

Technology Diffusion System Model of China's Communication Industry

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Abstract: This paper hopes to describe the technology diffusion of 5G in China's communication industry at a point in time almost two years after the commercialization, and to explore and verify the factors affecting its diffusion. Based on the data published by the Ministry of Industry and Information Technology of China, the model is established by using STELLA as a tool. Simulations are conducted by profiling the system from both the Chinese government and communication operators' perspectives to predict the change in the number of 5G adopters over time. The results show that two factors, namely the Chinese government increasing the construction of communication infrastructure, and the operators increasing the types of 5G technology services, have a more significant effect on increasing the rate of 5G user adoption in China during the early stage of 5G technology into the individual consumer market.

Keywords: 5G, BASS model, Technology diffusion, Communication industry.

1. Introduction

The information and communication industry is a strategic, fundamental, and pioneering industry that builds up national digital infrastructure and fully supports economic and social development, and plays a vital role in the development of a country's economy. 5G (Fifth Generation Mobile Communication System), as it is named here, has been in the market for two years since its first application in 2019. This new generation of mobile communication technology has developed rapidly around the world, and lots of countries have paid great attention to the concept of 5G. With the worldwide deployment of 5G networks, mobile operators and mobile device manufacturers in many countries are gearing up to compete in the 5G market [1]. At the beginning of 2022, 169 operators in 70 countries worldwide have already launched 5G, and with those investing in 5G, the number has exceeded 400. China is also laying out its R&D efforts for 5G technology on all fronts. At present, the promotion standards of 5G are not uniform, but the overall assumption of 5G promotion effect is the same in different countries. In the era of the Internet of Everything, how to seize the key nodes of the market in the early stage of 5G promotion, target the development strategy of the industry and accelerate the penetration of 5G is crucial to the improvement of the development speed of various industries in the country.

In China, for example, on November 16, 2021, the Ministry of Industry and Information Technology released the "14th Five-Year Plan for the Development of the Information and Communication Industry", in which it is mentioned that in the "14th Five-Year Plan" period the country will strive to build the world's largest 5G network. In 2025, the number of 5G base stations per 10,000 people will reach 26, and the penetration rate of 5G users will increase from 15% in 2020 to 56%. However, according to the literature survey and relevant data, due to the limitation of 5G terminal equipment, ambiguous improvement effect of user experience, high cost and high tariff, imbalanced development of 4G and 5G, and the promotion effect of 5G in the individual user consumption market is not ideal.

2. Problem Statement

During the parallel development of 4G and 5G, the topics of "forced upgrade of 5G" and "decline of 4G network speed" often cause hot discussion. Users speculate that operators choose to sacrifice the rights and interests of 4G users to develop 5G. While the overall development of 5G is accelerating, and users are strongly reacting, how can the country and operators balance the development of 4G and 5G? What is affecting the rate of user adoption of 5G technology in the individual consumer market? These questions need to be urgently explored and addressed in the market development of China's communications industry.

3. Key Research Objectives

This paper plans to use a system dynamics approach to investigate what are the important influencing factors in the migration of 4G users to 5G users in the communication industry. The purpose is to find the important influencing factors of technology iteration in communication industry by discussing the feedback relationship in the technology diffusion system of communication industry through simulation prediction [2]. Trying to seek a better promotion scheme for 5G technology in the personal market, and put forward suggestions to relevant managers, so that to maintain the balanced development of 4G and 5G in China's communication industry.

4. System Analysis

4.1. Literature review

According to the research report "14th Five-Year Plan for the Development of Information and Communication Industry" and the development literature of communication industry [3-6], it is concluded that the development of China's communication industry is facing certain pressure:

High costs, high tariffs, difficult to raise prices: With the development of 5G, the cost of building and improving 5G infrastructure in China will be increased by more than 50%

compared to the 4G era. This means that the traffic profit brought by 5G must exceed 50% of the value-added, otherwise it will be very troublesome to maintain. The high cost of 5G has brought a heavy burden to administrators. In order to promote the growth of the number of customers, operators can not raise the tariff price, and the operating income of communication services shows a downward trend.

Insignificant improvement in individual user experience: According to the information released by the data department of the communication industry, the number of mobile phone customers in China will reach 1.66 billion in 2022, and the individual customer market will be saturated. 4G technology essentially meets the needs of individual users. The innovation and progress brought by 5G is restricted by terminal equipment, and users cannot perceive the visual contrast between 4K video and 1080p video brought by 5G innovation. At the same time, 5G terminals, such like mobile phones, have limited functionality and few product variations, but with high prices and low sales. The effect of improved quality of service such as improved video clarity and increased network speed brought about by 5G can not be perceived by users.

