



The path and effect of technology lock-in in the automobile manufacturing industry

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SUMMARY: *“Technology lock-in” has become an important reason hindering the dynamic upgrade of China's manufacturing global value chain. Technology lock-in generally goes through five stages: marketization, systemization, application, institutionalization, and socialization. Among them, marketization is a key link in the formation of technology lock-in and system lock-in. Since traditional fuel vehicle technology has been locked in the fossil fuel-based energy system, the application range of new energy has been restricted. Therefore, getting rid of the lock-in of traditional fuel vehicle technology is the key to the leap-forward development of the new energy vehicle industry, not just the technological innovation of new energy vehicles. From the perspective of the automobile manufacturing industry, this article analyzes the locking factors and formation mechanisms that affect traditional fuel vehicle technology and new energy vehicle technology and uses and expands the Arthur model. Based on Matlab simulation, it better presents the impact of fuel vehicles. The locked-in relationship of automotive technology.*

KEYWORDS: *fuel vehicle technology; new energy vehicle technology; network effect; technology lock-in*

1 Introduction

As China's manufacturing industry has continuously expanded its integration into the Global Value Chain (GVC), and its depth has continued to expand, from 1995 to 2011, the participation rate of my country's manufacturing industry in the global value chain rose from 26.43% to 40.56% [1]. In 2020, the Ministry of Industry and Information Technology announced at the National Industry and Informatization Work Conference that from 2016 to 2019, my country's manufacturing industry will have an average annual growth rate of 8.7%, from 20.95 trillion yuan to 26.92 trillion yuan, accounting for 28.1% of the global share [2]. However, the high participation rate of GVC does not mean that the status of GVC participation is high. While the manufacturing industry continues to grow and develop, “technology lock-in” has become an important factor hindering the dynamic upgrade of China's manufacturing global value chain.

The phenomenon known as technology lock-in refers to the persistence of a technology's competitive advantage for a certain duration after it has initially established that advantage. Earlier studies posited that the obstacles encountered in the manufacturing innovation process stem from the intentional utilization of the lock-in effects associated with outdated technological trajectories. In the context of automotive technology, new energy vehicles face a paradox characterized by the phrase “appropriate but not popular.” This situation arises because

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traditional fuel vehicle technology is entrenched within a fossil fuel-based energy system, thereby constraining the application of new energy vehicle technology[3]. For instance, the development of necessary infrastructure such as gas stations and roads, as well as the involvement of various stakeholders[4]—including automobile manufacturers, consumers, industry associations, and traffic management agencies—are significantly impacted[5]. The establishment of regulations, traffic laws, and industry standards underscores that overcoming the lock-in associated with traditional fuel vehicle technology is crucial for advancing to next-generation vehicles[6]. Research on the lock-in of traditional fuel vehicle technology has evolved from a focus on individual technological systems to a more comprehensive understanding of systemic lock-in. Steinberg (2022) argues that the dynamics of increasing returns contribute to the formation of a complex technological system during the co-evolution of technology and its associated systems, ultimately leading to the lock-in of traditional fuel vehicle technology[7]. Furthermore, Abedsoltan (2024) analyzed this phenomenon from multiple perspectives, identifying that the formation of the traditional fuel vehicle technology system involved technical, systemic, and social lock-ins, which collectively intensified the overall lock-in effect[8].

In summary, the technology lock-in associated with traditional fuel vehicles pertains to the established energy technology system centered around fuel vehicle technology, which has evolved throughout the automotive industry's development. This traditional fuel vehicle technology not only dictates the developmental trajectory of the automotive industry but also constrains the application and promotion of new energy vehicle technologies.

2 The formation of the traditional fuel vehicle technology system lock-in

The formation of the traditional fuel vehicle technology system is characterized by the emergence and reinforcement of a "technology lock-in" associated with traditional fuel vehicles. This process undergoes five distinct stages of industrialization: marketization, systematization, application, institutionalization, and societal integration. Each stage contributes to the development of various forms of lock-in: technology lock-in, which makes it difficult to transition from the dominant automotive technologies; system lock-in, which complicates changes to the technical systems of fuel vehicles; application lock-in, which hinders shifts in consumer preferences and usage patterns; institutional lock-in, which poses challenges to the regulatory frameworks governing fuel vehicles; and social lock-in, which renders the socio-economic system resistant to change[9]. These five levels of lock-in effects are mutually reinforcing, culminating in the establishment of a traditional fuel vehicle technology system lock-in (see Figure 1). Notably, marketization serves as a critical link in the formation of both technology lock-in and system lock-in.

