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A SYSTEM DYNAMICS MODEL FOR BEIJING'S PRIVATE NEW ENERGY VEHICLES OWNERSHIP FORECASTING

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ABSTRACT

Beijing has a relative long history in new energy vehicles promotion and achieves series achievements. However, traditional fuel vehicle is still heavily outnumbered. In this paper, we build a system dynamics model to forecast Beijing's new energy vehicles ownership from 2017 to 2022. The simulation model also helps figure out how the policy, purchase price, psychology and usage affecting private new energy vehicles ownership.

Keywords: new energy vehicles, system dynamics, ownership, Beijing

NONMENCLATURE

Abbreviations

ICEV	Internal Combustion Engine Vehicles
NEV	New Energy Vehicle
PNO	Private NEVs Ownership
AD	Annual Demand
AS	Annual Scrap
GR	Growth Rate
PRF	Price Factors
USF	Usage Fees
PSF	Psychological Factors
POF	Policy Factors
RC	Road Congestion
EP	Environmental Pressure
PIO	Private ICEVs Ownership
AAPV	Average Area Per Vehicle
IIV	II Value
PR	Purchase Price
HDI	Household Disposable Income
UF	Usage Fees
CP	Charging Psychology
LWP	License Waiting Psychology
DE	Demonstration Effect
HO	Household Ownership
SDROCP	Supply Demand Ratio of Charging Pile
LWT	License Waiting Time

1. INTRODUCTION

Facing environmental issues, Beijing started NEVs' promotion since 2009[1]. Battery electric vehicle, plug-in hybrid electric vehicle, fuel cell electric Vehicle, are mainly what NEVs referred to[2]. As one of the 13 energy-saving and new-energy vehicle pilots[3], Beijing adopt series of policies. Coincided with the development route of national policies, the subsidy emphasis shifted from NEVs' purchase to their use, operation and charging infrastructure construction. Different from ICEVs' plate lottery, NEV license needs application and waiting in turn[4]. By the end of 2017, private electric vehicles has reached 124 thousand[5]and license application also sunk into long waits. As time goes by, the direct subsidies decrease, product requirements increase, market competition intensifies, also related technical advances.

System dynamics methodology was developed by Jay W. Forrester[6] and it's well-adapted for forecasting the development trend of a system[7]. It built system behavior relationship flowchart by bringing level variable, rate variable, information flow and other factors. More than qualitative description, it further specifies the quantitative relationship between the elements of the system[8]. Now the development of NEVs has become inevitable, it's essential to forecast its tendency. The NEV is a complex system and

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forecasting it fraught with uncertainty. In this paper, we took private car inventory as a standard and comprehensively analyzed the policy, price, psychological and use these four factors. Based on the relationship of each factors, we build a simulation model by a system flowchart, describing characteristics of variables and quantifying the private car inventory.

The rest of the paper is organized as follows. In Section 2, we build the model and give the main equations. And the model simulation is in Section 3. The conclusion is given out in last part.

2. THE MODEL

2.1 Basic assumptions

Assumption 1: Rich literature has shown that the demand of NEV consumers is mainly impacted by NEVs' price and usability, government policies, and consumers' self- psychology[9][10][11]. In this model, we imagine that only these four major factors influence demand growth rate.

Assumption 2: Apart from purchase price, consumers concern NEVs' range most[12].Now the 300km NEV prices at about 200,000RMB. In recent years the subsidies are fading and technical progress cannot be made overnight. So the purchase price in our model is assumed 200,000RMB and its markdown percentage is relatively slow.