4.2. Iceberg model

The iceberg model provides an easy-to-follow framework that can dive from obvious into essentials to help the modeler understand the nature of the system, and unravels the motivations that lead to problems. After investigating the data to understand the challenges faced by the communication industry, this paper uses the four steps of iceberg model to find the core problems, trying to find better solutions for the diffusion dilemma of 5G technology in the personal consumption market of China's communication industry. The thinking process is as follows:

Step 1-Event: The spread of 5G technology in the personal consumption market of communication industry is slow. Compared with 4G communication technology, users are less willing to use 5G technology.

Step 2-Pattern: 2019 is the first year of 5G adoption in the communications industry. By aggregating historical data to figure out the trends in the number of 4G and 5G subscribers (Figure 1 and Figure 2), it can be concluded that compared with 4G technology, users have lower willingness to adopt 5G and the adoption speed of 5G users is slower.

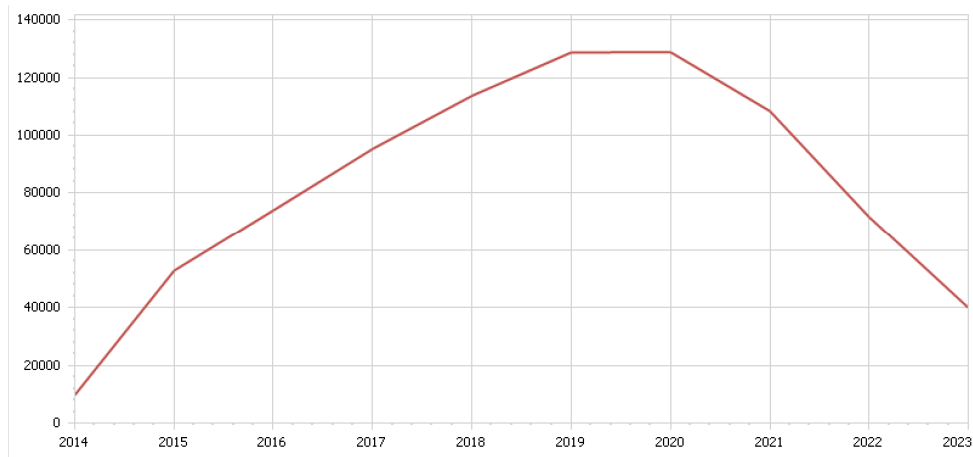


Figure 1. The number of 4G users

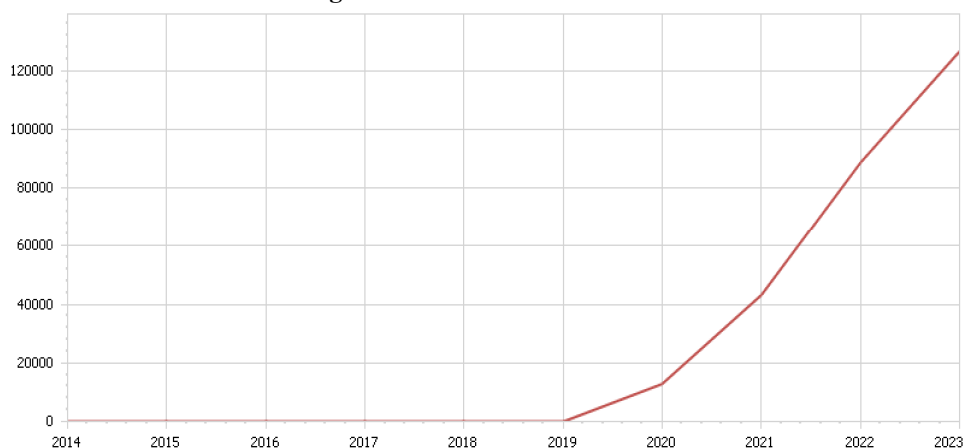


Figure 2. The number of 5G users

Step 3-Structure: What has led to low user adoption of 5G technologies in the individual consumer market?

①Limitation of the attractiveness of new technology: The attractiveness of 5G technology to individual users is influenced by its features. 5G technology has a limited variations of terminal devices and is overpriced; the

improvement in video clarity and network speed compared to 4G is not a significant improvement in experience among individual users; 5G construction costs are high, so tariffs are higher than 4G.