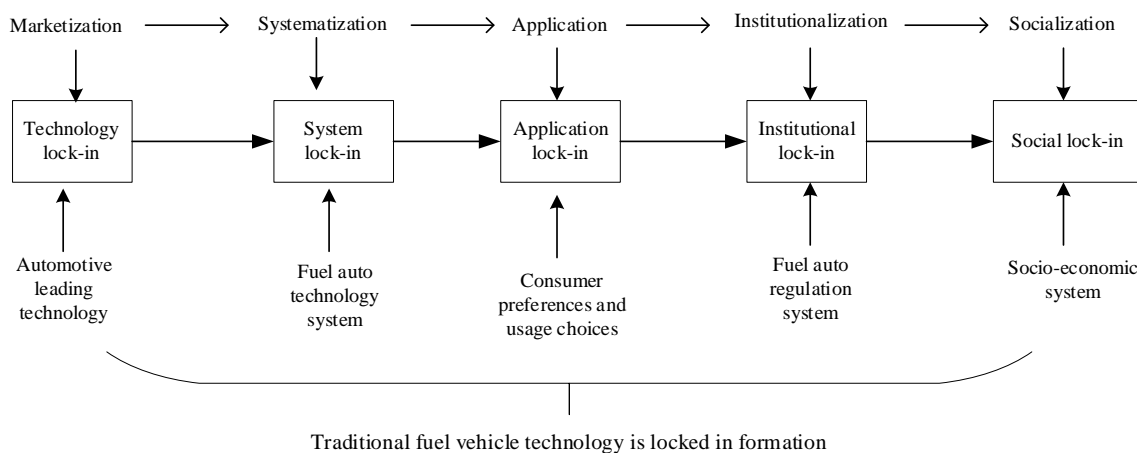


Figure 1: The formation process of traditional fuel vehicle technology system lock-in

2.1 Traditional fuel vehicle technology lock-in

In the early stages of fuel vehicle technology development, various competing technologies with differing environmental performances emerge through activities such as invention and innovation. When a particular fuel vehicle technology reaches the market's "critical volume" [10] (attraction wall), it becomes the de facto standard for that type of technology, known as the dominant technology. The dominant technology is not a single entity; rather, it is neither the best technology nor the most advanced. It typically manifests as a set of characteristics of a new product or a combination of several technological innovations represented in various earlier product designs, ultimately taking the form of a new product. Simultaneously, it aims to meet the diverse needs of users for a specific product to the greatest extent possible, targeting a broad, undifferentiated market and occupying the largest market share. Following the emergence of the dominant technology, it begins to "lock" into a specific technological path and develop along that trajectory. The dominant technology is characterized by a dynamic development process, influenced by advancements in economy, society, and technology. Leading technologies will continue to evolve and improve. Some technical components, as constituent elements, may be replaced, or new technical components may be introduced, while unique designs that were once distinctive features of certain products may be adopted and integrated across the entire industry into the leading technology [11]. For instance, after the dominant design of the American automobile industry was largely established in the 1920s, hydraulic brakes and power control systems became standard equipment in automobiles by the late 1930s and late 1960s, respectively (as shown in Table 1). The use of fossil fuels, supported by mature technology and low fuel prices, provides a distinct competitive advantage for fuel-powered vehicles. Consequently, many automobile manufacturers have adopted fuel-powered vehicle technology, which has led to its dominance in the automotive sector. This dominance has resulted in a technical lock-in for traditional fuel vehicles.

Table 1: The formation and development of leading technologies in the U.S. automotive industry

Characteristics	First use	Widely adopted
Speedometer	Used for Ozmoresby in 1901	Circa 1915
Automatic gearbox	First installed in 1904	Introduced as an option in 1938; In the early 1950s, luxury cars such as Cadillac were standard equipment.
Electronic lamp holder	General was introduced in 1908	It became standard in 1916
All-steel enclosed body	GM was introduced in 1912	It became standard in the early 1920s
Radio	Appeared as an option in 1923	It became standard in 1946
Four wheel drive	Appeared in 1924	By 1994, it had been use only to a limited extent
Hydraulic brake	Introduced in 1924	It became standard in 1939
Shatterproof glass	Introduced in 1927	Ford made it a standard in 1938
Power operation	Introduced in 1952	It became standard in 1969
Anti-lock brakes	Introduced in 1972	GM made it a standard in 1991
Airbag	GM was first adopted in 1974	By 1994, most of the new cars had been introduced

2.2 The traditional fuel vehicle technology system locks in

The further marketization of leading technologies will lead to the continuous enhancement and development of complementary technologies and assets associated with them. Consequently, the market share of fuel vehicle technology is expected to expand rapidly, leading to the establishment of an automotive technology system centered around fuel vehicle technology. In the production process of fuel vehicles, learning effects, such as 'learning by doing' and 'learning by interaction,' have consistently improved the performance of key technologies, including engines, while enhancing their reliability and efficiency. For instance, in 1957, German engineer Wankel invented the rotary piston engine, which has 40% fewer parts than the reciprocating piston engine, and features characteristics such as lightweight construction, high speed, compact size, and high power output. Additionally, with the rapid expansion of expressway mileage in my country, the number of gas stations has also seen a significant increase. In 1990, there were only over 5,000 gas stations, but by 2015, this number had surged to 113,593. The increase in gas stations has improved the convenience, practicality, and reliability of fuel vehicles, thereby strengthening the leading technologies associated with them. This has led to a rapid increase in the conversion costs of fuel vehicle technology and hindered the transformation of fuel vehicle technology systems, ultimately resulting in a system lock-in effect for traditional fuel vehicles.