Assumption 3: Per capita GDP, R value and II value

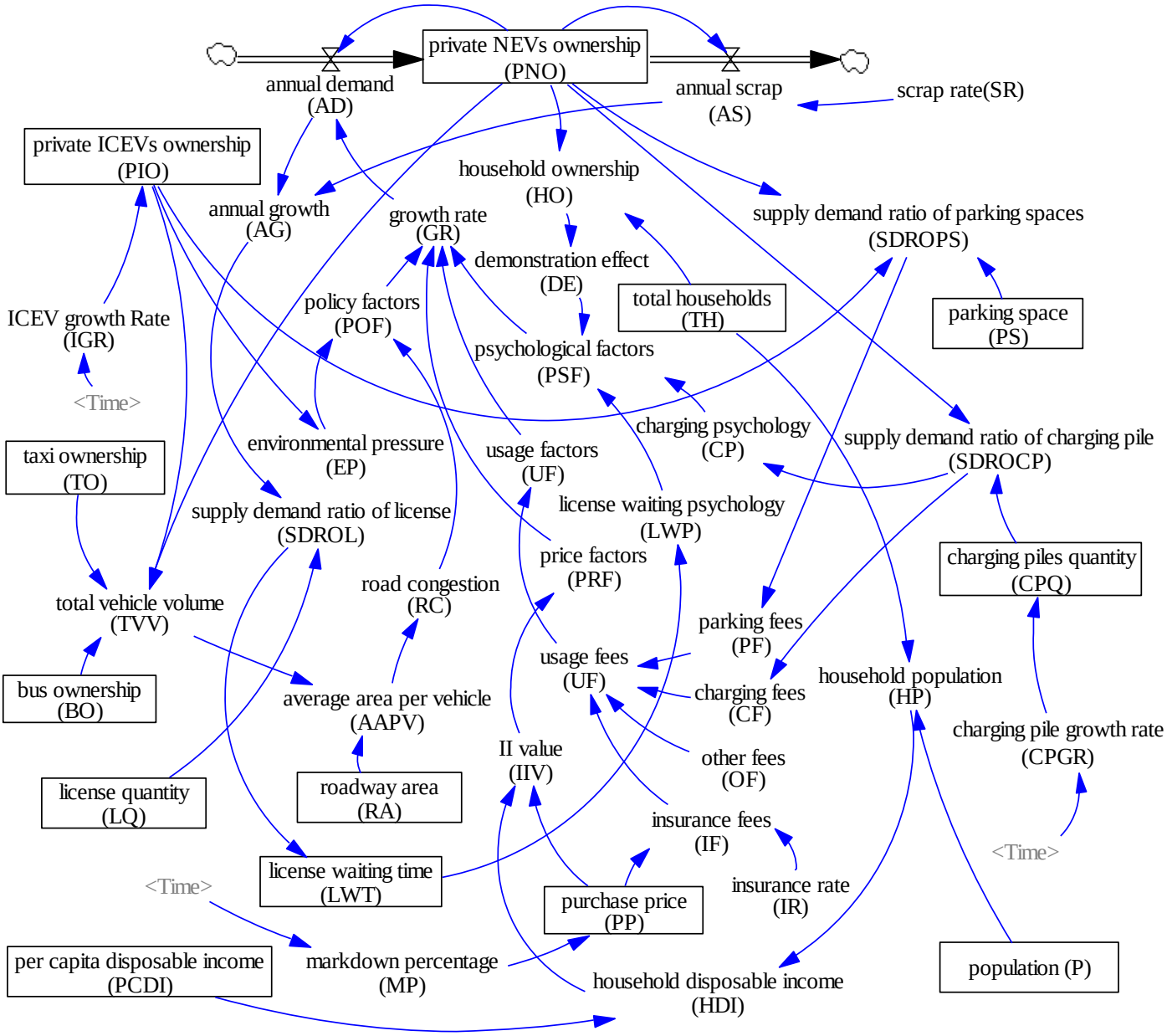

Fig 1 System Dynamics Flow Chart of New Energy Vehicle Ownership in Beijing.

are three important senses on predicting car can enter into family or not[13]. The II value based on purchase price and household disposable income determines the actual process of car entering the family. Our model choose the II value.

2.2 Model structure

We use Vensim DSS 5.9e build the model, as Fig 1 shown. The model contains 13 level variables, 32 auxiliary variables and 3 shadow variables.

