Electric Vehicle Market Prediction based on Improved Competitive Lotka-Volterra Systems

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Abstract: Unlike the classical economic model, we analyze the vehicle market under an improved competitive Lotka-Volterra system, dispensing with the assumption of market equilibrium. The dynamic population of internal combustion engine vehicles (ICEV), battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV) are supposed to perform in a similar manner to species competing for a shared limited resource. Different conditions are taken into account, such as soaring electricity bills and policies against ICEVs.

Keywords: Electric Vehicle; Lotka-Volterra System; Eco-competition Model

1. Introduction

There may be some relevant questions on widespread use of BEVs and PHEVs. Unlike the traditional economic model, which depends on the condition that Marginal Cost (MC) equals Marginal Revenue (MR) [2], we analyze the car market under an improved competitive Lotka-Volterra system, dispensing with the assumption of market equilibrium.

2. The Ecological Competition Model

Based on the similarities between market and species competition, the interaction among three kinds of cars can be described by a system of ordinary differential equations.

According to the Verhulst-Pearl Equation [3], the population growth of single species considering time-varying productive potential and carrying capacity can be represented in the following form:

$$\frac{dN}{dt} = rN\left(1-\frac{N}{K}\right) \tag{1}$$

where $N = N(t) \geq 0$ is the population biomass in the moment $t \geq 0, r = r(t) \geq 0$ t is the time-varing potential of population, and $K = K(t) \geq 0$ is the time-varing productive carrying capacity.

Given several species with logistic dynamics competing with each other for a shared limited resource, an additional term could be added to account for the species interactions according to Lotka-Volterra formulation [4]. Besides, we define ICE, BEV and PHEV separately as vehicle type 1, 2 and 3. Analogously, considering all types of vehicles sharing the same market, the interaction among ICEs, BEVs and PHEVs can be expressed as:

$$\frac{dN_i}{dt} = N_i r_i\left(1-\frac{1}{K}\sum_{j=1}^{3} s_{ij}N_j\right), i = 1,2,3 \tag{2}$$

where s_{ij} is the effect vehicle type j has on the amount of vehicle type i. Particularly, all self-interacting terms are set to 1 for simplicity, which means if $i = j$,then $s_{ij} = 1$.

The government policies have been taken into account, in order to present a more practical model. Based on the Gompertz Model [5], the policies against ICEVs are regarded as the virus attacking the species. The model for ICEs can be revised as

$$\frac{dN_1}{dt} = N_1 r_1\left(1-\frac{1}{K}\sum_{j=1}^{3} s_{ij}N_1\right) - N_1 g_1 \ln N_1, i = 1,2,3 \tag{3}$$

where g_1 is the coefficient of the policy strength.

3. Electric Vehicle Market Prediction in Different Scenarios

3.1. Prediction under basic condition

As our basic case, the factors such as the price changes and government are not considered for the moment. Based on the numerical method of Runge-Kutta-Fehlberg algorithm, the estimation result is shown in Fig.1

Then we extend our basic condition. We assume that the electricity becomes more expensive leading to the growth of BEV and PHEV hindered apparently. We reduce by 0.2 in the first 22 years, and increase it by 0.32 in the following period. Besides, the parameter and are both decreased by 0.1.

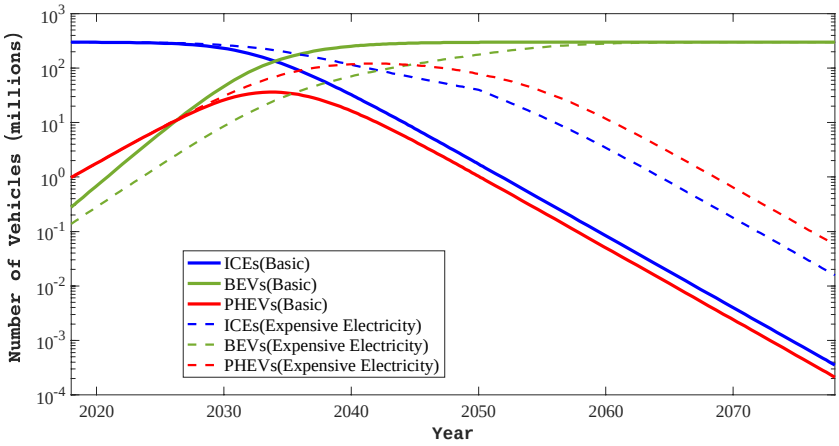

Figure 1. Prediction under basic condition

3.2. Prediction Under Policies Against ICEVs

Nowadays, many countries, such as India and Norway, are trying to completely ditch gas and diesel cars in favor of eco-friendly vehicles. According to the Equation (3), we predict the proportions as Fig.2.

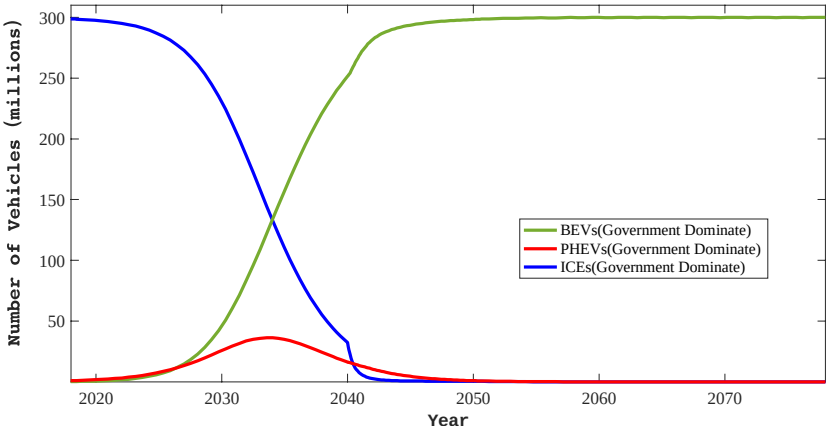

Figure 2. Prediction under Policies Against ICEVs

4 . Conclusions

If there are no outside forces in the following period, BEV enters the market with an apparently competitive advantage. It takes almost 17 years for BEV to match ICEV.

If the prices of electricity become higher, the time of equilibrium point will suffer a 7-year-delay, and the BEV will become more competitive and outperform the ICE.

If there are government policies against ICEVs, it will suffer a dramatic drop in 2040 and come to an end soon.

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