2.3 Application locking of traditional fuel vehicle technology

The technical and system locking of traditional fuel vehicles has significantly advanced the development of fuel vehicle technology. During the production process of these vehicles, many automotive technology developers rely on established fuel vehicle technologies, such as engine technology and transmission systems. For instance, at the onset of designing and developing new models, Toyota Motor Corporation incorporates considerations related to fuel vehicle technology from the beginning to the end of the process. This approach ensures that the design and development of new models have a clearer objective: to align more closely with market

demands and consumer preferences regarding car design, driving experience, and functional positioning. Consequently, this has accelerated the development, production, and market entry of new models, enhancing their competitive advantage while simultaneously fostering the continuous improvement and optimization of fuel vehicle technology systems, thereby reinforcing the application of traditional fuel vehicles.

2.4 Institutional lock-in of traditional fuel vehicle technology

As fuel vehicle technology remains the predominant approach, it is essential to ensure the proper functioning of fuel vehicle technology systems and the establishment of a regulatory framework for fuel vehicles. Consequently, specifications for the production and use of fuel vehicles will be developed, encompassing aspects such as vehicle production technology, driver behavior, and management conventions. This focus may inadvertently cause stakeholders in fuel vehicle technology—comprising developers and users—to overlook alternative technologies, thereby creating a system lock-in effect for traditional energy vehicles.

2.5 Socialized lock-in of traditional fuel vehicle technology

The technical system of fuel vehicles has gradually gained public acceptance, becoming an integral part of the social cultural framework. This system has established a mode of travel, lifestyle, and social ideology that aligns with the characteristics of fuel vehicles. For new energy vehicles to effectively replace traditional fuel vehicles, they must not only match them in terms of functional utility but also necessitate a shift in public attitudes towards travel and lifestyle. This requirement undoubtedly complicates the transition from traditional fuel vehicles to new energy vehicles, resulting in a social lock-in effect for traditional energy vehicles. The interplay of technological, systemic, application, institutional, and social lock-ins, which have developed during the evolution of the traditional energy vehicle technology system, has reinforced one another. Consequently, the advancement of automobile technology has become entrenched within the traditional fuel vehicle paradigm, hindering the transition to low-carbon and environmentally friendly alternatives. Furthermore, the high costs associated with new energy vehicle technologies pose significant challenges in competing with the established traditional fuel vehicle technology system in the short term.

3 The technical lock-in of traditional fuel vehicles to new energy vehicles

3.1 The basic idea of the Arthur model

The fundamental concept of the Arthur model posits that when two new technologies compete in the same market, users exhibit preferences for either technology. The selection of technology by users is random; however, the different technologies yield varying benefits. At a particular moment, influenced by a random factor, the user base for one technology may experience a sudden increase. This surge indicates that the technology has reached a level of maturity, prompting users who initially adopted alternative technologies to switch to this more favorable option. Consequently, this technology gains a relative advantage in the competitive landscape, which it can sustain for a certain period. The fluctuations in market share during this competitive process resemble a random walk constrained by a “suction wall” [12, 13].

3.2 Arthur model and numerical simulation

(1) Model assumptions

Suppose that in the automobile market, traditional fuel vehicles (G) and low-carbon and environmentally friendly new energy vehicles (E) compete with each other. The car user i enters the market at a period t and is divided into two categories: X and Y . The two types of users make independent decisions and have different preferences for different automobile technologies. Among them, X is an ordinary user, and their natural preferences for G and E are g_x and e_x , respectively, but they prefer traditional fuel vehicles (G), that is, $g_x > e_x$, Y are environmentalists, and their preferences for G and E are g_y and e_y , respectively, but they prefer low-carbon and environmentally friendly new energy vehicles (E), which is $g_y < e_y$. Suppose that the number of X and Y types of car users in the car market is n_G and n_E respectively, and the number of car users in the car market $N = n_G + n_E$.

Suppose that the user i enters the market at time t and the reward for choosing G or E is determined by two factors [14]: 1) the number of users who use G and E before i made the selection, namely n_G and n_E ; 2) i choose G and E to get a reward change factor of x or y . This means that the user's reward is only affected by his preference and past user's choice, without considering the influence of future choice on the user's reward. Because the value of x and y may be positive, negative or zero, it corresponds to increasing returns, decreasing returns and constant returns (As shown in Table 2).

Table 2: Evidence of returns to the Arthur model

	G Technology	E Technology
User X	$g_x + xn_G$	$e_x + xn_E$
User Y	$g_y + yn_G$	$e_y + yn_E$

The market share of assumed G technology is $m_G = \frac{n_G}{N}$, and the difference between the number of users of G technology and E technology is, then $m_G = \frac{d_N + n_E}{N} = \frac{d_N}{N} + \frac{n_E}{N} = \frac{d_N}{N} + (1 - m_G)$, So $m_G = 0.5 + \frac{d_N}{2N}$.