②Industry development restrictions: The adoption of new technologies by users in the consumer market of the

communications industry is influenced by the overall development of technology in the industry, with factors such as the degree of national policy support and the degree of infrastructure cost investment.

Step 4-Mental model: When individual users migrate from 4G technology to 5G technology, they will comprehensively consider various factors. In addition to the development of the industry and the attraction of new technologies, it will also be affected by the market environment, which can be summarized into two aspects: Firstly, it is externally influenced by the mass media's promotion of 5G; Secondly, it is internally influenced by word-of-mouth communication from 5G users.

4.3. BASS technology diffusion model

Rogers[7] pointed out that the innovation diffusion of a technology is dynamic, which refers to the process of spreading among system members through certain channels. BASS model is a marketing tool to predict the long-term market purchase of newly developed durable goods. Based on a set of differential equations, BASS model describes the process of a new product being adopted by people [8]. Swinerd used agent-based modeling and system dynamics in a case study to explore the potential of technology diffusion model in the simulation of mobile device diffusion in international communication industry[9]. Based on BASS model, this paper constructs a model to describe the continuous increase of the number of new technology adopters in the national communication industry and predict the sustainable development of the diffusion process.

$$\frac{dN(t)}{dt} = p[m - N(t)] + q \frac{N(t)}{m} [m - N(t)]$$

Figure 3. Basic equations of BASS model

The basic differential equation of BASS model is shown in Figure 3. $f(t)$ represents the probability density of the proportion of the number of users to the total number of potential users at time t ; the cumulative proportion of adopters to time t is expressed by $F(t)$ ($dF/dt=f$); p represents the external influence coefficient, also called innovation coefficient, that is, the influence degree of mass media on adoption; q indicates the internal influence coefficient, also called imitation coefficient, which indicates the influence degree of users' word-of-mouth influence on adoption. m represents the total number of final adopters, that is, the maximum market potential; $n(t)$ denotes the number of adopters at time t and $N(t)$ denotes the cumulative number of adopters at time t . According to the basic equations of BASS model, the basic curve form can be deduced. The cumulative number of users $N(t)$ is an S-shaped cumulative curve form, and the number of users at T time is a bell-shaped growth curve form, which accords with the changing trend of the number of users in the diffusion of new technologies in communication industry.

5. Simulation Design

5.1. Modeling ideas

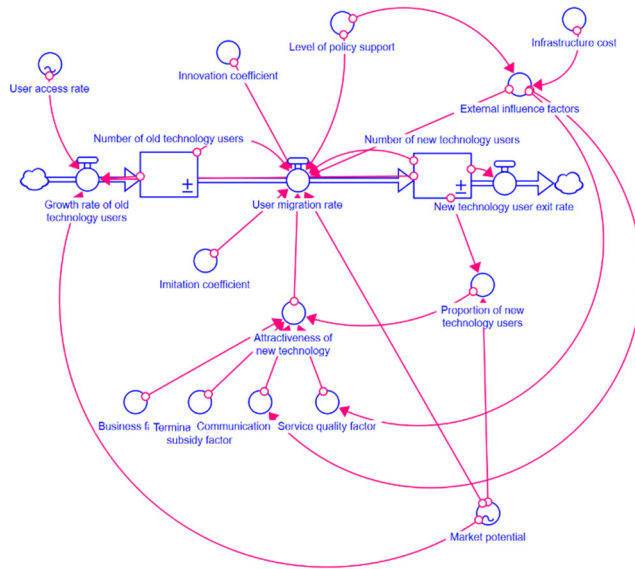


Figure 4. Technology diffusion model of China's communication industry

The diffusion process of new technology accumulates over time. Based on this characteristic, an equation-based rate model of new technology diffusion system in communication industry is established. The internal structure of the model is based on the BASS model initiated by Bass in 1969. Since consumers will consider many factors when using the new generation communication technology, the model adds factors such as "Attractiveness of new technology", "Level of policy support" and "Infrastructure cost" on the basis of BASS model, which together constitute a complete new

technology innovation diffusion model of communication industry. The internal structure of the model is shown in Figure 4.

5.2. Key assumptions

Openness: China's communication industry cluster is an open cluster

Staging: Assume that all users in the communication industry join the 4G network before migrating to 5G

Independence: The diffusion of one innovative technology

is independent of other innovative technologies
 Unconstrained: There is no supply constraint in the market,
 and the user transfer cost is not considered
 Homogeneity: Adopters are undifferentiated and

homogeneous

5.3. Variable definitions and formulas

The main variables and their definitions are as follows.

