs.
- ▸ The potential environment benefits of every car or the total were calculated.
- ▸ China's NEVs would produce more CO_2 than those of other countries.

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ABSTRACT

The Chinese government has outlined plans for developing new energy vehicles (NEVs) to achieve energy conservation and emission reduction. This paper used a logistic-curve to predict the market share of NEVs in the next decade, and then calculated the potential environment benefits of each and every car or the total according to the report of IPCC (2006). The results indicated that NEVs were of benefit in achieving above goals, particularly electric vehicles (EVs). However, they will have a limited impact in the short term. Finally, considering the empirical results and the Chinese reality, this paper proposed corresponding recommendations.

1. Introduction

New energy vehicles (NEVs) have emerged as an alternative to conventional vehicles as they emit less greenhouse gas (GHG) and consume less petrol by using electricity. Because of their high energy efficiency and little pollution to the environment in the pump-to-wheel (PTW) stage, EVs are regarded as a trend in this industry. Driven by the national policy of energy conservation and emission reduction, the Chinese government is making great efforts to make NEVs more widespread.

Although NEVs can achieve low emissions by using less petrol in PTW, they indirectly produce CO_2 by consuming large amounts of electricity. China is a country based on thermal power. Except for some thermal power transformed from natural gas and petrol, coal is used to produce electricity, accounting for 49% of national total coal consumption. Moreover, when 1 per degree (kW h) of electricity is consumed, 0.4 kg coal is consumed, while CO_2 emissions increase 0.997 kg (Gu et al., 2010). As different energies have different CO_2 emission coefficients, changes in power structures will lead to changes in emissions. Power supply structure is highly subject to the structures of energy production and consumption. China has long been working to improve the domestic energy consumption structure through expanding new energy industries. The recently released *Twelfth Five-year Plan* clearly pointed out that non-fossil energy's share of total primary energy will reach 11.48% in 2015. Taking other related information into consideration, we can see that China's energy structure is facing adjustments, i.e. reducing coal consumption and developing new energy.

At the same time, *energy-saving and the new energy vehicle development plan* has meant that over the next decade, the government will invest 100 billion RMB to support the NEV industry for the first time. However, some scholars object to this plan, since they do not think NEVs save energy or decrease emissions. Even with such a huge investment capital, the industry would still be immature due to current technology limitations, the limited number of charging stations and other issues. In this critical period of the industrialization of the NEV, we need to ensure that it is an effective way to achieve energy conservation and emission reduction. This has a strong practical significance in terms of the government's final attitude.

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2. Literature review

Most scholars' evaluations of vehicles have concentrated on pollution emissions and energy consumption during operation. As to the emissions and energy consumption, the calculations have mainly comprised the engine fuel consumption and power consumption of rechargeable energy storage systems. Since NEVs have more complex operating modes, scholars have explored carbon emissions through a simulation and modeling approach. Zhai et al. (2010) calculated that the mean average figure of CO_2 emissions of hybrid electric vehicles (HEVs) was 0.69 g/s, based on actual working conditions, such as engine types of HEVs, traveling speed and different driving situations. Comparing EVs to ICVs, Smith (2010) found great potential and specific environmental benefits of EVs in different traveling models. Many domestic scholars (Chen, 2010; Ou et al., 2009) have tested the energy consumption and pollutant emissions of three kinds of HEVs, namely, the series, parallel and hybrid types, with the help of vehicle emissions testing technology under actual working conditions. From the perspective of primary and secondary energy, Gu (2010) pointed that EVs had zero emission during the driving stage, but were generating a great deal of CO_2 by consuming electricity. He also found that emissions from Chinese EVs greatly exceeded those from Japan, and even those from ICVs, hence drawing the conclusion that China should not promote NEVs blindly.

Because there is considerable historical data on traditional vehicles, scholars can use the time-series method or establish models based on various factors which influence the amount of cars, to predict their number. However, the NEV industry is an emerging one, so the prediction methods are few. Brady and O'Mahony (2011) used the logistic-curve method to predict the number of EVs in 2020 in different scenarios, namely, high (20%), medium (15%), and low (10%), and calculated corresponding CO_2 emissions. The research showed that if great numbers of EVs were used, transportation reduction could be effectively realized. That is to say, the impact would be limited by introducing NEVs in the short term. Draper et al. (2008) used a logistic-curve to predict the number of NEVs in future decades when they studied the influence of NEV application on the US economy. Ma et al. (2009), using the maximization principle of customer utility, analyzed the weights of NEVs' cost, reliability, image, and safety, with the establishment of a prediction model of market share of NEVs in low, medium and high scenarios.