Assume that the market is shared with constant returns, in which case the range of the random walk is free, but the standard deviation of d_N increases as the \sqrt{N} increases. Thus, $\frac{d_N}{2N}$ tends to disappear. m_G tends to 0.5 (The probability is 1), Which is vehicle users X and Y choose traditional fuel vehicles (G) and low-carbon and environmentally friendly new energy vehicles (E), and the probability of the two technologies is equal, which is all 0.5, the market is split 50-50; If in the case of diminishing returns, the market is still shared, when N goes to infinity, $\frac{d_N}{2N}$ tends to zero, m_G must be tends to 0.5.

(2) Model analysis

In the case of increasing returns, which is $x > 0, y > 0$, when Y users enter the market to choose automobile technology, due to historical reasons, the reward of choosing G is greater than that of choosing E , which is $g_y + yn_G > e_y + yn_E$. So there is $d_N = n_G - n_E < \Delta_x = \frac{e_x - g_x}{x}$,

at this time, although Y has a stronger natural preference for E .

(3) Numerical simulation

In order to better show the increasing returns, the evolution of the competition between the two technologies, we can use computer simulation to depict the Arthur model. According to the description of the above model, the parameters are randomly assigned under the conditions of meeting the model [15]: $g_x = 40 > e_x = 27$ (Indicates X user preferences G), $g_y = 12 > e_y = 27$ (Indicates Y user preferences E); $x = 0.8$, $y = 1.2$ ($x > 0$, $y > 0$, illustrating increasing returns). At the beginning of the market, the number of users of the two technologies was $n_G = n_E = 50$, it shows that there is no difference in the number of users of the two technologies in the early stage of the market, which is $d_N = n_G - n_E = 0$. Assume that one user enters the market in each period, and make a choice between the two technologies, thereby positioning the first new user to enter the market. There are 500 new users entering the market in the first period, and 500 iterations are carried out in the simulation, as shown in Figure 2 ~ Figure 5.

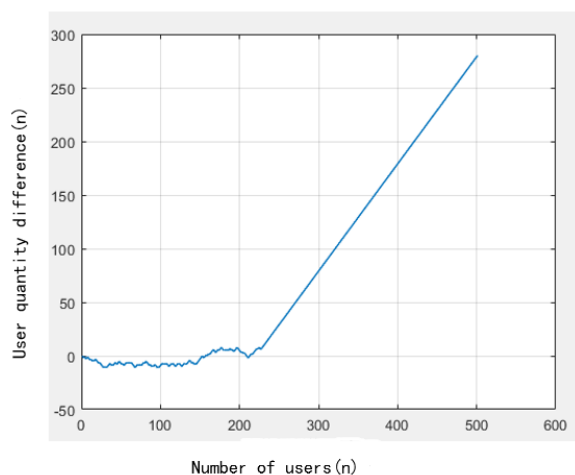


Figure 2: The changing trend of the difference between two kinds of automobile technology under the condition of G technology

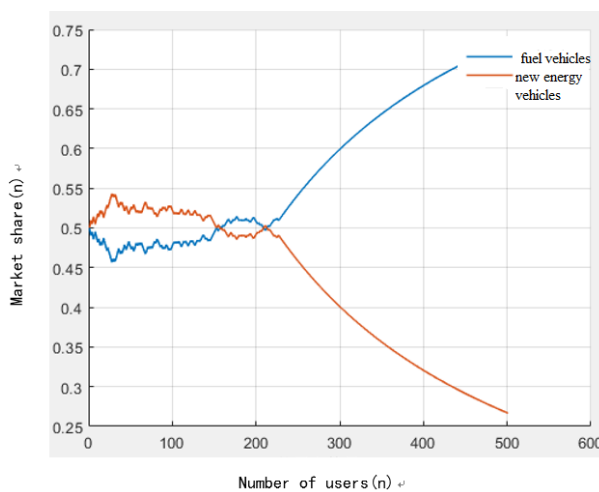


Figure 3: The changing trend of market share of the number of users of two kinds of automobile technology under the conditions of G technology

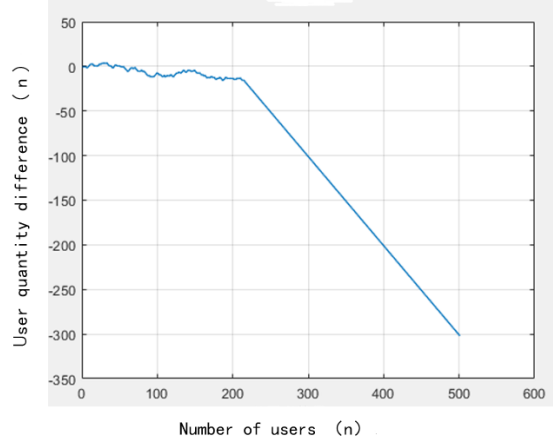


Figure 4: Trend of the change in the number of users of the two automobile technologies under the condition of E-technology lock-in

