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Research Article

Impact of Social Network and Business Model on Innovation Diffusion of Electric Vehicles in China

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The diffusion of electric vehicles (EVs) involves not only the technological development but also the construction of complex social networks. This paper uses the theory of network control to analyze the influence of network forms on EV diffusion in China, especially focusing on the building of EV business models (BMs) and the resulting effects and control on the diffusion of EVs. The Bass model is adopted to forecast the diffusion process of EVs and genetic algorithm is used to estimate the parameters based on the diffusion data of Hybrid Electric Vehicle (HEV) in the United States and Japan. Two different social network forms and BMs are selected, that is, battery leasing model and vehicle purchasing model, to analyze how different network forms may influence the innovation coefficient and imitation coefficient in the Bass model, which will in turn result in different diffusion results. Thereby, we can find the appropriate network forms and BMs for EVs which is suitable to the local market conditions.

1. Introduction

As a technical innovation, EV has experienced a fluctuating popularity up and down over the last 100 years [1]. In the past 20 years, EVs again began to attract people's attention because of global climate change and increasing shortage of the world's oil resources. Generally speaking, technical innovation is the driving force to industry change but not the only one [2]. It can trigger the change but may not be sufficient to overwhelm the industry's dominant logic [3].

Under the background of industry change, constructing the social network is vital for the success diffusion of innovations [4, 5]. As to the automobile industry, the introduction of EVs is characterized by complex network. The successful diffusion of EVs relies on the integration of multiagent system to form the whole network [6]. The network of multiagent contains charging station operators, car manufacturers, consumers, parts providers, maintenance providers, government, and other organizations. These actors interact with each other and are interdependent, which makes the process and results of diffusion complicated and uncertain.

BM innovation which takes the construction of social network or value network as its core component is the key to break the existing technological lock-in [3]. Different BM may result in different forms of network and generate different economic value. That is to say, constructing social network through BM innovation can achieve the inherent economic value of an innovation [7–9]. A critical prerequisite of a sustainable BM of EV is that each agent in the network can gain benefit. Further, the ability of each agent, such as the fueling infrastructure operators, to benefit from the BM largely depends on the diffusion rate and scale of the EVs. Therefore, study on the relationship between social network, BM innovation, and market diffusion of EVs is critical to the search for the suitable EV BM and promoting innovation diffusion and marketization of EVs.

It is well known that the structure of a social network can favor or impede the diffusion of innovations in the network [10, 11]. Bass model, which is one of the most used diffusion models, describes the process of how new products get adopted in a social network [12, 13]. However, with

Table 1: Cumulative sales of HEVs in US.

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Sales	9350	20282	36035	47600	84199	209711	252636	352274	312386	290271	274210	268755

Data source: [15].

Table 2: Cumulative sales of HEVs in Japan.

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Sales	10000	22500	37400	50400	74600	91200	132500	196800	256600	346900

Data source: [16].

the difficulty to access relevant data, existing research on forecasting EV market diffusion is limited [14]. Existing research mostly concentrates on the influence on EV market diffusion by external factors such as price and infrastructure. Taking these factors into consideration, a market forecast model is established based on Bass diffusion model in this paper, analyzing influence by different forms of social networks in different BMs on the coefficient of Bass diffusion model and verifying the accuracy of the forecast model with the case study of Shenzhen.

2. Methodology

Bass model is established mainly on the basis of Rogers' innovation diffusion theory (1962), which defines the innovation diffusion as the process by which an innovation is communicated through certain channels over time among the members of a social system [17]. Communication channels are divided into two categories, public media and word of mouth. Rogers suggests that the adoption of an innovation follows an S curve when plotted over a length of time and adopters can be divided into five categories: innovators, early adopters, early majority, late majority, and laggards. Adoption choices and the time of adoption of the latter 4 categories are all influenced by the internal pressure of the social system, by which the pressure increases with the increase of adopters. Bass classified the latter 4 categories as imitators and established a model on the basis of Rogers' innovation theory, which is the Bass diffusion model. The model is shown as follows [12]:

$$\frac{f(T)}{1-F(T)} = p + \frac{q}{m}Y(T) = p + qF(T), \qquad (1)$$

where $f(T)$ is the possibility of adoption choice made by adopters or the proportion rate of adoption in the time T.