Table 1. Variable list

Variable name	Variable meaning
Number of old technology users	Total number of users of old technology
Number of new technology users	Total number of users of new technology
User migration rate	Number of users who give up using old technology and choose new technology each year
User access rate	Contact rate between potential users to be developed in the market and old technologies
Innovation coefficient	Influence of publicity by public media on users adopting new technologies
Imitation coefficient	Influence of word of mouth communication on users adopting new technologies
Level of policy support	Influence of government policy support on users adopting new technologies
Infrastructure cost	Influence of infrastructure construction on users adopting new technologies
Proportion of new technology users	The proportion of the number of new technology users in the total number of users with market potential
Market potential	The total number of potential users in the communication industry market. Here is the total population of China
Terminal equipment subsidy factor	Measured by the proportion of subsidies. It is understood that China's communication operators subsidize terminals according to the standards of "qualified", "good" and "excellent". The subsidy standard proportions are 20% ~ 30%, 30% ~ 50% and 50% ~ 70% respectively. The initial terminal subsidy factor is 0.45 when the middle value is taken
Business factor	The impact of the business provided by the new technology on the overall attractiveness of the new technology, and the value is determined by taking the middle value of the business proportion
Communication tariff factor	The influence of new technology tariff price on the overall attractiveness of new technology is the same as above
Service quality factor	The impact of new technology service quality on the overall attractiveness of new technology is the same as above

The main formulas and their meanings are as follows.

Table 2. Formula list

Variable name	Variable meaning
User migration rate	$\frac{\text{Innovation_coefficient} * \text{Number_of_old_technology_users} + \text{Number_of_new_technology_users} * \text{Imitation_coefficient} * \text{Number_of_old_technology_users}}{\text{Market_potential} + (\text{Level_of_policy_support} + 0.5 * \text{External_influence_factors} + \text{Attractiveness_of_new_technology}) * \text{Number_of_old_technology_users}}$
Growth rate of old technology users	$(\text{Market_potential} - \text{Number_of_old_technology_users} - \text{Number_of_new_technology_users}) * \text{User_access_rate}$
New technology user exit rate	$\text{RANDOM}(0, 0.0008) * \text{Number_of_new_technology_users}$
Attractiveness of new technology	$0.181 * \text{Business_factor} + 0.193 * \text{Terminal_equipment_subsidy_factor} + 0.212 * \text{Communication_tariff_factor} + 0.955 * \text{Proportion_of_new_technology_users} + 0.119 * \text{Service_quality_factor}$
Communication tariff factor	$0.212 - \text{External_influence_factors} * 0.07$
Service quality factor	$0.432 + 0.04 * \text{External_influence_factors}$
Proportion of new technology users	$\frac{\text{Number_of_new_technology_users}}{\text{Market_potential}}$

5.4. Model testing

In this paper, the historical data test method is selected to test the model. Using the historical data of 3G users migrating to 4G users, the model is substituted to check whether the running performance of the model is consistent with the historical performance in the real world. The following figure shows the running results of the model. Figures 5 and 7 are the changes in the number of 3G and 4G users predicted by the model from 2014 to 2020, and Figures 6 and 8 are the actual trend charts of 3G and 4G users. The model structure

and history show the same behavior patterns. Paired T-test is used to verify the fitting degree of the model. The test results show that the correlation coefficient between the two indicators is 0.996, which shows that the correlation between them is very high. The results of the T test showed that $t=-2.67$, the significance was 0.794, far greater than 0.05, indicating that there was no significant difference between the two groups of data in statistical significance. It can be considered that the model has a high degree of fitting in historical test, thus the model passed the historical data test.