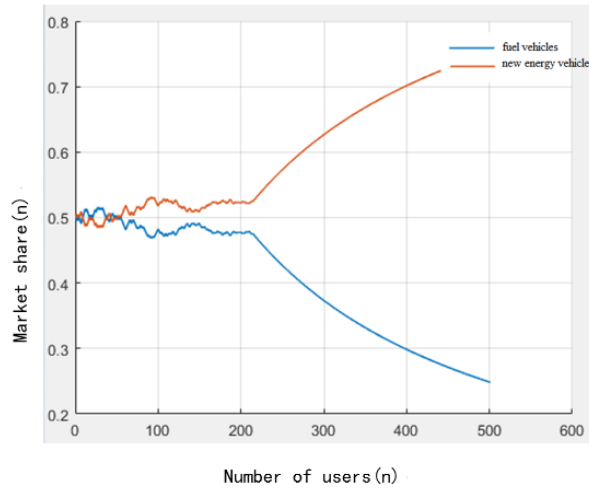


Figure 5: Trend of the change in the number of the two kinds of automotive technology market share under the condition of E-technology lock-in

As shown in Figure 2(or Figure 4), once the $|d_N|$ random walk exceeds the “attractive wall”, it will increase sharply, indicating that new users(X and Y) entering the market will all choose fuel vehicles(G) or new energy vehicles(E), as a result, n_G or n_E increase rapidly, and the market share m_G of fuel vehicles(G) (or new energy vehicles(E) (or m_E)) will also increase rapidly, and new energy vehicles(E) (or fuel vehicles(G))’s market share m_E (or m_G) will drop rapidly.

As shown in Figure 3(or Figure 5), compared to the case of increasing returns, the market share adopted by the X user will eventually be 0 or 1. This is because in the random walk theory, d_N eventually crosses the attraction with a probability of 1. Therefore, two competing technologies cannot coexist indefinitely: one technology will inevitably exclude the other, which means that the automobile market is completely locked in traditional fuel vehicles (G) or low-carbon and environmentally friendly new energy vehicles (E) on.

4 The breakthrough path of technology locks the compatibility of hybrid technology

In the aforementioned Arthur model, only two competing technologies—fuel vehicle technology and new energy vehicle technology—are considered, with the assumption that one technology will inevitably exclude the other in the long run. However, in practice, there exists another vehicle technology—hybrid technology—which is compatible with fuel vehicle technology. This hybrid technology not only influences those who have chosen it but is also affected by the number of its users. In light of this, this paper extends the Arthur model[16].

(1) Suppose k represents the degree of compatibility between the two technologies, k_{GE} represents the degree of compatibility between the fuel vehicle technology (G) and the new energy vehicle (E), and k_{EG} represents the new energy vehicle (E) to the fuel vehicle technology (G). The degree of compatibility, $k_{GE} \in [0,1]$, $k_{EG} \in [0,1]$. When $k_{GE} = 1$, it means that G technology is fully compatible with E technology, that is, the market demand for E technology is completely equivalent to the demand for G technology; When $k_{GE} = 0$, it means that G technology is compatibly incompatible with E technology, that is, the market demand for G technology has nothing to do with the demand for E technology; when $0 < k_{GE} < 1$, it means that G technology is partially compatible with E technology, that is, the market demand for G technology has partly related to the demand for E technology.

Similarly, when $k_{EG} = 1$, $k_{EG} = 0$ and $0 < k_{EG} < 1$. When both $k_{GE} = 1$ and $k_{EG} = 1$ are true, indicating that the two technologies are fully compatible with each other, in this case, the competition between two kinds of technologies is completely equivalent to the competition between two kinds of differentiated goods without network effects; When both $k_{GE} = 0$ and $k_{EG} = 0$ are true, indicating that the two technologies are completely unrelated to each other and that their respective user bases are proprietary. Especially, let $\Delta k = k_{GE} - k_{EG}$, when $\Delta k > 0$, indicating that the G technology is more compatible than the E technology, that is, G technology is compatible with E technology; And when $\Delta k < 0$, indicating that the E technology is more compatible than the G technology, that is, E technology is compatible with G technology[17].

(2) Assume that the network sizes of the two technologies are N_G and N_E , its size is affected by three factors: 1) Two technologies when the respective user base for n_G and n_E ; 2) The respective expectations for the future user base are n'_G and n'_E ; 3) The intersecting effect of the two network on scale, the size and compatibility of the two network are k_{GE} and k_{EG} , then

The network scale of fuel automobile (G) technology is

$$N_G = n_G + n'_G + k_{GE}(n_E + n'_E) = (n_G + k_{GE}n_E) + (n'_G + k_{GE}n'_E) \quad (1)$$

The network scale of new energy vehicle (E) technology is

$$N_E = n_E + n'_E + k_{EG}(n_G + n'_G) = (n_E + k_{EG}n_G) + (n'_E + k_{EG}n'_G) \quad (2)$$

(3) The size of the effect that users get from the network scale depends on the strength π ($\pi_G \geq 0$, $\pi_E \geq 0$) of the network effect, since this paper examines the choice of technology in

the automotive industry, in order to simplify the analysis, we assume that the difference of network effect is $\pi_G = \pi_E = \pi$.