Doucette and McCulloch (2011), based on a model which calculated emissions of plug-in hybrid electric vehicles, found that the reduction effects were different in the US, France and China, since the three countries had different energy structures. They stated that the effect in China would be relatively worse than in the other two countries, since China relied on coal to produce electricity. Moreover, many domestic scholars (Lin and Wu, 2010; Chen, 2010; Ou et al., 2009) compared the energy consumption and emissions of ICVs and NEVs and calculated the amounts of reduction and energy consumption from 2010 to 2030.

In short, scholars have conducted both qualitative and quantitative analyses of energy consumption structure and the effect of its change on emissions as well as the outcome of the conservation and reduction of EVs. Since the NEVs industry is a emergent one, there is little empirical research on China's energy consumption structure, power supply structure and the effects of their changes on the conservation and reduction of NEVs. Therefore, this paper will adopt an internationally-used method of CO_2 emissions (Zhao et al., 2009) to analyze the effects. Based upon the results of the analysis, the paper will provide corresponding policy recommendations and specific measures to help China achieve its formulated aim of energy conservation and emission reduction by introducing NEVs.

3. Methodology

3.1. *Predicting the number of vehicles in China based on the modified Gompertz model*

3.1.1. *Establishing the basic Gompertz model*

In fact, there are many factors contributing to the vehicle population, such as income, oil prices, and policies. Per capita income plays a decisive role in the population and growth rate of vehicles. As cars are durable goods, the car ownership rate tends to grow slowly when the per capita income level is relatively low, and to increase rapidly as the per capita income level rises. As the ownership rate grows, however, the satisfaction caused by purchasing a new car decreases. In addition to the long cycle of use of durable goods, the growth rate of car ownership will gradually decelerate when it reaches a particular level. In sum, the ownership rate of cars will go through 3 stages, namely, accelerated growth, slowdown in growth, and saturation. The quasi-logistic model and Gompertz curve is commonly used in the model which has a saturation restriction. The second one is applied to describe the cycle process from beginning to saturation. Compared with the quasi-logistic model, Gompertz curve is more flexible, since it allows a different curvature at different stages of income. After the reform and opening up, the national income of Chinese has changed a lot, so the Gompertz curve is more suitable to predict the number of cars in China. It can be seen from the above analysis that the general trend of automobile consumption conforms to the Gompertz curve. Based on Chinese GDP per capita, the number of cars and the total population at the end of the years from 1985 to 2009, we could establish the following model:

$$V(X) = \gamma e^{\alpha \exp(\beta X)}. \quad (1)$$

where $V(X)$ is the ratio of the number of cars to population, X is GDP per capita, α and β are parameters to be estimated. A key parameter yet to be estimated in this mode is γ, the saturation of car ownership. According to a comparison with the international research results, the urbanization rate is an important factor restricting the growth rate. The higher the level of urbanization, the higher the rate of car ownership. For example, countries with an ownership rate of 90% or more had urbanization rates of more than 60%. Thus, for industrialized countries, the car saturation rate γ is 0.62, while that of China is set as 0.5 taking the low level of development of its economy into account. The basic model formula (2) obtained from formula (1) is

$$\ln(\ln\gamma - \ln(V(X))) = C + \beta_1 X + \beta_2 \ln(X) + \varepsilon. \quad (2)$$

3.1.2. *Model testing and improving*

By testing, we knew there was serious autocorrelation problem in the basic model (2), and DW statistic was 0.0916228. As a result, this model cannot be used to reflect the economic relationships. In addition, the test of omitted variables and the plot of residuals-X indicated that model (2) had omitted some variables. Because the omission variable was not linear or related to X, this paper added x^2 or $\ln(X)$ to address this issue, as models (3) and (4) show:

$$\ln(\ln\gamma - \ln(V(X))) = C + \beta_1 X + \beta_2 X^2 + \varepsilon. \quad (3)$$

$$\ln(\ln\gamma - \ln(V(X))) = C + \beta_1 X + \beta_2 \ln(X) + \varepsilon. \quad (4)$$

From the regression results (Table 1), it was found that the variable $\text{Ln}(X)$ increased the R-squared value of the model, which improved the estimated effect. Compared to the regression residual plots of each model in Fig. 1, the regression residual of