Analysis of Rapid Demand Variation in Electric Vehicle Industry based on Innovation Diffusion Theory

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Abstract. The emerging industries are usually driven by innovations and represent the development directions of advanced economic. Particularly, this manuscript explores the innovation diffusion and S-Curve theories to study emerging industries which are characterized with rapid demand variations, where the new energy vehicle industry serves as an example. The S-Curve is deduced in detail as a theoretical foundation for the study of the rapid demand changes of emerging industries. Based on authority data of vehicle sales in past decades, the NPS and EV30@30 scenarios from IEA are analysed to reveal the worldwide trend of electric vehicle industry. And as the largest market of new energy vehicles in the world, Chinese electric vehicle industry exhibits obvious impetus of government policies on the market development, and foresees a significant penetration of electric vehicles into traditional transportation sector in near future.

1. Introduction

The emerging industries typically exhibit some influential power in the market and represent the advanced economic future, such as the advanced telecommunication industry of 5G technologies, the shared bicycle industry abiding by sharing economic concepts, the e-business logistic industry, and the new energy vehicle industry. The emerging industries are usually driven by novel and complex technologies in different professional fields, and on the initial market stage of innovation and growth. The whole life cycle of emerging industries can be divided into the seed, startup, growth and maturity stages, where technical innovation and innovation diffusion are vital mechanisms to catalyse the market. With the quick development of internet technologies, a virtual and novel business community can be formed easily to cut down transaction costs, and innovation diffusions are speed up by eliminating the information barriers and the time and space constraints in business activities, then the market resources are allocated more effectively compared to the traditional market. Once the market explores a new, effective and economical innovation (a product or a service) to be the pain point solver, intense demand changes are catalysed by modern internet technologies. Also, the capital market shoulders an important mission to promote the innovation diffusion of emerging industries and drive the financial capital to serve the innovations better, by enhancing the combination of financial and industrial capitals and boosting the market of emerging industries. And resources allocation in
between technical and capital funds amplifies the market fluctuation of emerging industries and catalyses rapid demand changes.

2. Rapid Demand Variation is a prominent feature of emerging industries

For many years, the Chinese GDP growth is mainly driven by resource intensive or labour-intensive industries, and marginally by technical innovations and competitiveness. To enhance the quality of economic development, several industrial stimulus policies by the Chinese government has been planned, such as the “Outline of the National Medium and Long-Term Plan for Scientific and Technological Development (2006-2020)” and “Made in China - 2025” by the State Council of China in 2006 and 2016 separately [1]. The targets of these stimulus policies focus on fostering technical competences, supply chains of industries, environment protection, and advanced emerging industries. And the 4G and 5G telecommunication markets, the shared bicycle market, the new logistic industry, and the new energy vehicle industry show as the typical achievements of these stimulus policies.

The 4G communication market shows a typical development of blowout to gain the world’s telecommunication market since the first construction of 4G LTE commercial network by TeliaSonera, Ericsson and Huawei, in January 2009, which is characterized with impressive technical innovations such as higher data transmission speed, stronger interference immunization capability, and wider system compatibility. By the end of Q1 2020, there are 797 LTE network operators and 5.43 billion LTE subscriptions globally [2]. Now, the 5G network appears, targeting to the next generation of telecommunication market after 4G techniques, which is characterized with even more higher data transmission rates, much better energy efficiency, and ultra-high spectrum utilization. The GSA 5G Ecosystem report of July 2020 certifies the continuous market spreading of 5G devices. The announced 5G devices exceeded 200 in January 2020, and by the end of June 2020, 317 5G devices had been announced, and among them, 135 5G devices are commercially available. The construction of 5G commercial network will definitely continue to spread and lead to a sharp demand development of blowout.

The development of modern communication techniques has created many new business opportunities and forms, and the concept of “sharing economy” is one sweet fruit of the world-wide internet system to reconstruct the product values from “occupation” to “sharing of the use value”. The purchasers can own the rights of consumer and supplier simultaneously. The “sharing bicycles” industry is a typical application of the “sharing economy” concept, which was proposed to tackle the “last kilometre” problem of urban traffic congestion in one trip after the great market development of Didi Taxi and Uber. “Getting through the last kilometre” by “sharing bicycles” combines the concepts of green earth, low carbon, healthy exercise and fitness together as their business tokens, and overwhelms the Chinese market quickly. In 2017, just the second year of the new business form, the market of “sharing bicycles” grew greatly to a large scale of 100 billion Yuan market value and 200 million Chinese consumers, according to the IResearch Global statistics. Following was the fierce competition and market reshuffle in the obvious oversaturation market, which was driven and catalysed by capital investments. At the end of 2017, two top-line brands in “sharing bicycles” industry, OFO and Mobike were forced to be sold to industrial capitals, and the second or third-line brands, Bluegogo and Xiaoming Bicycles announced bankrupt, where intense demand fluctuation and rapid deterioration of competitive environment occurred.

