Environmental Science and Pollution Research (2022) 29:82324–82335
https://doi.org/10.1007/s11356-022-21110-3

RESEARCH ARTICLE

Research on green technology marketing model based on dynamic evolutionary game under low-carbon background

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Received: 4 March 2022 / Accepted: 22 May 2022 / Published online: 25 June 2022
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Abstract
With the present situation of development in green technology as the background, combined with technology marketing models in other areas, this paper builds three technology marketing models, based on the Stackelberg game between the technology suppliers and distributors. Namely, the three models are direct official marketing, agency relationship cooperation, and agency sale relationship cooperation. Dynamic system model is built on relationship cooperation. By comparing with and analyzing the model solution results, and observing the effect of various parameters in terms of numerical simulation on enterprise decision variables, profits, and the optimal mode policy selection, we find that the level of price discount will decide whether the technology supplier selects the agency sales model, while the level of the profit distribution factor decides whether the technology supplier takes direct official sale. Meanwhile, excessive price adjustment speed will disturb the market stability and interfere with enterprise decision-making.

Keywords Technology marketing · Dynamic system · Profit distribution · Price discount strategy selection

Introduction
For a long time, many countries have been continuously affected by various environmental problems, including the greenhouse effect and water pollution. Among them, many problems are caused by objective factors such as automobile exhaust emissions and improper disposal of used batteries. Due to the insufficient development level of green technology and bottlenecks in technology, the low-carbon conversion degree of energy is relatively low and many waste materials cannot be treated in time (Kehrein et al. 2020). In order to solve related problems, in recent years, many countries have issued a series of policies to promote the development of the new energy industry and encourage enterprises to carry out low-carbon technological transformation and upgrading. As a result, aiming at the iteration of green technology, many enterprises have invested a lot of manpower and material resources for a while in the past. Taking the battery industry as an example, the new storage battery has gradually alleviated the problem of recycling lithium battery and saved a lot of recycling costs for enterprises (Liu et al. 2019). Therefore, we can clearly see that productive technological progress and green technology innovation are the necessary conditions to improve the working condition and productivity of the industry (Song & Wang 2018). Meanwhile, green technology innovation will further alleviate the pressure of social low-carbon emissions and enhance people’s happiness.

Technology is the foundation of the enterprise in the market. As a confidential information, in many fields, if an enterprise has a high level of technology, it tends to occupy high competitiveness in the market. However, to better expand the market business and occupy market shares, many enterprises began to sell some of their internal technologies to other enterprises directly or indirectly, so as to promote
their technologies and reduce their technology iteration costs. Taking the Internet industry as an example, the existing Alibaba Cloud, Tencent Cloud, and other products not only provide services for their internal users but also provide external services such as data storage and analysis for profits. In this process, there are many modes of technical marketing including direct sales and agent sales.

However, in the new energy industry, most enterprises are still having the physical product transaction while technology marketing is in the primary stage. Meanwhile, no matter it is physical products or technologies, under different trading modes, the ownership of rights and interests, the degree of trust, and the final profit-sharing among related chain enterprises have gradually become important factors affecting the transaction results. Therefore, this paper takes the technology marketing in the new energy industry as the research background to analyze the issues such as technical authority among various chain enterprises so as to finally provide certain suggestions for related enterprises.

This paper mainly has contribution to the following points compared with preventing literature: (1) Based on the development status of green technology, combined with the relevant technical marketing experience in other fields, this paper builds three models of technology marketing based on the Stackelberg game between technology suppliers and agents and builds a dynamic system model based on one of three models. (2) We make a comparative analysis on the solution results of the model and further observe the impact of each parameter on enterprise decision variables, profits, and the choice of optimal mode scheme through numerical simulation.

This chapter is mainly divided into five parts. The second part mainly summarizes the related literature around the content. In the third part, this paper constructs three game models of chain enterprises under different marketing modes and analyzes the related models. Then, in the fourth part, each parameter is analyzed and studied by numerical analysis. Finally, it is the summary of the whole paper and the prospect of the future.