$F(T) = \int_0^T f(t)dt$, $F(0) = 0$, and $F(T)$ is the cumulative proportion of adopters in the time between 0 and T; p is the coefficient of innovation; q is the coefficient of imitation; m is the whole potential adopters of the innovative product; $Y(T)$ is the cumulative number of adopters in the time between 0 and T; $S(T)$ is the number of adopters at the time of T:

$$Y(T) = \int_0^T S(t)\,dt = m\int_0^T f(t)\,dt = mF(T),$$
$$S(T) = mf(T). \qquad (2)$$

The following result could be calculated from Formulation (1):

$$S(T) = \frac{m\left((p+q)^2/p\right)e^{-(p+q)T}}{\left(1+(q/p)\,e^{-(p+q)T}\right)^2}. \qquad (3)$$

Existing research on forecasting EV diffusion based on Bass model is limited. One of the important reasons is the difficulty to access relevant data. According to relevant research, forecast on coefficient could be based on the method of judgment, analogy, and so forth [18–22]. The method of judgment is to use external information to estimate parameters, such as information from experts. The method of analogy is to simulate according to diffusion data of analogous products. Besides, some optimization algorithms, such as genetic algorithms and ant colony algorithm, are increasingly applied in the innovation diffusion. Venkatesan and Kumar [23] believe that the parameter estimation result of genetic algorithm is better than that of other algorithms.

3. Diffusion Results of EVs in China under Different Business Models

According to Bass model, different p, q, m values will affect the diffusion rate and scale of an innovation product. EV BMs would have an impact on the innovation coefficient p and imitation coefficient q, thus affecting the market diffusion of EVs. According to Rogers, innovations could be classified along five dimensions, which are relative advantages, value compatibility, complexity, trialability, and the observability [17]. The BM, which can make early adopters' perception of EVs matching these five dimensions to the greatest degree, would have a higher innovation coefficient. Imitation coefficient q describes the process of communication and diffusion among imitators. The BM which is more suitable for word of mouth and has more possibilities to activate the choices of imitators would have a higher imitation coefficient.

3.1. Parameter Estimation. Considering that EV is still in the early stage of introduction and lack of available historical data for simulation, so we adopt the sales data of HEV as basis [14]. Since the time for HEV in Chinese market is short, we adopt the sales of HEVs in US and Japan and genetic algorithm to estimate the relevant parameters. The data and estimation results are shown in Tables 1, 2, and 3.

Table 3: Model estimation result.

Parameter	R^2	SSE $* 10^7$	m	p	q
Estimated value (US)	0.90	1911	2360513	0.0148	0.5676
Estimated value (Japan)	0.95	63	1020338	0.0032	0.4189

Determination coefficient R^2 is 0.90 in US and 0.95 in Japan, showing a good fit, particularly in Japan. Meanwhile, the innovation coefficient p is significantly smaller than the imitation coefficient q both in US and Japan, which is consistent with the general situation of innovation diffusion. This means that the diffusion of EVs would be relatively slow at the beginning and would be affected by the imitation coefficient to have an increasingly higher diffusion rate among consumers. In addition, Mahajan et al. [24] made a statistical summary of estimated value of p, q in a general condition as follows. According to this statistical summary, we can see that estimated result of data in Japan fits the statistical law better:

$$0.3 < p + q < 0.7, \quad p < 0.01, \; 0.3 < q < 0.5. \tag{4}$$

Figure 1 shows the comparison of HEV sales in actual condition and estimated value. It can be seen that the actual value of HEV sales fits well with the estimated value in both countries.