2.3 Main equation

The table function is often appeared in our model. Table function is an important characteristic of system dynamics. It is used to describe the non-linear relationship between two variables, especially the relationship between soft variables[14]. The expression form of table function in Vensim software can be listed by choosing "with Lookup" in variable type selection. The "with Lookup" function contains an independent variable X, a dependent variable Y and a factor table of Y with respect to X.

$$\begin{aligned} Y = &with\ Lookup(X, \\ &([(\mathrm{minX}, \mathrm{MinY}) - (\mathrm{maxX}, \mathrm{maxY})], \\ &(\mathrm{X}_1, \mathrm{Y}_1), (\mathrm{X}_2, \mathrm{Y}_2), \\ &...., (\mathrm{X}_n, \mathrm{Y}_n))) \end{aligned} \tag{1}$$

Where:

X represents the independent variable

Y represents the dependent variable

minX represents the minimum value of the independent variable

minY represents the minimum value of the dependent variable

maxX represents the maximum value of the independent variable

maxY represents the maximum value of the dependent variable

$(\mathrm{X}_n, \mathrm{Y}_n)$ represents the the value of the nth X and the nth Y

In our model, private NEVs ownership and annual demand, annual scrap are mutual-determined. From the flow chart, it can be found that annual demand is affected by growth rate and annual scrap is affected by scrap rate. We assume the scrap rate is constant, So the decisive factor is growth rate. The policy, price, psychological and use factors directly influence the growth rate, below we list the main equations. We use abbreviation of every variables, the correspondence can be found in Fig 1. Also as many parameters involved in the model and the value relatively difficult to determine, we combine parameter selection with model operation.

$$PNO = AD - AS \tag{2}$$

$$\begin{aligned} GR = &PRF\text{^}0.3 * USF\text{^}0.35 * \\ &PSF\text{^}0.2 * POF\text{^}0.15 \end{aligned} \tag{3}$$

2.3.1 Policy factors

We choose environmental pressure and road congestion as two quotas influencing the government's policy. Private ICEVs ownership determines environmental pressure to some extent and so as average area per vehicle to road congestion. The equations are as follows.

$$POF = RC\text{^}0.4 * (1 - EP)\text{^}0.6 \tag{4}$$

$$\begin{aligned} EP = &with\ Lookup(PIO, \\ &([(500,0.6) - (500.005,0.78)], \\ &(500.001,0.67), (500.002,0.75))) \end{aligned} \tag{5}$$

$$\begin{aligned} RC = &with\ Lookup(AAPV, \\ &([(0,0) - (20,1)], (2,0.05), \\ &(3,0.2), (4,0.37), (6,0.65), \\ &(9,0.87), (11,0.95))) \end{aligned} \tag{6}$$

2.3.2 Price factors

II value is the ratio of purchase price and household disposable income. It is the decisive variable acting on price factors.

$$\begin{aligned} PRF = &with\ Lookup(IIV, \\ &([(0,0) - (10,1)], (0.1,1), \\ &(0.7,0.99), (1,0.97), (1.2,0.9), \\ &(1.35,0.68), (2,0.6), (2.7,0.55), \\ &(4.5,0.5), (10,0.4))) \end{aligned} \tag{7}$$

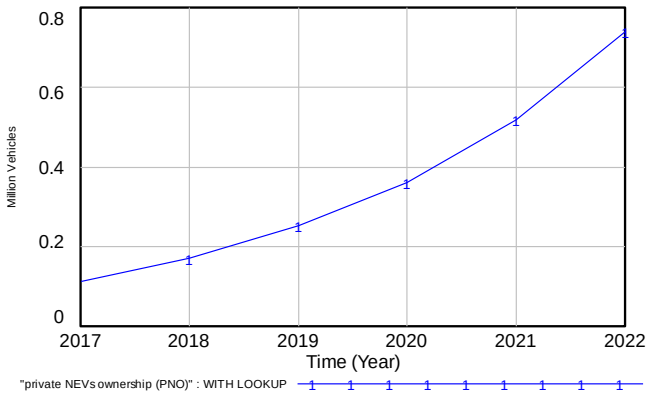

Fig 2 Initial simulation of Beijing's PNO trendency

$$IIV = PP / HDI \quad (8)$$

2.3.3 Usage factors

The usage factors mainly embodied in usage fees. Adding insurance fees, charging fees, parking fees, some other fees together is the usage fees.