Literature review

Profit distribution

Based on the commodity trading process, combined with external factors such as government policies, how to reasonably distribute the profits of upstream and downstream enterprises has become an important issue that chain enterprises pay attention to. For revenue-sharing contracts, Song and Gao (2018) established two green supply chain game models to coordinate the distribution of benefits between upstream and downstream members of the green supply chain. Modak and Kelle (2019) studied the dual-channel supply chain with random customer demand depending on price and delivery time and used generalized asymmetric Nash bidding to distribute surplus profit. Similarly, for the dual-channel supply chain, channel coordination is achieved through the profit-sharing mechanism; Ranjan and Jha (2019) achieved a win–win situation for each member of the supply chain. Zhao and Sun (2020) studied the differences between these two states and established profit distribution models in a closed-loop supply chain without government subsidies and with government subsidies. By comparison, it was found that government subsidies could promote the change of members’ profit distribution and expand the scale of a closed-loop supply chain. In addition, by constructing two game models — the peer fair attention model and the distribution fair attention model, considering the competitive supply chain with fair attention, Jian et al. (2020) analyzed the influence of revenue-sharing contracts on its pricing decision and profit distribution.

Rights management

In many commodity trading situations, upstream suppliers tend to regulate the using rights of products according to the specific conditions of downstream enterprises. According to the licensing right of consumers’ advertising, Esteban and Hernández (2017) made a game between pricing and information advertising with horizontally differentiated products and competed by targeting advertisements at potential customers. Frattini et al. (2019) developed a framework based on negotiation research, which identified the factors affecting technology licensing price, to focus on the pricing in technology licensing transactions. In addition, Yang et al. (2019) studied whether and how patent-holding companies licensed their technology patents to potential competitors. Assuming that there may be technology transfer between innovator and non-innovator companies, Bode et al. (2021) considered a differentiated Stackelberg model when follower companies provided innovative technologies to reduce costs during R&D. Hong et al. (2021) investigated the technology licensing decision of incumbent patentees with quality improvement technology in the duopoly model with heterogeneous consumers, as well as the quality information disclosure strategies of patentees and licensees competing in quantity.

Complexity analysis

In our daily life, influenced by many internal and external factors, many things are often complicated and need to be explained by concrete modeling. Many papers are similar to this manuscript from the perspective of methodology and method. Roundy et al. (2018) linked the study of entrepreneurs and the complexity of risk levels with the study of
the entrepreneurial ecosystem and put forward three related forces influencing the emergence of the entrepreneurial ecosystem. Li et al. (2019) proposed a new analysis and prediction system, which consists of complexity analysis, data preprocessing, and optimization prediction modules, and solved the problem of air quality monitoring. Bao et al. (2020) studied the short-term and long-term repeated game behaviors of two parallel supply chains and built a complex system model to explore its stability. Based on three different game power structures, Ma et al. (2020, 2021a, b) studied the game characteristics and equilibrium strategies of the three-channel supply chain under the carbon subsidy policy and studied their complex dynamic characteristics. At the same time, Ma et al. (2020, 2021a, b) clarified the influence of different market structures and different price adjustment speeds on the operation and system stability of automobile manufacturers. Based on the topic of sustainable energy, many scholars studied the topic of solar investments by utilizing complexity theory as well (Ma and Xu 2022; Xu and Ma 2021). Besides, carbon neutrality becomes more and more popular recently, so that tremendous literature investigated the problems related to carbon emission (Shuai et al. 2017; Ahmed et al. 2021; Kurramovich et al. 2022; Zhu et al. 2021a, b). Karaer et al. (2017) find that in the case of a single supplier, if the buyer’s optimal strategy is to offer a premium to the supplier, he will also fully subsidize the investment cost of its construction quality. By developing the supplier’s capabilities, the buyer can increase the impact of the premium he offers. Lou and Ma (2018) study the complexity of sales effort and carbon emission reduction effort in Bertrand’s home appliance supply chain system, and found that price adjustment has a far greater impact on stability and profit than sales effort and carbon emission reduction effort. Manzetti and Mariasiu (2015) find that electric vehicles contribute to an increase in greenhouse gas emissions due to excessive demand for energy, especially in countries with limited renewable energy. At the same time, chemical and electronic components of automotive batteries and their waste management also require significant investment and development of recycling technologies to limit the diffusion of e-waste materials in the environment. Xie et al. (2020) find when the seller has high bargaining power and can control the uncertain yield, the buyback contract can fully coordinate the supply chain. On the contrary, if the seller’s bargaining power is low or lose the stability of the yield, the contract will not work. Yang et al. (2021) construct a game model consisting of the government and two competing enterprises and analyzes the role of government subsidies. The results show that government subsidy can be an effective way to relieve the prisoner’s dilemma by reducing the financial burden of technological improvement. At the same time, government subsidies help expand the market for green products and improve social welfare.