Virtual business community based on advanced internet technologies breeds various e-business and on-line activities. The expansion of online consumption into public life is unstoppable in China. Based on the statistical trade data of the Ministry of Commerce of China, the online retail business has experienced decades of rapid development and will continue to grow, and the total internet retail sales reached 7.18 and 9 trillion Yuan in 2017 and 2018, respectively. Relying on the emerging techniques and opportunities, new business ecologies are prosperous, including electronic certification, third party electronic payment, big data analysis, cloud computing, and express logistics. Among them, the
logistics distribution network is the key foundation to support e-business era, and it becomes far more complex than the traditional one due to the huge scale of industrial and personal consumers, their various distribution requests and packages, and their punctual delivery requirements. According to the statistical data from State Post Bureau of China, the domestic express delivery volume has increased rapidly, from 9.19 billion in 2013 to 31.28 billion in 2016, an increase of 340.4%. According to the data of "Research Report on the prospects and investment opportunities of China's express industry in 2018-2023" released by the China Business Industry Research Institute, the express business volume reached 40.06 billion pieces in 2017. By 2018, China's express business volume reached 46.8 billion pieces, and the express income reached 572.5 billion Yuan. By the end of 2020, the express delivery business volume will reach the annual target of 74 billion pieces [3]. Obvious business successes are achieved by express giants like SF-express, JD.COM, STO-express, and so on, to satisfy the rapid growth of parcel distribution demands, and the logistics distribution market continues to be recast with complex distribution conditions and labour costs.

This manuscript chooses the new energy electric vehicle industry as the example to analyse the market characteristics of rapid demand changes, since this industry represents the global efforts to solve or alleviate the earth crisis of energy shortage, air pollution and climate change, by substituting general fuel vehicles with new electric ones. Currently, the best power sources of electric vehicles are from lithium ion batteries (LIBs) which are characterized with the advantages in high-energy density, low self-discharging rate and long cycle life. According to the 2019 annual report of China EV100, the market sales of new energy vehicles had reached 1.242 million, and there are about 3.44 million new energy vehicles in China by the end of 2019. And the market sales of battery electric vehicles (BEV), plug-in hybrid electric vehicles (PHEV) and fuel cell vehicles in 2018 are 984, 271 and 1.527 thousands, respectively [4].

3. The innovation diffusion theory for the market analysis of rapid demand variation

“Innovation” is a new object, an advanced method or a novel event to the adopter. It is not important for the innovation adopter to acknowledge whether the “innovation” is founded for the first time or not, but to believe that the emerging thing is new by adopter's subjective judgment. The erratic, confused feelings and responses of adopters to the “innovations” guide the “innovation diffusion” process in between social members, in a period of time and with some specific channels. As one special type of information dissemination, a two-way convergence process exists while the individual adopters try to pass information to potential recipients. Specific dissemination conduct or event in “innovation diffusion” can be accurately described by the theory of dissemination in human society, where the innovation, dissemination channel, time and social system are major factors[5].

This manuscript applies the innovation diffusion model which was proposed by Rogers in 1962 [6]. An emerging technique experiences a life cycle from initial commercial deployment, popularization and wide adoption, to its dying out, which can be described by the innovation diffusion model. In 1969, Bass proposed the infectious model, a famous and widely adopted approach of innovation diffusion model [7], where innovators and followers are defined in buyers of an innovative product or service. In the emerging market of innovative product or service, the innovators adopt the product or service first based on their subjective judgments on some external factors like the mass media propaganda, and the followers will be influenced by some internal factors such as consumer impartation and imitation, where a positive correlation between the adopter population and purchase behaviour of followers can be found. The innovation diffusion process and its demand changes can then be described by setting a mathematical model, and its industrial evolution process can be analysed. Following is the derivation process of the BASS (or S-Curve) model based on innovation diffusion theory.