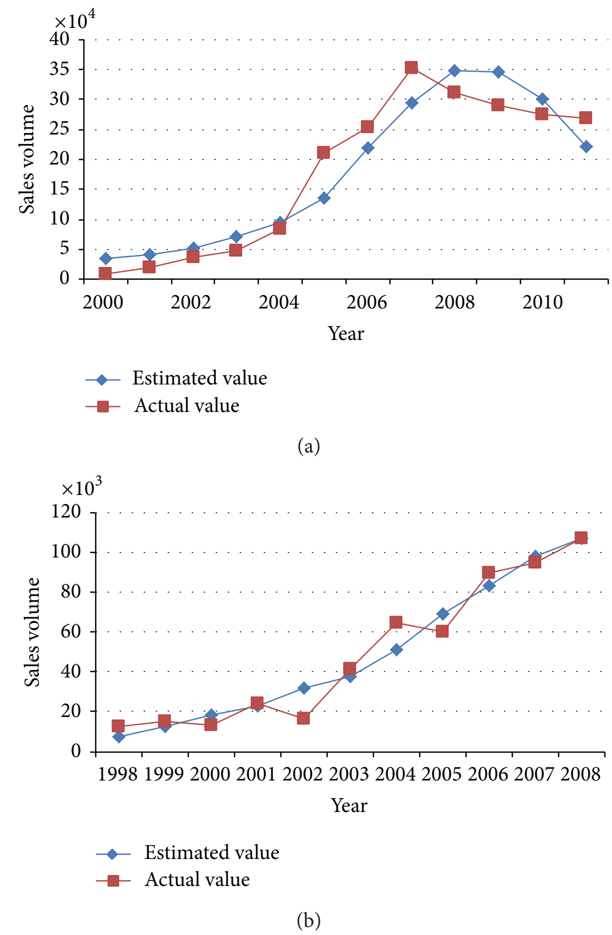


Figure 1: (a) Annual HEV sales in US. (b) Annual HEV sales in Japan.

3.2. Parameter Adjustment. Before using the above-mentioned parameters to forecast the EV diffusion in Chinese market, we need to adjust them according to the development of Chinese EV market so as to fit with the actual condition better.

3.2.1. Adjustment to the Value of m. The development of EVs in China is still in its infancy and is heavily influenced by policies, so the potential of Chinese EV market has a strong variability, which imposes uncertainty on the estimate of market potential [25, 26]. Taking all these factors into consideration, we choose the year of 2020 as the estimation time point of EV market's potential and assume that this potential is stable.

According to estimate of HIS company, the ownership of light-duty vehicles would achieve 0.15 billion by 2020 [15]. And some experts predict that EV sales in China would reach a 5% penetration in 2020 (data source: http://news.hexun.com/2009-10-24/121455528.html, accessed on December 4, 2013). So this paper assumes that market potential m in China would be 7.5 million by 2020. It is worth mentioning that the estimation value of m is based on the current development trend of EVs in Chinese market and only represents the volume that EV ownership would reach by 2020, not the whole market potential of future EV market.

3.2.2. Adjustment to the Value of p and q. In Bass model, innovators' purchasing decisions would not be affected by external pressure and p stands for the characteristic of the innovation [14], which varies not much among different countries. The differences between HEVs and ICEs are more evident, because HEVs and EVs both require a higher risk spirit for innovators. So, we choose the smaller value of p in the estimation of US and Japan. As to q, it mainly describes the impact of countries' economy, culture, politics, and population on innovation diffusion [27–29]. So we would need to adjust the value of q so as to make it more suitable for consumers in Chinese market.

According to the report *Accenture End-Consumer Survey on the Electrification of Private Transport* by Accenture in 2011, the proportion of positive choice made by Chinese consumers to the question "*Whether consider purchasing EV as the second car*" is much higher than US and Japan [30]. The survey results are listed in Table 4. We can also see that the acceptance ratio in US is higher than Japan, which is consistent with the estimation results of parameter q. Moreover, a survey from Deloitte also shows the same

Table 4: Acceptance ratio of EV from consumers of different nations.

China	Italy	Korea	Canada	US	Germany	Japan	Sweden	UK	France
95%	73%	70%	58%	57%	57%	53%	53%	51%	42%

Table 5: Comparison of q in US, Japan, and Taiwan.

Durable consumer goods	Monochrome TV	Washing machine	AC	Car
US	0.39	0.13	0.39	0.29
Japan	0.59	0.19	0.47	0.39
Taiwan	0.75	0.36	0.65	0.45

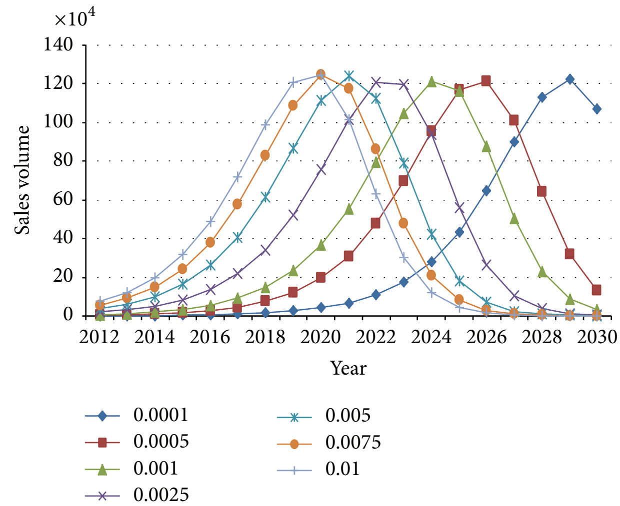
conclusion (data source: http://auto.sina.com.cn/news/2011-10-12/1947852631_6.shtml, accessed on December 4, 2013). Based on the comparison between China, US, and Japan, adjusting the estimated parameter q to be higher would be appropriate.