$$USF = with\ Lookup(UF, ([(10000,0)-(30000,1)], (15000,0.87),(18000,0.73), (19000,0.65))) \quad (9)$$

2.3.4 Psychological factors

The psychological factors contain demonstration effect, charging psychology, license waiting psychology. Demonstration effect relies on household ownership, charging psychology depends on supply demand ratio of charging pile and license waiting time influences the waiting psychology.

$$PSF = CP\text{^}0.5 * \mathrm{LWP}\text{^}0.35 * \mathrm{DE}\text{^}0.15 \quad (10)$$

$$\mathrm{DE} = with\ Lookup(\mathrm{HO}, ([(0,0)-(0.3,1)], (0.035,0.17), (0.127,0.29),(0.252,0.43), (0.412,0.61))) \quad (11)$$

$$CP = with\ Lookup(\mathrm{SDROCP}, ([(0,0)-(2,1)], (0.167,0.76), (0.25,0.5),(0.75,0.3),(1,0.2), (1.5,0.1))) \quad (12)$$

$$LWP = with\ Lookup(LWT, ([(0,0)-(10,1)], (1.5,0.91), (2,0.75),(3,0.42),(5,0.24), (7,0.1),(8,0.09))) \quad (13)$$

3. SIMULATION

As shown above, the model purposely established for Beijing's private NEVs ownership forecasting. According to the existing circumstances and the statistics data of Beijing and NEV market, the simulation model is to calculate the NEVs private ownership changes in Beijing from 2017 to 2022.

3.1 Initial simulation

According to Beijing Statistical Yearbook 2018[15] and data from Beijing bus indicator management information system, the initial value of the level variable in the established model is set as Table 1 shown, the initial simulation results are based on these values. The Beijing's private NEVs ownership forecasting from 2017 to 2022 shown in Fig 2, showing a continuous strong rising trend. Actually our simulation value in 2018 is 17.1 thousand, almost close to the actual value 17.4[16] [17]thousand, in part explained the effectiveness of the model。

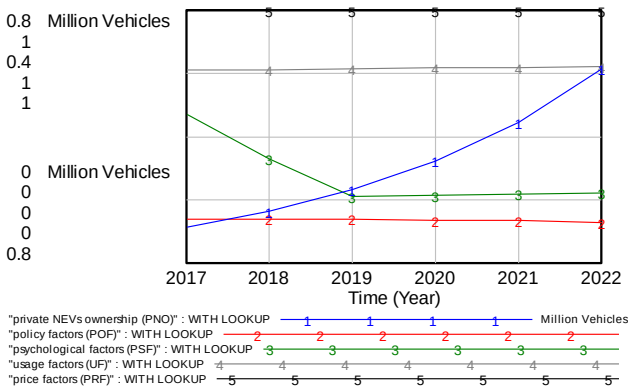

Fig 3 Impact of four factors on private NEVs ownership

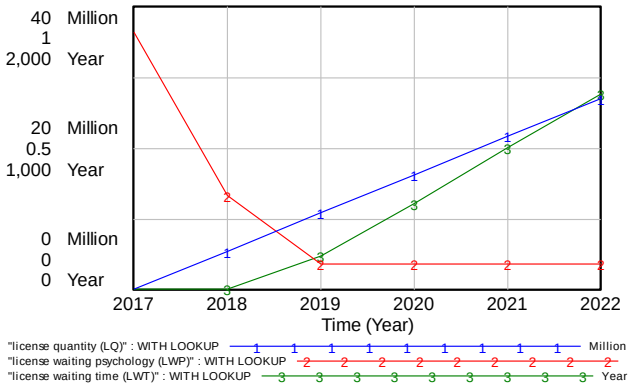

Fig 4 License waiting trendency

Apart from ownership forecasting, we aim at clarifying every factor's role in PNO trend change, which can be found from Fig 3. It showed that psychological factors have a side-effect on PNO. This because this factor contains demonstration effect, charging psychology, license waiting psychology. The former one has a positive effect, however, the latter two both take negative effect. Consumers have been concerned about the charging of the NEVs. Although governments put forward series of policies and subsidies to encourage public charging facilities construction[18], but it still far from consumers' psychological expectation[19]. More NEVs mean more charging facilities needed, causing more worries. As for license waiting psychology, it also plays negative role. According to the current trend, Beijing limits 54,000 NEV plates every year, but there

are significantly more citizens applied. All 2018 NEVs licenses has been exhausted, the ranking has reached 2021[20]. Too long to wait lower consumers' waiting psychology.

