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EVOLUTIONARY SIMULATION MODEL OF DYNAMIC HFCV INDUSTRY MARKET STRUCTURE

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ABSTRACT

Facing the hydrogen energy economy, Hydrogen Fuel Cell Vehicles (HFCVs) will play an important role. China is becoming more and more interested in transitioning their vehicle fleet to HFCVs as they look forward into this century. The aim of this paper is to highlight some of the research and development work which has occurred in the past five years on HFCVs commercialization, with a focus on simulation model of its dynamic market structure. We take Lotka-Volterra model account into the evolutionary simulation model of the dynamic HFCVs market structure. And with which to analysis the market evolutionary character aimed on increasing the HFCVs supply. First, based on the rules of increasing the HFCVs industry market supplement and the substitution, assert the evolutionary simulation model of the HFCVs industry market and its market structure. Then improve the Lotka-Volterra equation with time variable. Based on above we set the evolutionary simulation model of the HFCVs industry market. Secondly, with the mean value method to solve the model, we analyze two kinds of relationships about the evolutionary system: the one is between the supply increase of HFCVs industry market and the annealation of the non-hydrogen energy, and the other is among the increment speed of the renewable energy supply, the annealation of the HFCVs industry market and its fluctuate. During the analysis, our reasoning comes down to four deductions about the limit of the the HFCVs industry market supply, the relative dependence and the growth in the HFCVs industry market. Lastly, combining of the above analysis, we discuss the enlightenment of the four types of the the HFCVs industry market on the HFCVs industrialization policy.
Keywords: *HFCVs Industry Market, Lotka-Volterra Simulation Model, Dynamic Evolution.*

1. INTRODUCTION

China is worrying about its finite nature of fossil fuel resources and climate change due to the combustion of those fossil fuels, which has sparked the government and industries to seek a clean, sustainable energy source for the increasing demands [1,2]. Hydrogen has been called the optimal replacement for fossil fuels, particularly in the transportation sector which represents the majority of petroleum consumption world-wide. The properties of hydrogen make it a unique fuel and give it certain advantages and disadvantages over conventional fuels. Hydrogen can be used for automotive applications via a blended mix of hydrogen and hydrocarbons used in a hydrogen internal combustion engine (ICE). There has been much research into hydrogen fuel cell vehicles (HFCVs) in the recent past. At the same time, China's per capita fossil energy resources is a serious shortage and even more serious situation of high-quality energy shortage. It will be further highlighted because of China's sustainable economic and social development. Since 1993, China has become the net oil importer and has become the world's second largest oil-importing countries after the United States. Oil imports

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increased year by year, the degree of dependence on foreign oil (net imports account for the proportion of domestic consumption) having been up to 35% [3,4]. According to the International Energy Agency (IEA) forecasts that China's dependence on foreign oil will rise to 44% by 2010 and to rise to 56% to 60% in 2020.

The clean HFCVs have become the urgent problems for the development of the world's energy. It is most important for the HFCVs research to be clean, efficient, and renewable. The development of the HFCVs economy is not an effective solution to the energy future, but a kind of important way to build resource-conserving and environment-friendly society. For example, hydrogen energy is a kind of important renewable energy. In recent years, the amount of hydrogen production in China is in a steady growth, having been reached 7,810,000 tons in 2002, and in the same period, that of United States, European Union and Japan, were 8,200,000 tons, 7,100,000 tons and 1,550,000 tons. China has become the world Hydrogen production ranks of the great powers. At present, its main application is the chemical and industrial, which the most important task is the amount of hydrogen used in the production of synthetic ammonia. However it has not yet formed a commercial level of HFCVs industrialization.[5] It is not possible to carry out large-scale production and not support for HFCVs large-scale demand. In addition to technical reasons, the shortage of investment in HFCVs industry is the main reason for the economic level, which led to a lack of investment in HFCVs industry. It is the key to the formation of HFCVs market. It can form an effective profit incentive to promote investment in HFCVs industry so as to promote the large-scale HFCVs production and research and development.[6]

Lotka-volterra model is a type of population dynamic model. From the perspective of the population dynamic evolution system, this paper focus on using Lotka-Volterra model to analysis the evolution simulation model of the dynamic HFCVs market mechanism. It is helpful for the rational development of the HFCVs industry and industrialization policy.