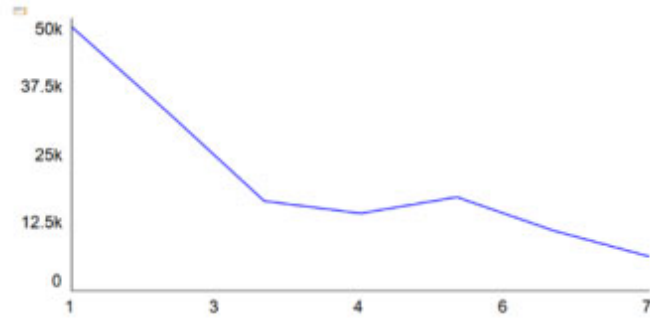


Figure 5. The number of 3G users predicted by the model

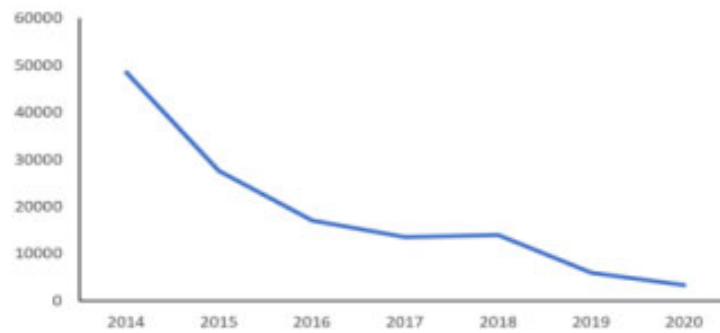


Figure 6. The actual number of 3G users

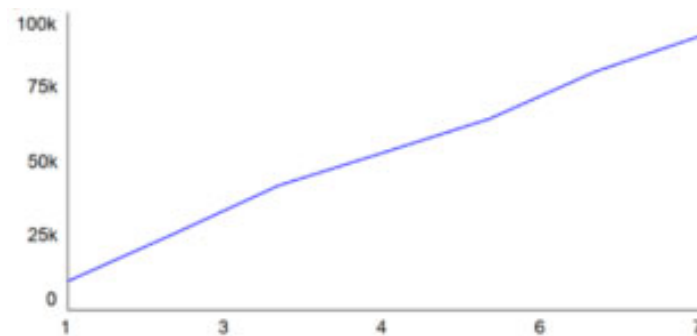


Figure 7. The number of 4G users predicted by the model

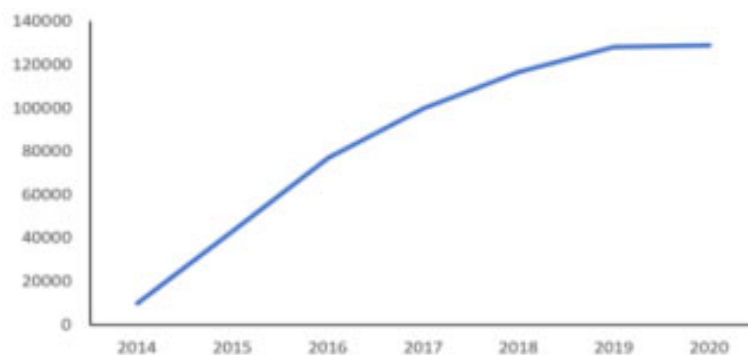


Figure 8. The actual number of 4G users

5.5. Working assumptions

After testing the model with parameters adjustment, the model can be run with appropriate initial values, taking the population in 2019, the year when 5G was first applied, for example. As expected, the growth rate of users in the first few years of 5G technology is not as high as 4G situation.. This is because the diffusion of 5G technology is affected by many factors, such as the limited content service of terminal equipment and business services offered by operators, high tariffs due to the high cost of investment in communication infrastructure by the Chinese government, etc. As a result, the diffusion in the individual market is not effective and the adoption rate of the new technology is low. In this context, this paper will explore what factors should be adjusted to increase the rate of 5G diffusion in China from both the Chinese government and operators' perspectives.

From the perspective of the Chinese government: How do the "Level of policy support

" and the "Infrastructure cost" affect the speed of adoption of 5G technologies?

From the perspective of Chinese operators: How do the "Terminal equipment subsidy factor" and "Business factor" parameters affect the speed of adoption of 5G technology?

6. Scenario and Policy Analysis

With the base model above, the parameters of the variables in the system are set to reflect the possible development pattern of the communication industry and to simulate the relevant factors affecting the development of the industry. Taking into account the actual situation and existing research, two perspectives, the Chinese government and Chinese communication operators, are selected for sensitivity analysis of the development factors of the Chinese communication industry. Four parameters are investigated: from the perspective of the Chinese government, the weight ratio of "Level of policy support" and "Infrastructure cost", and from the perspective of Chinese operators, the weight ratio of "Business factor" and "terminal equipment subsidy factor".

Perspective I: The Chinese Government

With different weight ratio of the two parameters "Level of policy support" and "Infrastructure cost", Four model setting modes were developed to check the influence of the two parameters on the adoption rate of 5G users in China.