(4) Assume that the user's unit payment for technical compatibility is λ ($\lambda > 0$), then

The user selects G technology and is paid λN_G for compatibility (3)

The user selects E technology and is paid λN_E for compatibility (4)

Thus, in consideration of compatibility, the rewards obtained by user X and user Y from G technology and E technology are shown in Table 3.

Table 3: The reward matrix of Arthur's extended model

	G Technology	E Technology
User X	$g_x + xn_G + \lambda N_G$	$e_x + xn_E + \lambda N_E$
User Y	$g_y + yn_G + \lambda N_G$	$e_y + yn_E + \lambda N_E$

In the case of compatibility, that is, $x > 0$, $y > 0$ when user Y chooses G technology, the reward he gets is greater than the reward he gets when he choose E technology, that is, $g_y + yn_G + \lambda N_G > e_y + yn_E + \lambda N_E$, let $k_{GE} = k_{EG} = k$, deformed finishing:

$$d_N = n_G - n_E > \frac{e_y - g_y}{\lambda(1-k) + y} - \frac{\lambda(1-k)(n'_G - n'_E)}{\lambda(1-k) + y}, \text{ in this case, } Y \text{ turns to select } G$$

technology.

Similarly, when user X chooses E technology, the reward he gets is greater than the reward he gets when he chooses G technology, that is $e_x + xn_E + \lambda N_E > g_x + xn_G + \lambda N_G$, let $k_{GE} = k_{EG} = k$,

deformed finishing[18]: $d_N = n_G - n_E < \frac{e_x - g_x}{\lambda(1-k) + x} - \frac{\lambda(1-k)(n'_G - n'_E)}{\lambda(1-k) + x}$, in this case, X turns

to select E technology.

In order to better consider compatibility, computer simulation is used to characterize the Arthur-extended model. Suppose $\lambda = 2$, $k = 0.4$, the remaining parameter assignments are the same as described above, Figure 6 and Figure 7 available.

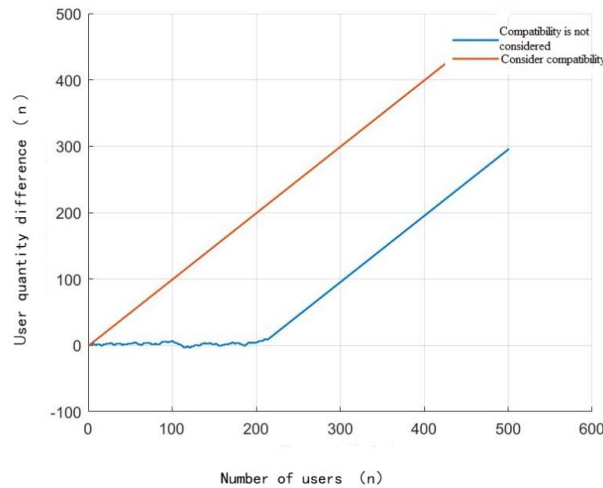


Figure 6: Consider the number of users trends in the case of compatibility

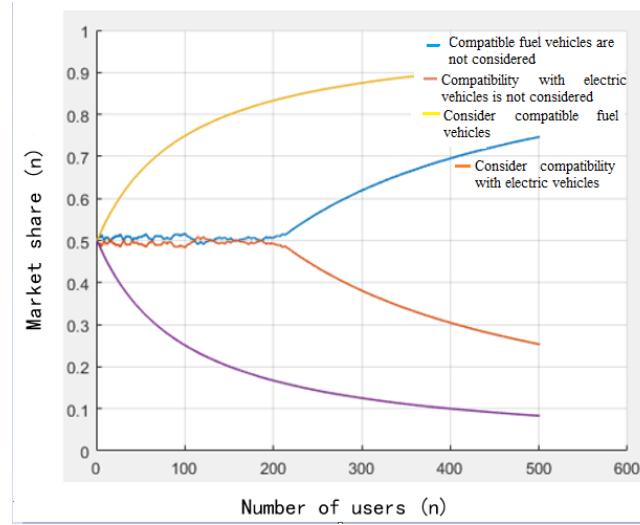


Figure 7: Consider market share trends in the case of compatibility

To sum up, it can be seen from Figure 6 and Figure 7 that the existence of compatibility reduces the threshold of critical capacity and enlarges the network effect.