3.2 Sensitivity analysis

In our model we assume that the price markdown percentage is relatively slow. That's why price has little influence on ownership change. However, price is quite an important factor. To further explore this relationship, we change the price markdown percentage as Table 2 shown, then get Fig 5.

Table 1 Initial value of horizontal variables in system model

Variable	Type	Value	Unit
Private NEVs Ownership	Level	0.1197	Million Vehicles
Private ICEVs Ownership	Level	5	Million Vehicles
Taxi Ownership	Level	0.068484	Million Vehicles
Bus Ownership	Level	0.030996	Million Vehicles
License Quantity	Level	0.051	Million
License Waiting Time	Level	1	Year
Roadway Area	Level	46.01	Million square meters
Per Capita Disposable Income	Level	57230	RMB
Purchas Price	Level	200000	RMB
Population	Level	13.592	Million Person
Charging Piles Quantity	Level	0.023991	Million
Total Households	Level	5.431	Million Households
Parking Space	Level	3.82	Million
Insurance rate	Constant	0.04	1
Other Fees	Constant	4000	

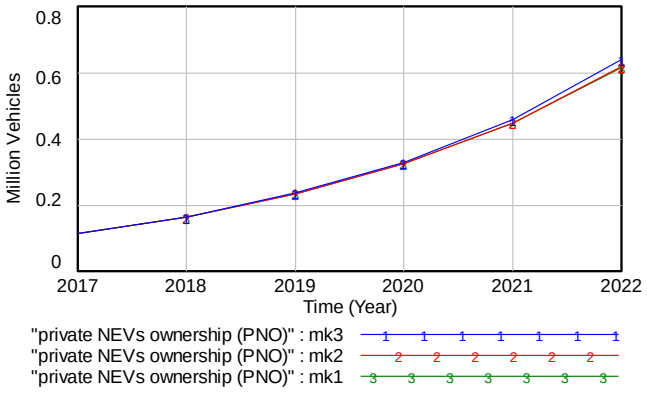

Fig 5 Private NEVs ownership and price factors

The corresponding purchase price shown in Table 3. Between the mk1 and mk2, the rate of purchase price reduction is slow, reflecting in the figure the ownership is almost no difference. However, mk3 situation has a large reduction after 2020, then the ownership start to emerging bigger gaps. That's could be explained that purchase price and household disposable income together influence the ownership. As time goes by, household disposable income increases, slight price reduction won't attract consumers much. Consumers are more rational, they concern more than just at price.

Table 2 markdown percentage in three circumstances

Time	2018	2019	2020	2022
MP(mk1)	0.005	0.008	0.01	0.015
MP(mk2)	0.01	0.015	0.018	0.020
MP(mk3)	0.1	0.15	0.17	0.2

Table3 purchase price in three circumstances

Time	2018	2019	2020	2021	2022
PP(mk1)	199000	198005	196421	194457	192026
PP(mk2)	198400	196813	194845	190018	182317
PP(mk3)	180000	162000	159570	132443	107941

4. CONCLUSION

New energy vehicle is still a developing industry in China. So taking Beijing as an example to forecasting its private NEVs ownership is of great importance. By building the simulation model using system dynamics mechanism , we forecast the ownership changing from 2017 to 2022 in the allowable range of error and study how policy, price, psychological and use these four factors influencing the ownership. According to our simulation result, psychological factors obviously has a negative influence and the other three are all positive. The appearance of the above result has some Beijing characteristics, but another cause is the imperfect technique and infrastructure. In our model, the simulation PNO in 2020 is 324.8 thousand, less than the target of 400 thousand[21]. It means that promotion efforts are still needed.

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