Mode 1: Basic development mode: In this mode, the sustainable development of 5G users is directly simulated and predicted without changing the values of variable parameters in the above model, and the number changes of 5G users in the next 6 years are obtained, which is used as a basic reference to design other modes.

Mode 2: Increased infrastructure investment mode: Under this model, it is assumed that the country will increase capital

investment in communication infrastructure construction in the next few years, other conditions unchanged, and appropriately increase the value of the "Terminal equipment subsidy factor" parameter.

Mode 3: Increased policy support mode: Under this model, the state focuses on the development of the communication industry, increases the formulation of relevant policies and regulations, other conditions unchanged, and appropriately increases the value of the "Level of policy support" parameter.

Mode 4: Coordinated development mode: The above research changes the parameter values of policy support and infrastructure respectively, and analyzes the influence of a single part change on the system. Mode 4 comprehensively considers two aspects, giving attention to improving the values of two parameters: "Terminal equipment subsidy factor" and "Level of policy support", and developing in a balanced way.

Perspective II: Chinese Communication operator

With different weight ratio of two parameters" Business factor" and "Terminal equipment subsidy factor" to check the influence of the two parameters on the adoption rate of 5G users in China.

Mode 1: Basic development mode: Same basic development mode as the perspective I.

Mode 2: Service enrichment mode: Under this mode, Chinese operators focus on the research of 5G service types, and improve the attractiveness of services through diversified 5G service forms, other conditions unchanged and appropriately increase the value of the parameter "Terminal equipment subsidy factor".

Mode 3: Increased subsidies for terminal equipment: Under this mode, major operators increase subsidies for 5G mobile terminal equipment, lower the price of 5G terminal equipment, and lower the threshold for users to enter 5G technology, other conditions unchanged, and appropriately increase the value of the parameter "Terminal equipment subsidy factor".

Mode 4: Coordinated development mode: The above studies changed the parameter values of business factor and the terminal equipment subsidy factor respectively and analyzed the impact of a single part of the change on the system. Model 4 considers the two aspects together and increases the values of the "Business factor" and "Terminal equipment subsidy factor".

7. Recommendations and Policy Design

According to the design ideas of the above two perspectives development mode, each parameter is set accordingly, and after repeated adjustments, the dynamic simulation diagram of the technology diffusion system of the Chinese communication industry under the above model design is obtained. It is discussed from two perspectives.

Perspective I: The Chinese Government

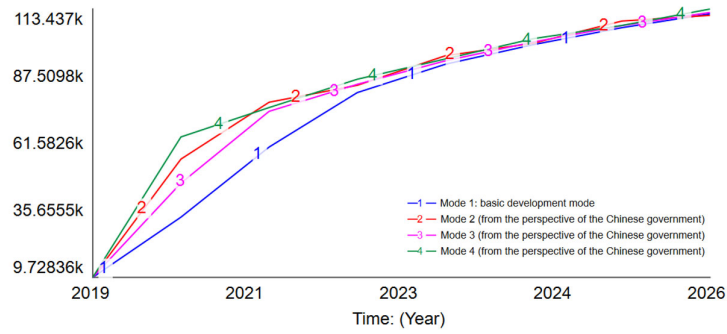


Figure 9. Number of 5G users from the perspective of the Chinese government

Figure 9 shows the forecast trend chart of the number of 5G users in four modes from the perspective of Chinese government. The changing trend of indicators in each mode is consistent and the change speed is different. Among them, the number of 5G users under Mode 4 has the fastest growth rate in the early stage, followed by Mode 2 and Mode 3. It

shows that in the initial stage of technology promotion, compared with increasing policy support for the communication industry, the Chinese government's improvement of communication infrastructure construction has a greater impact on the adoption speed of 5G users.

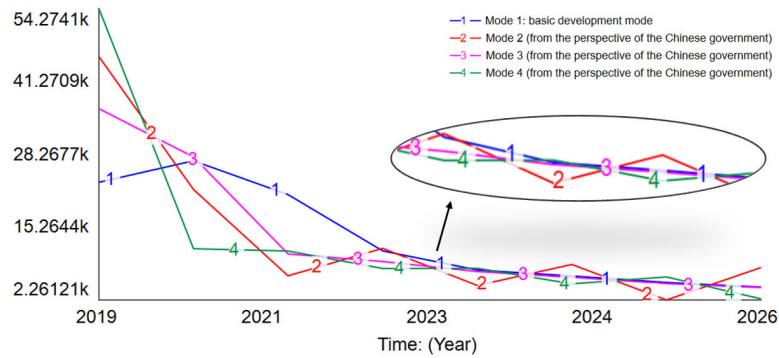


Figure 10. Adoption speed of 5G users from the perspective of the Chinese government

By observing Figure 10, it is found that improving the adoption of a single influencing factor in the middle and late development of 5G technology has certain volatility. Mode 4 averages the focus to two aspects. In the early stage of development, due to the limitation of national strength, the adoption situation is not as good as putting the focus on one aspect. However, due to the balanced development of both policies and infrastructure, it has strong stability in the later stage of technology popularization.