Through the existing literature research, it can be found that few scholars have studied the relevant marketing strategy of low-carbon green technology. Meanwhile, the trust degree of upstream and downstream enterprises brought by technology licensing exchange is also rarely mentioned. Based on the existing literature and the background of green enterprise technology marketing, this paper explores the different marketing strategies between upstream and downstream enterprises and the influencing factors in the transfer of technical authority. In addition, this paper further constructs a dynamic complex system model to explore the impact of price strategy adjustment on the market.

Modeling and analysis

Basic model

With green technology marketing as the background, suppliers need to provide technical sales authority distribution to downstream agents, enabling agents to help suppliers expand the market and gain revenue from it. Based on it, we construct a Stackelberg game model between a single technology vendor and an individual agent. Among them, technology suppliers, as leaders of the supply relationship, have certain decision-making initiatives, while agents act as followers of the game.

With the fact that countries attach great importance to green emissions, more and more countries begin to issue relevant low-carbon policies, and in order to meet the relevant carbon emission reduction standards under the corresponding policy conditions. In addition to updating facilities and equipment and other hardware, enterprises often need to seek green technical support from other enterprises. In this context, there are some technology suppliers in the market to sell the edge technology externally with the public price as \( p \). And technology demand party’s preference for the technology purchase is \( u \), that is, the higher the preference for purchasing technology, the more the number of orders the technology supplier receives. Here, we use \( a \) to represent the total existing potential demand for green technology in the market, and when companies strive to expand the market, their potential market will increase by a certain proportion \( \theta \). According to the inverse demand function mentioned by Yang (2021), we can get that the demand function of the technology market is:

\[
q = (1 + \theta)a - ap + \beta u
\]  

In Eq. (1), \( q \) represents the number of orders purchased by green technology consumers, but \( a \) and \( \beta \) are the influence coefficient of the declared price of the technology supplier and the technology preference of the consumer on the order quantity. According to the content of the technology
marketing scene, the lower the public price of the technology or the higher the technical preference of consumers, the higher the consumers’ desire to buy, and the more the number of orders sold in the overall market, so it is set here in case \( \alpha, \beta > 0 \).

As the owner of the technology, in addition to cooperating with agents to sell edge technology, technology suppliers can also sell by themselves through online and offline channels. Among them, the self-management promotion level of technology suppliers is set as \( \theta_1 \), and the technology promotion degree of agents through efforts to promote is set as \( \theta_2 \). The two together form the final level of total promotion, \( \theta = \theta_1 + \theta_2 \). At the same time, enterprises often need to pay a certain amount of effort to expand a wider user group to buy their products. According to Karner’s (2017) definition of cost, combined with the level of enterprise promotion, this paper sets up the cost of the enterprise as \( \frac{1}{2} k \theta^2 \) to win more users, among which \( k \) is the influence coefficient of the promotion level on the effort cost.

According to the different channels of technology suppliers selling edge technology, from Fig. 1, we can see that it is roughly divided into the following three types: official direct marketing (Model 1), agency partner marketing (Model2), and commission partner marketing (Model3).

In technology research and development, technology suppliers need to spend a certain capital investment for improvement, and in a certain stage, the technology has maintained certain stability, so in technology, it has a certain sales cost \( c \), that is, the depreciation cost of technology iteration. Combined with Fig. 1, technology suppliers can sell products directly to customers through official channels, so combined with formula (1), we know that the demand function of the direct selling channel (Model 1) is:

\[
q^1 = (1 + \theta_1^1) a - ap^1_m + \beta u \tag{2}
\]

According to formula (2), we can obtain the profit function formula of the direct channel (Model 1) is:

\[
x_m^1 = (p^1_m - c) q^1 - \frac{1}{2} k \theta_1^2 \tag{3}
\]