To further determine the exact adjustment figure of q, this paper adopts the study results by Takada [27], who compared the imitation coefficient q among three Pacific Rim countries and regions. Table 5 shows the comparison results and we can see that four kinds of imitation coefficient q in Taiwan are much higher than those in US and Japan. Moreover, in automotive industry, the coefficient in Taiwan is about 15% higher than that in US and Japan. Taking the condition in Taiwan into consideration, we adjust the above-mentioned parameter q into 0.6527.

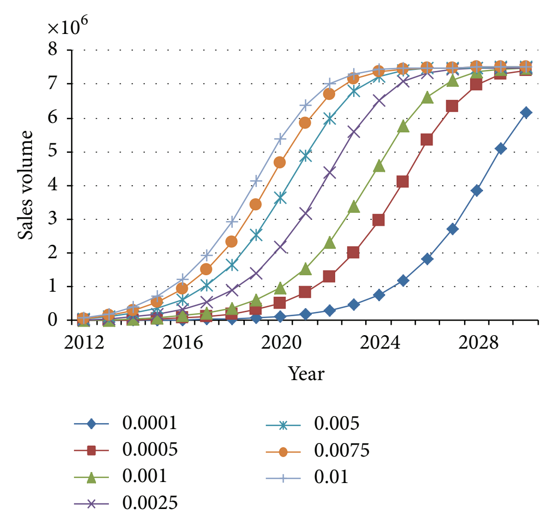
3.3. Diffusion Result of EV Market under Different BM. Since the values of p and q are not directly obtained on Chinese EV data, it would be more analyzable to forecast EV diffusion in China based on the different values of p and q rather than on using constant parameters. So this paper conducts a sensitivity analysis over p and q.

3.3.1. Sensitivity Analysis over Innovation Coefficient p. EV BMs in China could be categorized as two basic types: vehicle purchasing and battery leasing. Vehicle purchasing is more alike the traditional automotive BM, of which the value compatibility, complexity, and observability of innovations show more possibilities to improve early innovators' perception level of EVs, so the parameter p under the BM of vehicle purchasing should be higher than that under battery leasing BM. The results are shown in Figure 2.

Figure 2(a) shows the annual sales of EVs in China with different values of p and Figure 2(b) shows the cumulative sales with different values of p. We can see that the change of p affects slightly the sales of EV. However, the change of p affects directly the time required in the diffusion of EV reaching the critical mass, which is the key factor influencing the success diffusion of new products. When the threshold of new product diffusion is reached, the subsequent diffusion would no longer need to rely on the external variables, and the cumulative amount of the product itself can generate continuous growth momentum, attracting a sufficient number of potential consumers, thus completing the diffusion process of new products.



(a)



(b)

Figure 2: (a) Sales volume of EVs by p. (b) Cumulative sales volume of EVs by p.