(5) The magnitude of the network effect is denoted by U^n , U_G^n is the network effect of fuel vehicle technology (G), U_E^n is the network effect of new energy vehicle technology (E), so

$$U_G^n = \pi N_G \quad (5)$$

$$U_E^n = \pi N_E \quad (6)$$

(6) In the presence of network effects, the utility of class X users from adopting G technology and E technology is:

$$U_G = U_G^x + U_G^n = U_G^x + \pi N_G \quad (7)$$

$$U_E = U_E^x + U_E^n = U_E^x + \pi N_E \quad (8)$$

The utility that Y users get from adopting G technology and E technology respectively is:

$$U'_G = U_G^y + U_G^n = U_G^y + \pi N_G \quad (9)$$

$$U'_E = U_E^y + U_E^n = U_E^y + \pi N_E \quad (10)$$

(7) The price of the two technologies (the price of the product produced by the two technologies replaces the price of the technology itself) are P_G and P_E respectively, without considering the transaction cost and the use cost, the consumer surplus obtained by X user from the adoption of G technology and E technology is:

$$CS_G = (U_G^x + \pi N_G) - P_G \quad (11)$$

$$CS_E = (U_E^x + \pi N_E) - P_E \quad (12)$$

The consumer surplus obtained by Y user from the adoption of G technology and E technology is:

$$CS'_G = (U_G^y + \pi N_G) - P_G \quad (13)$$

$$CS'_E = (U_E^y + \pi N_E) - P_E \quad (14)$$

If two types of users eventually choose the G technique, then there must be for the user:

$$CS_G > CS_E \quad (15)$$

$$CS'_G > CS'_E \quad (16)$$

Tape the formula (11), (12) into(15), the formula (13), (14) into(16) can be obtained:

$$U_G^x - U_E^x + \pi \Delta n - (P_G - P_E) > 0 \quad (17)$$

$$U_G^y - U_E^y + \pi \Delta n - (P_G - P_E) > 0 \quad (18)$$

where $\Delta n = N_G - N_E$ substitute the previous formula (1), (2)into this formula can be obtained:

$$\Delta n = (1 - k_{EG})(n_G + n'_G) - (1 - k_{GE})(n_E + n'_E) \quad (19)$$

The specific analysis is as follows:

1) when $\pi = 0$, formula(17), (18) can be changed to:

$$(U_G^x - P_G) - (U_E^x - P_E) > 0 \quad (20)$$

$$(U_G^y - P_G) - (U_E^y - P_E) > 0 \quad (21)$$

Apparently, as can be seen from formula (17) to (18): in the vehicle market, only by bringing more consumers to the users, the remaining products will dominate the whole vehicle market. If the information between users is complete, there must be $\Delta n = n_G, n_E = 0$, that is, fuel vehicle technology occupies the whole market, while new energy vehicle technology does not exist. But when $\pi > 0$, the size of π will have an impact on the speed of the emergence of a single vehicle technology[19].

We can make $U_G^x - U_E^x = 20, U_G^y - U_E^y = 20, \Delta n = 50, P_G - P_E = 0$, when $\pi = 0.15$, for formula (17), apparently there is $U_G^x - U_E^x + \pi \Delta n - (P_G - P_E) = 27.5$, that is formula (15) holds, X users will choose fuel vehicle technology(G); But, for formula(18), $U_G^y - U_E^y + \pi \Delta n - (P_G - P_E) = -12.5$, at this point, formula(16)doesn't stand. Y users choose

new energy vehicle technology (E), at this time, the vehicle technology market will show the coexistence of two technologies, a single vehicle technology will not emerge. If $\pi = 0.5$, the formula (15) holds, $U_G^y - U_E^y + \pi\Delta n - (P_G - P_E) = 5$, the formula(18) holds, at this point, both X and Y users prefer fuel vehicle technology(G), a single vehicle technology will emerge. In summary, the strength of network effect π determines the size of Δn . It decided whether a single technology would emerge in the vehicle market. In practice, this factor is usually determined by the technology itself, independent of the impact of the vehicle industry.

2) As can be seem from formula (19), the smaller k_{EG} is, the larger k_{GE} is, and the more favorable it is to the fuel oil technology that G is determined to be the dominant technology. For $\Delta k = k_{GE} - k_{EG}$, when $\Delta k > 0$ is used, G technology is more compatible than E technology, or G technology has a compatibility advantage over E technology.

3) User Base From formula (19), it is evident that the number of existing households significantly influences the choice of technology. In practice, under the influence of the network effect, the increased use of fuel vehicle technology correlates with a heightened demand for its supporting parts and products. Consequently, a substantial number of components are actively developed to create a variety of high-quality supporting products, leading to a continuous reduction in the costs of related products. This, in turn, increases consumer surplus and enhances the utility level derived by users, which is conducive to attracting more consumers.

4) Expected Users The anticipated number of users often exerts a more significant influence on technology choices than the existing user base. Although the current user base for new energy vehicle technology is relatively substantial, the ongoing development of this technology, coupled with government support for new energy vehicles, prompts consumers to foresee the future trajectory of new energy vehicle technology based on various information sources[20]. Moreover, a higher anticipated number of users signifies greater potential for the development of related supporting products in terms of availability, pricing, and quality performance. Consumers tend to base their technology choices on the expected number of future users rather than solely on the existing user base, creating a self-fulfilling expectation.