2. BUILDING THE EVOLUTIONARY SIMULATION MODEL OF DYNAMIC HFCVS INDUSTRY MARKET STRUCTURE

2.1 The Basic Assumption

First of all, the basic assumption is given to the assumption of a HFCVs market in order to facilitate the analysis:

(1) The market is divided into the HFCVs market and non-HFCVs market.

(2) HFCVs industry is an irreversible alternative for fossil vehicles in recent years.

(3) The scale of whole vehicles industry market supply and the demand remains close unchanged;

(4) The amount of HFCVs increase substitutes the one of fossil vehicles reduction obeying a certain law.

Then, based on the above, we can the definite the system evolution model of a HFCVs market structure:

(1) The system consists of two basic variables: S is the amount of the HFCVs production, and D is the replacement amount which the HFCVs demand increment substitutes the fossil vehicles supply reduction. The mathematical expectation of S is $\overline{S}$, and the fluctuation of HFCVs market system is *Var(S)*. The amount of HFCVs supply is $S = s_1 + s_2 + \cdots + s_n = \sum_{i=1}^{n} s_i$,and the amount of HFCVs demand is $D = d_1 + d_2 + \cdots + d_n = \sum_{i=1}^{n} d_n$, in which $n \le N$ (N, the natural number, which is not less than 1).

(2) The mathematical expectation of $S(t)$ is $E_t[S]$ from $t=0$ to $t=t$, which could be expressed by $E_t[S] = \frac{1}{t}\int_0^1 S(\tau)d\tau$. If we suppose the limit of $\lim_{t\to\infty} E_t[S]$ exist, the ratio of HFCVs substituting the fossil vehicles exists, in which the limit is the mean of S , being expressed by $E[S]$ or $\overline{S}$.

(3) $Var(S)$ imply that HFCVs substituting the fossil vehicles occurred around a certain stable state, at the same time, the relevance of S and D is $Cov(S,D)$.

$$E_t\left[\frac{dS}{dt}\right] = \frac{1}{t}\int_0^1 \frac{dS}{d\tau} d\tau =$$
$$\frac{1}{t}[S(t) - S(0)] \le \frac{1}{t}[\max(S) - \min(S)]$$

(4) The mean of the derivative of the HFCVs market supply function according to the above definition, can be expressed as follows:

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$$E_t\left[\frac{dS}{dt}\right]=\frac{1}{t}\int_0^1\frac{dS}{d\tau}d\tau=$$
$$\frac{1}{t}\left[S(t)-S(0)\right]\le\frac{1}{t}\left[\max(S)-\min(S)\right]$$

In the above equation, $\max(S)$ and $\min(S)$ are the maximum and minimum value of S in the interval of $[0,t]$. The equation shows the first corollary.

The First Corollary: the HFCVs substituting the fossil vehicles or the amount of HFCVs demand. It is a limited evolution process. In the process, no matter what the value of t access, the value of S ,the HFCVs supply function, is not Infinite. It is as follows:

$$E\left[\frac{dS}{dt}\right]$$
$$=\frac{1}{t}\left[S(t)-S(0)\right]\le\lim_{t\to\infty}\frac{1}{t}\left[\max(S)-\min(S)\right]=0$$