3.3.2. Sensitivity Analysis over Imitation Coefficient. The battery leasing business model could reduce the price of EVs

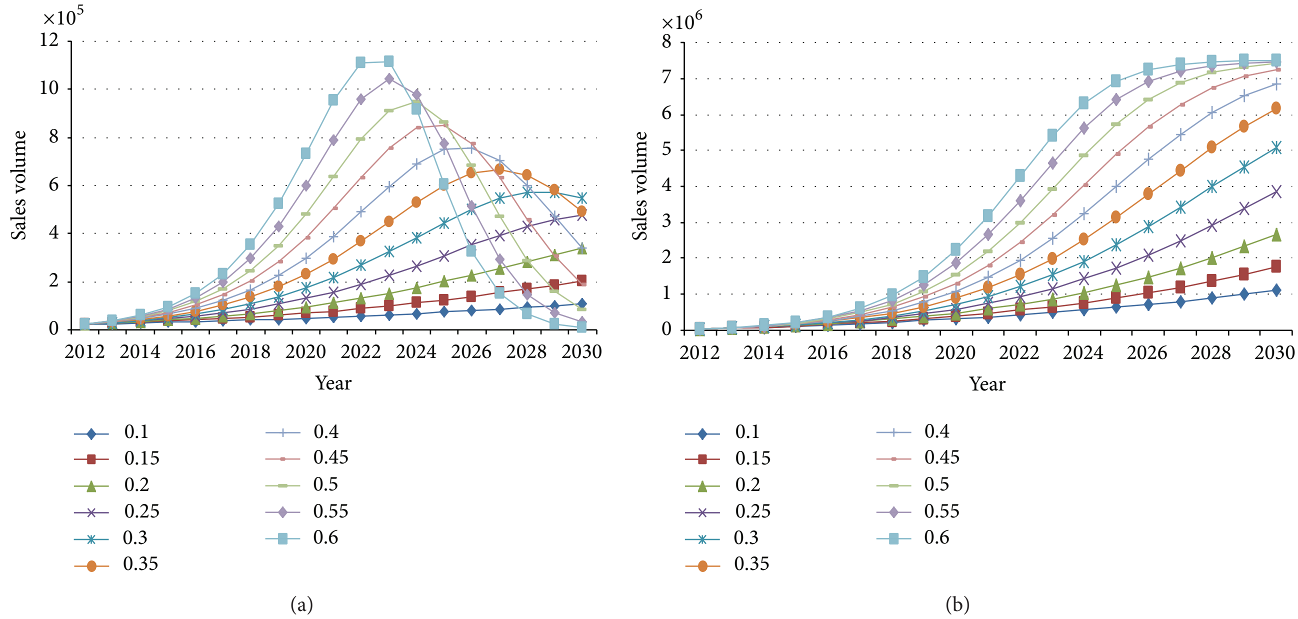


Figure 3: (a) Sales volume of EVs by q. (b) Cumulative sales volume of EVs by q.

and improve the convenience of battery charging and vehicle daily use, thus affecting more imitation coefficient q. That is to say, once the battery leasing model breaks the critical value of the initial stage of development, its diffusion rate would be higher than the vehicle purchasing model, which means that the imitation coefficient q under battery leasing model is higher than that under vehicle purchasing model.

In this paper, we could analyze the impact from different BMs on the sales of EV in China by giving different values to parameter q, of which the results are shown in Figures 3(a) and 3(b). Figure 3(a) shows the annual sales number of EV in China from 2012 to 2030 with different values of parameter p and Figure 2(b) shows the cumulative result with different values of parameter p.

Figure 3 shows that the change of parameter q affects slightly the time required for the sales of EV in China to reach the critical mass but affects significantly the maximum annual sales of EV in China. When the imitation coefficient increases from 0.1 to 0.55, the minimum annual sale increases from 0.2 million to 1.11 million, which is a big variation.

Figure 3 also shows that the slope of the diffusion curves with different imitation coefficients had a significant change after the diffusion of EV market reaches the critical value, which means the change of imitation coefficient directly affects the time required in EV market to reach the saturation. For example, when the imitation coefficient varies from 0.1 to 0.55, the time required for the EV market to reach saturation extends from the year of 2013 to 2047.

3.3.3. Economic Analysis of the BM. Based on the study of EV innovation diffusion, it would be possible to analyze the economy of EV BM. This paper adopts the EV BM in Shenzhen as an example because it is representative in China. Sosna et al. argue that a single case would be appropriate if the case is extreme, unique, or revelatory [31]. Chinese government launched a demonstration program Ten Cities, Ten Thousand Vehicles in 2009, and 13 cities (Batch I) were approved to carry out the demonstration, which was followed by 7 additional pilot cities (Batch II) and five more cities (Batch III). One aim of this program is to explore appropriate BMs for EVs through testing and implementing new BMs in the 25 demonstration cities. Among the 25 cities, Shenzhen is one of the "dual-pilot cities:" EV demonstration pilots and pilots of subsidizing private EV buyers. During 2009–2012, SZ has established two different BM models in taxi and bus sectors. The BMs are very representative in China and Shenzhen achieved large-scale commercial operation for the first time in electric buses and electric taxis areas. By June 2012, there are 3147 EVs out on the road in Shenzhen, which is the highest nationwide. So, we select SZ to conduct a case study.