In Model 1, technology suppliers can decide on their own whether to continue technology marketing, while having pricing power on technology products at the same time. Based on this, combined with the formula (3), we conduct a partial guide analysis of the official price \( p^1_m \) and promotion level \( \theta_1^1 \), and the results are as follows:

\[
\begin{align*}
\frac{dx_m^1}{dp^1_m} & = (1 + \theta_1^1) a + \alpha (c - 2p^1_m) + \beta u \\
\frac{dx_m^1}{d\theta_1^1} & = a(p^1_m - c) - k \theta_1^1
\end{align*} \tag{4}
\]

From the partial guide results in the joint formula (4), we can conclude that the optimal official price and promotion level of technology suppliers in Model 1 are:

\[
\begin{align*}
p^1_m &= - \frac{\alpha^2 m + \theta_1^1 + \beta \alpha n}{a^2 - 2ak} \\
\theta_1^1 &= - \frac{\alpha^2 m + \theta_1^1 + \beta \alpha n}{a^2 - 2ak}
\end{align*} \tag{5}
\]

In addition to direct marketing through official channels, technology suppliers also tend to seek agents for cooperation to jointly explore the market, and reach agreements with them with certain profit distribution principles, so as to expand their income and market influence. Among them, in Model 2, technology suppliers need to grant agents the right to promote the technology while agents need to pay a certain registration fee \( C_1 \) to the technology supplier. Then, the agent will independently promote and expand the market, and sell the technical products at the official price \( p^2_m \), and bear the promotion cost during the period by himself. Based on this, combined with the formula (1), we can conclude that the demand function of Model 2 is:

\[
q^2 = (1 + \theta^2) a - ap^2_m + \beta u \tag{6}
\]

In Model 2, the promotion and promotion of the technology market are jointly completed by technology suppliers and agents, so the total market promotion level in formula (6) is met \( \theta^2 = \theta_1^2 + \theta_2^2 \). In Model 2, the technology supplier will make a certain profit distribution \( \lambda \) to the agent according to the income of the agent, so the profit function formula of both in this model is as follows:

\[
\begin{align*}
x_m^2 &= (p^2_m - c) q^2 (1 - \lambda) - \frac{1}{2} k \theta_2^2 + C_1 \\
x_s^2 &= (p^2_m - c) q^2 \lambda - \frac{1}{2} k \theta_2^2 - C_1
\end{align*} \tag{7}
\]

As the technology supplier and the agent are the Stackelberg game relationship, and the agent is the follower, the technology supplier is the leader, so in Model 2, technology suppliers will make decisions on the official sale price \( p^2_m \) and their promotion level \( \theta_1^2 \) according to the promotion level of agents \( \theta_2^2 \). According to the inverse induction method and the formula (7), based on the partial guide results of the agent
extension level $\theta^2_2$, we can get the optimal promotion level for the agents:

$$\theta^2_2 = \frac{a(k(p_m - c))}{k}$$  \hspace{1cm} (8)

After that, we substitute the results in formula (8) into the partial derivative solution formula for the official price and promotion level of technology suppliers. Combined with the formula (7), the specific partial derivative solution formula is as follows:

$$\begin{aligned}
&\frac{\partial p^*_m}{\partial \theta^2_2} = \frac{a\lambda(p_m - c)}{k} \\
&\frac{\partial \theta^2_1}{\partial \theta^2_2} = a(-1 + \lambda)(c - p^2_m) - k\theta^2_1
\end{aligned}$$  \hspace{1cm} (9)

Similar to Model 1, from joint formula (9), we can get the optimal official sales prices $p^*_m$ for technology suppliers in Model 2 and their promotion level $\theta^2_1$ with the specific results as follows:

$$\begin{aligned}
&\begin{aligned}
&p^*_m = \frac{ak - a^2c(a^2 - 1)(1 + \lambda) + k(a + \beta \theta)}{2ak - a^2(a + \beta \theta)} \\
&\theta^2_1 = \frac{ak - a^2c(a^2 - 1)(1 + \lambda) + k(a + \beta \theta)}{2ak - a^2(a + \beta \theta)}
\end{aligned}
\end{aligned}$$  \hspace{1cm} (10)