For a given consumer durable, the first Equation (1) defines the linear relationship between the acceptance possibility P(t) for the first time and the current adopter population Y(t) of this innovation, at a given time t.

\[ P(t) = p + q \frac{Y(t)}{m} \]  

(1)
Here, the constant $p$ is called innovation factor, referring to the preference of innovators and the acceptance probability of a consumer durable at initial stage in a social system. The constant $q$ is called imitation factor, referring to the pressure from social system on imitators. And the constant $m$ refers to the total population of all innovation adopters throughout the product cycle.

Equation (2) defines the relationship between $f(t)$, the ratio of adopter numbers at time $t$ to the final adopter population throughout the product cycle, and $F(t)$, the accumulative ratio of adopter numbers at time $t$.

$$P(t) = p + q \cdot F(t) = \frac{f(t)}{1-F(t)} \quad (2)$$

Equation (3) can be derived from Equation (2).

$$f(t) = \frac{dp(t)}{dt} = p + (q-p) \cdot F(t) - q \cdot [F(t)]^2 \quad (3)$$

Define $F(0)=0$, and solve the above equations to get the relation expression of $F(t)$ with time $t$, as following Equation (4).

$$F(t) = \frac{1-e^{-(p+q)t}}{p} e^{-(p+q)t+1} \quad (4)$$

Equation (5) defines $Y(t)$, the accumulative number of adopters within interval $(0,t)$.

$$Y(t) = m \cdot \frac{1-e^{-(p+q)t}}{p} e^{-(p+q)t+1} \quad (5)$$

Equation (6) defines the relationship between $f(t)$ and time $t$.

$$f(t) = \frac{(p+q)^2}{p} \left[ e^{-(p+q)t} - \left( \frac{q}{p} e^{-(p+q)t+1} \right)^2 \right] \quad (6)$$

Equation (7) defines the first-order inflection point of the $F(t)$ curve, a time point which can be derived from $f(t)$ and correspondsto an extreme value of the adoption rate for the new product:

$$t^* = \frac{1}{p+q} \ln \left( \frac{q}{p} \right) \quad (7)$$

Equation (8) defines the second-order inflection point of the $F(t)$ curve, a time point when the adoption acceleration rate reaches extreme value.

$$t^{**} = \frac{1}{p+q} \ln \left( 2 - \sqrt{3} \right) \frac{q}{p} \quad (8)$$

The time point $t^{**}$ is usually treated as the market take-off moment, and the corresponding adoption population reaches a key scale.

Fig 1. shows one S-Curve example based on above derivations, and the $m$, $p$, $q$ parameters are $1$, $0.001$ and $0.3$ respectively. Following is the model interpretation:

1) At the beginning, the innovation diffuses slowly, then at the time point $t^{**}$, the diffusion gets the maximum acceleration rate, and at the time point $t^*$, the maximum adoption ratio is reached. The curves in the periods of $[0,t^*]$ and $[t^*,2t^*]$ are symmetric;

2) When $q>p$, the equations get positive $t^*$, and the curve $f(t)$ of the successful diffusion can reachesits highest point at $t^*$. When $q<=p$, there is no positive $t^*$, and adoption ratio of the failed diffusion will decline with time.

3) The above derivations reveal that the critical time points of $t^{**}$ and $t^*$ are decided by innovation factor and imitation factor, not related to the market scale.
4. Analysis of the global new energy vehicle industry based on BASS model

In Global EV Outlook 2019, IEA proposed two measurement models: NPS (The New Policies Scenario) and EV30@30. The NPS model is IEA's major prediction model for the world energy outlook, which may be considered somewhat conservative but integrated with the collection of specific policies and development goals around the world. As for the EV30@30 model, its data is based on the EV30@30 Campaign development declaration, which was signed by EVI member countries including China, EU, Japan and India in 2017. EVI is an international organization advocating electric transportation, affiliated to IEA. The EV30@30 Campaign set an aspirational goal to reach 30% sales share by 2030 for electric new energy vehicles in light-duty vehicles, buses and trucks. If the target can be hit, accompanied with the half cut down of carbon consumption in electricity supply, the carbon reduction goal at 2030, set on Paris Agreement signed at the UN Climate Change Conference on December 12, 2015, can also be hit.