The business model of EVs in Shenzhen can be categorized into the model of vehicle purchasing and it takes three years for Shenzhen to achieve the social network of EVs. This business model or social network is mainly made up of six groups, which are government, grid operators, infrastructure operators, auto manufacturers, taxi companies or bus companies, and consumers. In this social network, the government of Shenzhen is mainly responsible for policy development and financial subsidy. The government grants financial subsidy to the auto manufactures so that the manufacturers can sell the EVs at a relative lower price. In Shenzhen, one of the major EV manufactures is BYD. It sells EVs to taxi companies and consumers. China Southern Power Grid (CSPG) in Shenzhen is responsible for electricity supply and is one of the two infrastructure operators. The other infrastructure operator is China Potevio. The taxi company purchases EV taxi from BYD and the EV taxi is charged in

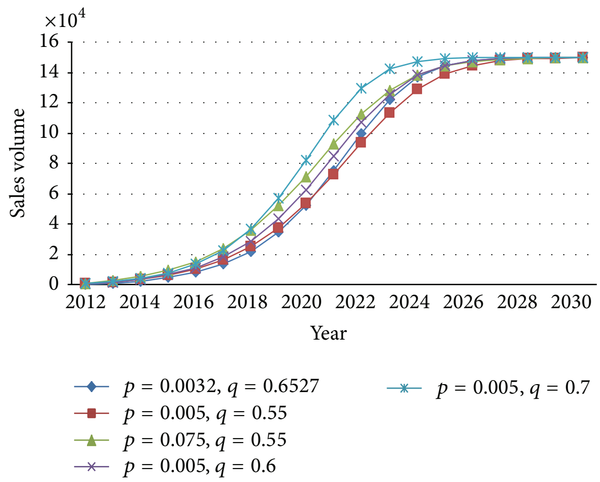


FIGURE 4: Different scenarios of EV diffusion in Shenzhen.

the charging stations run by CSPG and China Potevio. To sustain this social network, it is necessary for any of the agents such as infrastructure operators and EV manufacturers in this social network to get profit. The diffusion number of EVs in Shenzhen is one critical factor to determine the profitability for these companies.

According to the national and Shenzhen regional civilian and private car ownership statistics in 2009 and 2010, both civilian and private car ownerships in Shenzhen account for about 2% of the whole country [32, 33], so we assume that the proportion of EV sales in Shenzhen is also about 2% of the whole country. By setting five different groups of p and q, we can get the diffusion results of EVs in Shenzhen from 2012 to 2030 as shown in Figure 4.

Figure 4 shows that total ownership of EVs in Shenzhen varies from 4000 to 7000 based on different scenarios. According to [34], to achieve sustainable BM, EV charging stations in Shenzhen would need to serve 2,301 EVs every day to achieve breakeven under existing technical constraints. Currently there are four charging stations and this figure would reach 150 by 2015 according to the report *Electric Vehicle Charging Facilities Planning 2010–2015* released by Shenzhen government. Considering the competition, it would be difficult for each station to achieve the breakeven point. So, keeping the number of charging stations in a reasonable level is critical in maintaining the profitability of charging stations in the early stage of EV diffusion.

4. Discussion

This paper analyzes how different social networks would affect the EV diffusion results by the terms of different BMs. By affecting the innovation and imitation coefficients, different social networks would lead to different diffusion effects. Vehicle purchasing model has a higher innovation coefficient, which is conductive to promoting EV market to reach a critical value earlier. The other battery leasing model has a higher imitation coefficient, which would increase the maximum annual sales of EVs and shorten the time required for EV to reach saturation. This would further affect the time amount for different commercial agents to achieve profit in the networks. Estimation results indicate that innovation coefficient in China is not very high, while the imitation coefficient is much higher. It means once EVs are purchased by some innovators, it would diffuse quickly among the potential consumers, but it also means that if innovators were not satisfied with EVs, the negative opinions would also diffuse quickly in potential consumers and affect their choices and may lead to the failure of EVs. So we suggest that EVs should be positioned in a niche market precisely in the early stage and should not be marketed too rapidly. Meanwhile, early purchasers' needs should be met through a variety of tools and policies so that they can give positive word of mouth which can greatly influence the potential consumers in the network.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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