In addition to direct sales profit-sharing cooperation, cooperation between technology suppliers and agents can also be conducted through price discounts. Similar to Model 2, in Model 3, technology providers will first offer promotion privileges and a certain price discount $r$ to agents. At this time, the agent does not need to pay the registration fee to the technology supplier. The agent then attracts more users to buy technology products with lower prices based on the discounted market prices $p_g$ given by the technology supplier, as to expand the market, where discount prices are met $p^*_g = r p_m$. Thus, we can conclude that the demand function of the Model 3 is:

$$q^3 = (1 + \theta^3_2)c - a p^3_2 + \beta u$$  \hspace{1cm} (11)

Similar to Model 2, the promotion of the technology market is jointly completed by the technology suppliers and agents, that is, the total market promotion level is met $\theta^3 = \theta^3_1 + \theta^3_2$. In Model 3, technology vendors make profits by the difference between the discount price $p_g$ and technology depreciation cost $c$, while agents increase profits through the price difference between the official selling price $p_m$ and the discounted price $p_g$. Therefore, the profit function formula in this model is shown below:

$$\begin{aligned}
&\begin{aligned}
&\pi^3_m = \left(p^3_m - c\right)q^3 - \frac{1}{2}k\theta^3_2 \\
&\pi^3_g = \left(p^3_m - p^3_g\right)q^3 - \frac{1}{2}k\theta^3_2
\end{aligned}
\end{aligned}$$  \hspace{1cm} (12)

Similar to Model 2, according to formula (12), using the inverse induction method $\theta^3_*, we can obtain the optimal promotion levels of agents $\theta^3_2$, the optimal official price of technology suppliers $p^3_m$, and their promotion level $\theta^3_1$. The specific solutions are as follows:

$$\begin{aligned}
&\begin{aligned}
&p^3_m = \frac{a\lambda(c + \beta \theta)}{2ak - 2a^2(a + \beta \theta)} \\
&\theta^3_1 = \frac{a\lambda(c + \beta \theta)}{2ak - 2a^2(a + \beta \theta)} - \frac{a\lambda(c + \beta \theta)}{2ak - 2a^2(a + \beta \theta)} \\
&\theta^3_2 = \frac{a\lambda(c + \beta \theta)}{2ak - 2a^2(a + \beta \theta)} - \frac{a\lambda(c + \beta \theta)}{2ak - 2a^2(a + \beta \theta)}
\end{aligned}
\end{aligned}$$  \hspace{1cm} (13)

Combined with the above solution process, we summarized the results of relevant variables according to different models and decision objects, whose specific contents are shown in the following Table 1:

Combined with the above solution results, we will compare and analyze the differences between the three models in the next subsection and propose the standard judgment of the corresponding parameter adjustment scheme for the technology suppliers and agents.

Then, taking Model 2 as an example, we further analyze and discuss the long-term game behavior between technology suppliers and agents. Combined with the game model constructed above, we will construct a long period dynamic game model. It is further assumed that both sides of the game will adopt a bounded rational decision-making method when making decisions at the next stage, thus obtaining the following dynamic game model. System (14) describes the dynamic decision-making system composed of technology suppliers and agents.

### Table 1: Optimal solutions for each enterprise in different models

|                | Model 1                  | Model 2                  | Model 3                  |
|----------------|--------------------------|--------------------------|--------------------------|
| Technology supplier | $p^*_m$                  | $\frac{a\lambda(c + \beta \theta)}{2ak - 2a^2(a + \beta \theta)}$ | $\frac{a\lambda(c + \beta \theta)}{2ak - 2a^2(a + \beta \theta)}$ | $\frac{a\lambda(c + \beta \theta)}{2ak - 2a^2(a + \beta \theta)}$ |
| $\theta^*_1$    | $\frac{a\lambda(c + \beta \theta)}{2ak - 2a^2(a + \beta \theta)}$ | $\frac{a\lambda(c + \beta \theta)}{2ak - 2a^2(a + \beta \theta)}$ | $\frac{a\lambda(c + \beta \theta)}{2ak - 2a^2(a + \beta \theta)}$ |
| Agency          | $\theta^*_2$             | $\frac{a\lambda(c + \beta \theta)}{2ak - 2a^2(a + \beta \theta)}$ | $\frac{a\lambda(c + \beta \theta)}{2ak - 2a^2(a + \beta \theta)}$ |

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Table 2  constraint relationship of \( k \) under different modes.