The adoption speed of Mode 2 and Mode 3 fluctuated anomalously in the later stage of new technology popularization. Under these two modes, the adoption degree of users in the first year of new technology promotion is high, but the adoption number of users in the later period of technology promotion fluctuates to a great extent. The ability of the country to invest in the communication industry is limited. When the country puts its focus on one hand under Mode 2 and Mode 3, the investment on the other hand will be affected to a certain extent. For example, at the beginning of the adoption, the Chinese government increased its policy support in the communications industry. However, it could not take into account the investment in infrastructure construction, a large number of users flowed into the new market, while the hardware support capacity of the communications industry was not enough to support the huge number of users, which would affect users perception, reduce the effect of word-of-mouth communication and affect the number of users in the following year, so the development was not smooth and fluctuated more significantly.

Mode 4 in the early stage of technology promotion, the adoption speed has a cliff-like decline. This paper analyzes the reasons for this situation. At the initial stage of 5G technology promotion, the state increased investment in policy support and infrastructure construction, which brought about a good new technology promotion effect. On the one hand, the communication industry belongs to high-tech industry, and the influence of the innovation coefficient on the personal consumption market in this industry is higher than that of the imitation coefficient. That is to say, the industry has a higher percentage of innovative consumers and a higher sensitivity to new technologies. When a new technology enters the market, a large number of users flock to use the innovative technology because it is in line with the consumer psychological trend. On the other hand, because of the limited total number of potential development users in the market, innovative users with a high willingness to adopt are already engaged in the use of the new technology at the beginning of the roll-out, after which there is bound to be a period of decline in the rate of user growth. In contrast, observation of Figure 7.2 reveals that in the middle and late stages of technology diffusion, Mode 4 has a slightly higher rate of user diffusion than Mode 2 and 3, and has a smooth development. A country that wants to have a coordinated and smooth development in the communications sector has to balance the development of both policy support and infrastructure construction at the same time.

PERSPECTIVE II: CHINESE COMMUNICATION OPERATOR

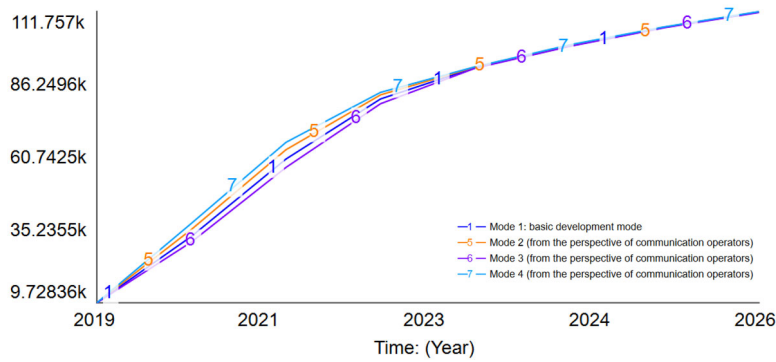


Figure 11. Number of 5G users from the perspective of communication operator

Figure 11 shows the trend of 5G subscriber numbers forecast for the four modes from the perspective of Chinese operators. Figure 12 shows the trend of 5G subscriber adoption speed under the four modes. Under each mode, the changing trend of indicators is consistent and the change speed is different. The number of 5G subscribers grows fastest in the early stage under Mode 4, followed by Mode 2, while the growth rate of subscribers under Mode 3 is lower

than the growth rate of subscribers under the basic development of Mode 1. It shows that from the perspective of operators, to increase the adoption of new technology users in the personal consumer market, it is necessary to increase the types of 5G technology services, enhance subsidies for communication terminal equipment and reduce equipment costs.