In this manuscript, based on the predicted data from IEA's NPS and EV30@30 models, the following innovation diffusion curves represent the market shares of global new energy passenger vehicles in two situations, as shown in Fig. 2.

Based on the S-Curve analysis, the innovation factor \( p \) and the imitation factor \( q \) in the NPS model are \( 6.46 \times 10^{-4} \) and 0.158 respectively. It is expected that the market would take off in 2031-2032. The innovation factor \( p \) and the imitation factor \( q \) in the EV30@30 model are \( 2.51 \times 10^{-4} \) and 0.250 respectively. It is expected that the market would take off in 2027-2028.

This manuscript also conducts a fitting analysis through innovation diffusion model based on actual sales data provided by China EV100 and sale goals from "Technology Roadmap for Energy Saving and New Energy Vehicles". The coefficient \( m \) is set as 36 million, the 90% of the total vehicle sales in 2025 predicted by CPCA (China Passenger Car Associate). The S-Curve is obtained in Fig. 3.

Based on the S-Curve analysis, the innovation factor \( p \) and the imitation factor \( q \) are \( 1.10 \times 10^{-3} \) and 0.272 respectively. It is expected that the market would take off in 2026 - 2027, with the relative key scale factor being about 7.8 million vehicle sales.

![Figure 1. The S-Curve sample (m=1,p=0.001,q=0.3).](image1.png)

![Figure 2. Analysis of the Proportion of Global Sales of New Energy Passenger Vehicles in All Passenger Vehicle Sales](image2.png)
Figure 3. S-Curve of Annual Sales of Chinese New Energy Vehicles Based on CPCA Data and Chinese Government Planning

Data predicted by IEA's NPS model match policies that have been promulgated or implemented by global countries, where 12.5 million and 22.3 million electric vehicles will be sold worldwide in 2025 and 2030 respectively, and the market share being about 7.65% and 15.6% respectively. As predicted by the EV30@30 model, 43.15 million electric vehicles would be sold worldwide in 2030, accounting for 31% of the total vehicle market. It can also be predicted that the development of electric vehicles will be greater in urban areas than in rural areas due to more demands and better recharging infrastructure in urban areas. Additionally, elevated market promotions by governments, such as stricter fuel consumption and tax standards, would help BEV vehicles take up a larger market share than plug-in hybrid ones.

The NPS model is more consistent with the current capacity expansion planned by the world's major vehicle manufacturers, while the EV30@30 model goes above the announced capacity arrangement. Therefore, to achieve EV30@30 targets, it is necessary for global governments to exert more aggressive efforts. As shown in Fig 3., the Chinese market take-off point (2026) is close to the global EV30@30 scenario (2027) of new energy vehicle sales, which fully signifies the crucial Chinese role in the global market, especially in 2019 when more than half of the new energy vehicles were sold in China. That also manifests the tremendous positive influence of the Chinese government in new energy development. But compared with the more realistic NPS model, Chinese market was probably pushed ahead too fast, and market fluctuations already emerge currently, especially when market subsidy reduction is under implementation.

Also, statistic data shows that Chinese market for all vehicles will step out the growth spurt and level off in the next decade. However, the Chinese new energy vehicle market will enter ‘sharp change’ stage in 2026 or so, after experiencing the ‘gradual change’ stage. This means the arrival of ‘upheaval’ stage of the vehicle market for the substitution of traditional fuel vehicles with new energy ones, which will profoundly influence the performances of market entrants and users. Besides, the new energy vehicles will also gain extra market growth through the popularization of auto vehicles, and will fluctuate with demographic changes in China.

5. Conclusion

In the past decade, many advanced emerging industries, like 4G/5G telecommunication, ‘sharing bicycles’, new logistic system and new energy vehicles were boosted by novel techniques and economic stimulus policies. From development to maturity stages, a large number of small and medium-sized enterprises are rapidly growing up or dying out in fierce competition in a short period. The market exhibits obvious demand fluctuations, and the innovation diffusion model can be applied here for accurate description of innovation dissemination. In this manuscript, the innovation diffusion and S-Curve model is introduced for the evolution analysis of emerging new energy vehicle industry. Policies clearly shows a major impetus on the development of electric mobility, and the world will probably experience a big growth spurt of electric vehicle sales in the next decade, especially in Chinese auto market. Whether the electric vehicle industry can take off smoothly depends on whether it
can enter the mass market by winning more innovation adopters or pragmatists, besides the aid from government policies.

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