2.2 The HFCVs Industry Market Structure Evolution Model Based On Lotka-Volterra Model

Carrying the basic Lotka-Volterra model of predator-prey system[7], the relationship of the r HFCVs industry demand amount and supply in the HFCVs industry market, could be expressed as follows:

$$\begin{cases}\dfrac{dS}{dt}=aS-bSD\\ \dfrac{dD}{dt}=bSD-cD\end{cases}$$

If we change aS (the growth ratio of renewable energy amount) to $I(t)$ (which being over time), it could be understood that, as a result of technological progress and the change of economic structure, the amount of the HFCVs industry market supply grows in accordance with a specific law. In addition to there exist a certain reduction rate, that is C , for the replacement fossil vehicles or the HFCVs industry market demand amount having been met, the above-mentioned system will be unchanged, the evolution equation can be expressed as follows:

$$\begin{cases}\dfrac{dS}{dt}=I-(PD+C)S\\ \dfrac{dD}{dt}=D(PS-Q)\end{cases}$$
(1)

In which, $I=I(t)$, which is the time function of the HFCVs industry market evolving.

3. THE SYSTEM EVOLUTIONARY SIMULATION ANALYSIS OF THE MODEL

3.1 The Evolution Simulation Relationship Analysis Between S And D

It is difficult to analyze the equation (1) by the way of linear equalization analysis having the steady state solution, so we take the mathematics nature of the derivative average value being zero to analyze the law of HFCVs industry market supply and demand system evolution[8]. Using average law, we can conclude as follows:

$$E\left[\frac{1}{D}\frac{dD}{dt}\right]=P\overline{S}-Q=0 \quad \text{or} \quad \overline{S}=\frac{Q}{P} \tag{2}$$

$$E\left[\frac{dD}{dt}\right]=0=\overline{D}(P\overline{S}-Q)+PCov(S,D) \tag{3}$$

After comparing the equation (2) and (3), we can conclude the equation (4):

$$Cov(S,D)=0 \tag{4}$$

And then, we get the Second corollary:

Second corollary: This indicates that although S and D represents an alternative relationship in this model, but there is no inevitable correlation between them. As a result, the HFCVs industry market system can be drawn as: for the vehicles market whose total scale remains relatively steady during the period of time[9], the supply amount change of HFCVs industry market will not affect the reduction amount of the fossil vehicles or the amount of the HFCVs industry market demand being met. Both the different variables will be independent convergence in their steady state solution.

According to the first equation of equation (1), we also can conclude that the equation (5):

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$$E\left[\frac{dS}{dt}\right]=0=\bar{I}-(P\bar{D}+C)\bar{X}-PCov(S,D)\text{M} \qquad (5)$$

put (5) into (3), we can get (6) :

$$\frac{\bar{I}}{S}=P\bar{D}+C \qquad (6)$$

Then, combining the equation (2), we can get the equation (7):

$$\bar{D}=\frac{\bar{I}}{Q}-\frac{C}{P} \qquad (7)$$

As of this, we can get the third corollary:

The third corollary: At this point, we can see the mean of S and D is the same as the steady state solution of I being constant. When I changes over time, $I(t)$ can be in place of its mean. (It may be relevant with that S^* and D^*, constant equation's steady state solution, are stable when I is a constant in the equation)

3.2 The Evolution Relationship Analysis: D And I With $Var(D)$

Further, according to (1), we can get as follows:

$$E\left[\frac{1}{S}\frac{dS}{dt}\right]=0=E\left[\frac{1}{S}\right]-(P\bar{D}+C)$$
$$=\bar{I}\overline{\left(\frac{1}{S}\right)}+Cov(I,\frac{1}{S})-(P\bar{D}+C) \qquad (8)$$

or

$$\bar{I}\overline{\left(\frac{1}{S}\right)}=(P\bar{D}+C)-Cov(I,\frac{1}{S}) \qquad (9)$$

According to the nature of the function monotone, we can get as follows:

$$\overline{\left(\frac{1}{S}\right)}>\left(\frac{1}{\bar{S}}\right) \qquad (10)$$

Comparing (6) and (9), we get (10) come into existence when $Cov(I,\frac{1}{S})<0$. Namely, S is positive correlation with I , its growth rate. (It is due to the negative correlation between I and $\frac{1}{S}$)