5) PriceAs indicated by formulas (17) and (18), price levels play a crucial role in determining vehicle technology choices. In challenging circumstances, lower prices invariably lead to greater consumer surplus and stronger adoption among a larger user base. Furthermore, industries characterized by network effects exhibit greater price elasticity of demand compared to other sectors, making the impact of low-price penetration more pronounced (see Figure 8).

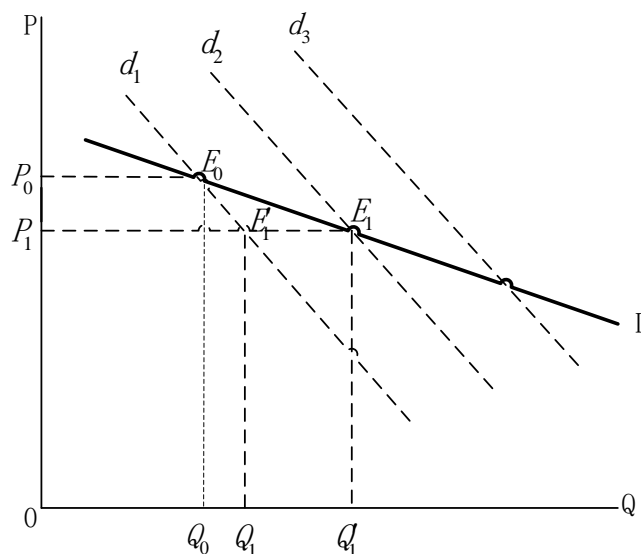


Figure 8: The effect of product price reduction under network effect

In Figure 8, when the price is P_0 and the market demand is Q_0 . When the price is P_1 , the demand will increase to Q_1 , in industries where there is no network effect, but in industries where there is a network effect, a positive feedback effect will occur when lower prices attract more consumers to join. More consumers make up a larger user base, which in turn attracts more users.

5 Conclusion

China's auto industry has established a traditional fuel vehicle technology system based on fossil fuels, forming a dominant technological framework that directly contributes to the locking effect of fuel vehicle technology on the advancement of new energy vehicle technology. To address the technological lock-in associated with traditional fuel vehicles and to promote the development of new energy vehicle technologies, this paper presents key research conclusions derived from modeling and simulation analysis:

(1) The decision of users to adopt new energy vehicle technology significantly depends on the adoption of the technology by other users. In the presence of network effects, the incentives for users who select a specific automotive technology increase with the growth of the network size that has adopted that technology; thus, when users evaluate the benefits of a particular technology, their choices also reflect an increasing function of the number of users engaged with that technology.

(2) The initial advantages associated with the early development of fuel vehicle technology are amplified due to increasing returns, leading to path dependence in technological development. This results in a lock-in effect for new energy vehicle technologies. Furthermore, once fuel vehicle technology attains the market's "critical capacity", subsequent users tend to opt for fuel vehicle technology irrespective of their preferences, causing a rapid increase in the market share of this technology. Without considering other external interventions, this phenomenon ultimately leads to a complete market lock-in to fuel vehicle technology.

(3) The user's choice between the two technologies in the automotive market depends on: 1) the utility of the two technologies to the user; 2) the size of the network (the size of the network depends on: the current respective user base n_G and n_E ; the respective expectations for the future user bases n'_G and n'_E the degree of compatibility of the two networks in terms of scale k_{GE} and k_{EG}); 3) The price of the two technologies, that is, given other factors, lower prices necessarily mean greater consumer surplus and greater willingness to adopt, as well as a larger user base.

(4) In the automotive market, only products that deliver greater consumer surplus will dominate. The presence of compatibility lowers the threshold for "critical capacity" and enhances the network effect. When fuel vehicle technology possesses compatibility advantages, it can more effectively leverage the existing user base and the anticipated users of new energy vehicle technology. Conversely, new energy vehicle technology faces a disadvantage due to its smaller user base reliant on fuel vehicle technology. This asymmetry in compatibility is critical for the competition between fuel technology and new energy technology.

With the advancement of automobile technology and improvements in environmental standards, new energy technologies have increasingly penetrated the traditional fuel vehicle market, gradually diminishing the market share of conventional fuel vehicles. During the reform of the automobile market, varying consumer preferences and expectations, along with

the coexistence of two technological paradigms—traditional fuel technology and new energy technology—have instigated significant changes within the automotive industry. Specifically, traditional fuel vehicle technology is being progressively supplanted by new energy technology, thereby altering the foundation of industrial competition. This shift has transformed the existing automotive technology market structure, leading to the emergence of new pathways and the establishment of new behavioral norms. Consequently, this evolution has facilitated the gradual transition from traditional fuel vehicle technology to new energy vehicle technology, resulting in not only a technological breakthrough but also a pronounced demonstration of strong value effects.

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