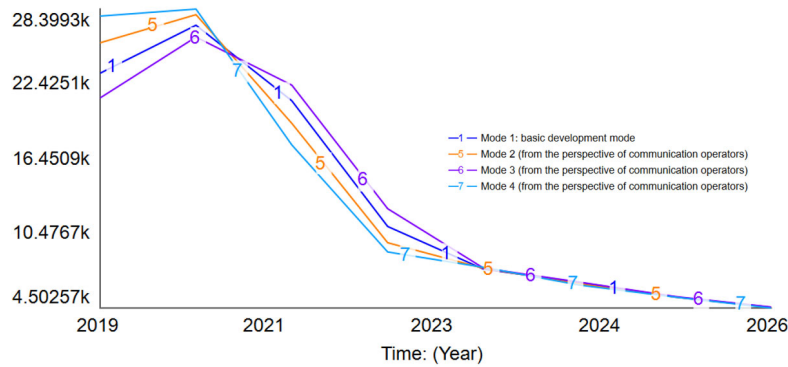


Figure 12. Adoption speed of 5G users from the perspective of communication operator

By comparing the user adoption speed charts of Mode 2 and Mode 3, it can be concluded that improving the technical service richness has a greater impact on the adoption speed of 5G users than increasing the subsidy for communication terminal equipment. When operators can only take into account the development of one party with limited efforts should prioritize increasing the variety of 5G technology services and focus on diversified service forms to attract more users to 5G technology.

8. Conclusion

This paper describes the development of 5G in the past two years, explores and verifies the factors affecting its diffusion from the perspectives of the Chinese government and communication industry operators, and then predicts the change in its number of users with time. It is found that compared with increasing the policy support of the communication industry, the Chinese government's improvement of communication infrastructure construction has a greater impact on the adoption speed of 5G users. Compared with enhancing subsidies for communication terminal equipment and reducing equipment costs, communication operators give priority to improving the types of 5G technology services, focusing on diversified development of business forms, has a greater attracting on users. The results of the model are analyzed to provide

recommendations for the Chinese government to formulate mobile communication development policies and for operators and terminal equipment R&D manufacturers to formulate development strategies.

In the process of establishing the technology diffusion system model of China's communication industry, the author learned some system thinking tools and practical operation methods of modeling through the video seminar held by the competition organizing committee. Specific gains are as follows:

- Learned systems thinking tools and model concepts such as the Iceberg and BASS technology diffusion model.

- Use causal loop diagram, "WHY 5" and other tools to systematically think and summarize the system structure from past historical events.

- Use extreme conditions, pulse test or historical data to verify the model.

- Through different policy design, explore the model to predict the situation, and trace the root cause of the development of different situations according to the causal feedback loop.

- Through the modeling process, learning of STELLA software deepened the level of skill of system dynamics tools.

- This competition makes the author know and understand the subject of system dynamics, and has the opportunity to apply the knowledge of system dynamics to practice, which

not only consolidates the mastery of theoretical knowledge, deepens the cognition of new technology diffusion system in communication industry, but also increases the author's operation experience and tool software learning in actual system dynamics modeling, which provides great help for the author's later study and research in system dynamics.

Acknowledgment

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References

- [1] Gao F, Zhao C-W, Zhang X, Zhao Y-H. Overview of global 5G development status[J]. Global Science and Technology Economic Outlook,2014,29(07):59-67.
- [2] Eldabi T, Balaban M, Brailsford S, et al. Hybrid simulation: historical lessons, present challenges and futures[C]//2016 Winter Simulation Conference (WSC). IEEE,2016:1388-1403.
- [3] Mou Chunbo. Solidifying the base for digital development of economy and society: interpretation of the chapter of new digital infrastructure in the 14th Five-Year Plan for the Development of Information and Communication Industry[J]. China Telecom Industry,2021(12):16-19.
- [4] Hu Jianbo. Interpretation of the 14th Five-Year Plan for the Development of Information and Communication Industry[J]. DOI:10.13571/j.2021.23.004.4
- [5] Huang Biao. Research on the development trend of communication industry and its planning index system [J]. China Construction,2021(03):76-77.
- [6] Li Jinliang. Analysis and suggestions on Chinal's 5G network building dilemma in 2020[J]. Mobile Communication, 2020, 44(02): 54-57+63.
- [7] Bass F M. A new product growth for model consumer durables [J]. Management Science (S0025-1909), 1969, 15(5): 215-227.
- [8] Rogers E M. Diffusion of innovations[M]. Simon and Schuster, 2010.
- [9] Swinerd C, McNaught K R. Design classes for hybrid simulations involving agent-based and system dynamics models[J]. Simulation Modelling Practice and Theory(S1569-190X), 2012, 25: 118-133.