Then, we discuss the relationship between I and D . Multiplying $(PS-Q)$ by the same on both sides of the second equation of the equation (1), we get the equation (11):

$$(PS-Q)\frac{dD}{dt}=D(PS-Q)^2 \qquad (11)$$

After analyzing the right side of the equation, the value of D should be non-negative and $(PS-Q)^2$ is also non-negative, so the average value takes positive, and the equation (12) can be educed as follows:

$$E\left[(PS-Q)\frac{dD}{dt}\right]=PE\left[S\frac{dD}{dt}\right]-QE\left[\frac{dD}{dt}\right]>0 \qquad (12)$$

Taking the mathematics nature of the derivative average value being zero, we get the equation (13):

$$E\left[S\frac{dD}{dt}\right]>0 \qquad (13)$$

Furthermore, taking the function boundedness nature of SD integrable function, we can get the equation (14):

$$E\left[S\frac{dS}{dt}\right]<0 \qquad (14)$$

After multiplying D by the same on both sides of the first equation of the equation (1), taking that on average and using the equation (14), we get the equation (15):

$$Cov(D,I)-PCov(D,SD)-CCov(S,D)<0 \qquad (15)$$

After multiplying D by the same on both sides of the second equation of the equation (1),taking that on average, we can get the equation(16):

$$PCov(D,SD)-QVar(D)=0 \qquad (16)$$

Put the equation (16) and (4) into the equation (15), the equation (17) can be drawn:

$$Cov(D,I)-QVar(D)<0 \qquad (17)$$

This relationship implies that there can be two situations:

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$Cov(D,I) < 0$ or $0 < Cov(D,I) < QVar(D)$

So, we can get the fourth corollary:

The fourth corollary: for the HFCVs industry market system, there are two possible situations: First,I , the velocity function of S (the HFCVs supply amount of HFCVs industry market), is a negative correlation with D (the alternative fossil vehicles supply amount or the HFCVs increment demand amount being met). Second, their correlation degree would be less than the product between the fluctuation of D (the alternative fossil vehicles supply amount or the HFCVs industry increment demand amount being met) and$Q$, and more than zero.

4. CONCLUSIONS AND THE ENLIGHTENMENT TO INDUSTRY POLICY

Summing up, through the transformation type of Lotka-Volterra system model and taking on derivative average method, we analyze the evolution simulation natures of a relatively simple HFCVs market model. It is epitomized by the text of the inference of the four corollaries. Furthermore, we can discuss the simulation development of in HFCVs initial stage of industrialization:

First of all, based on the first inference, the development of the HFCVs industry can not be given much too expectation. The HFCVs market is at a higher level of vehicles markets in determining the upper and lower limits of convergence. We should considering the various industry-related factors with a clear understanding. HFCVs will not completely replace the existing fossil vehicles [10]. At the same time, while its process from lower limit to the higher, there will be a period of faster growth. The business-level industrialization should focus on the stage.

Second, based on the second inference, the external environment in the given conditions, the HFCVs supply expansion and the reduction of the size of fossil vehicles are not necessarily related. If the impact of technological progress and economic changes of fossil vehicles to HFCVs is given[11], the market of HFCVs industry development and alternative vehicles such as fossil vehicles are independent. And there is no influence to each other. From the technical line of the vehicle development, it reveals the significance and more rational thinking of a comprehensive HFCVs and fossil vehicles to the long-term development and planning.

Once again, based on inference three and four, although the evolution of HFCVs growth varied in market system, its average growth rate in the evolution may replace the increase speed. It may help to estimate a more accurate long-term HFCVs market scale. From the relationship of mutual impact [12], HFCVs market growth and reduction of fossil vehicles are either the opposite directions, or in the same direction. But the extent of interaction will be less than the self - fluctuation reduction of fossil vehicles.

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