| Model1 | Model2 | Model3 |
|--------|--------|--------|
| \( k > \max \left\{ \frac{\omega_c}{\omega_c + \beta \alpha}, \frac{\omega^2}{2a} \right\} \) or \( 0 < k < \max \left\{ \frac{\omega_c}{\omega_c + \beta \alpha}, \frac{\omega^2}{2a} \right\} \) | \( k > \max \left\{ \frac{\omega^2(1+\alpha)}{2a}, \frac{\omega^2(1+\mu)}{\omega_c + \beta \alpha} \right\} \) or \( 0 < k < \min \left\{ \frac{\omega^2(1+\alpha)}{2a}, \frac{\omega^2(1+\mu)}{\omega_c + \beta \alpha} \right\} \) | \( k > \max \left\{ \frac{\omega^2(1+\alpha)}{2a}, \frac{\omega^2(1+\mu)}{\omega_c + \beta \alpha} \right\} \) or \( 0 < k < \min \left\{ \frac{\omega^2(1+\alpha)}{2a}, \frac{\omega^2(1+\mu)}{\omega_c + \beta \alpha} \right\} \) |

\[
\begin{align*}
p_m^2(t+1) & = p_m^2(t) + v_1 \frac{\partial p_m^2(t)}{\partial \omega_c} + \frac{\partial p_m^2(t)}{\partial \omega_c} \theta_1^2(t) + v_2 \theta_1^2(t) + v_3 \theta_2^2(t) \\
\theta_1^2(t) & = \theta_1^2(t) + v_1 \frac{\partial \theta_1^2(t)}{\partial \omega_c} + \frac{\partial \theta_1^2(t)}{\partial \omega_c} \\
\theta_2^2(t) & = \theta_2^2(t) + v_2 \frac{\partial \theta_2^2(t)}{\partial \omega_c} + \frac{\partial \theta_2^2(t)}{\partial \omega_c} \tag{14}
\end{align*}
\]

Proposition 1  The technology supplier’s optimal selling price can be ensured to be true when the level of promotion has a greater or lesser degree of impact on costs.

Proposition 2  On the premise of \( a \neq ac + \beta \alpha \), when \( k > \max \left\{ \frac{\omega_c}{\omega_c + \beta \alpha}, \frac{\omega^2}{2a} \right\} \), the official sale price of the technology supplier \( p_m^1 \) is positive, and the enterprise obtains marketing income at this time; when \( 0 < k < \min \left\{ \frac{\omega_c}{\omega_c + \beta \alpha}, \frac{\omega^2}{2a} \right\} \), the official sale price of technology suppliers \( p_m^1 \) is positive, but at this time, the enterprise’s revenue is damaged.

Proposition 3  Under the premise \( k \neq \frac{\omega^2(1+\alpha)}{\omega_c + \beta \alpha} \) of Proposition 3, when \( k > \max \left\{ \frac{\omega^2(1+\alpha)}{2a}, \frac{\omega^2(1+\mu)}{\omega_c + \beta \alpha} \right\} \), the official sale price of the technology supplier \( p_m^3 \) is positive, and the enterprise obtains marketing income at this time; when \( 0 < k < \min \left\{ \frac{\omega^2(1+\alpha)}{2a}, \frac{\omega^2(1+\mu)}{\omega_c + \beta \alpha} \right\} \), the official sale price of technology suppliers \( p_m^3 \) is positive, but at this time, the enterprise’s revenue is damaged.

According to Proposition 2 and 3, in the Models 1 and 3, when the cost impact coefficient of promotion level \( k \) is large, because of the capital stimulation, technology supplier prefer to adjust market as to increase their own income; conversely, when \( k \) is small, it will hurt the enterprise’s revenue.

Next, we will compare the optimal profits of technology suppliers in Models 2 and 1, with difference parameter analysis, to analyze the influence of profit distribution coefficient \( \lambda \) on its difference \((\pi_m^2 - \pi_m^1)\). The specific results are as follows:

\[
\frac{\partial (\pi_m^2 - \pi_m^1)}{\partial \lambda} = k\left( a^2 - ak \right)\left( a - ac + \beta \alpha \right)^2 \left( -2ak + a^2(1 + \lambda) \right)^2 \tag{15}
\]

From formula (15), we can see that on the premise of \( a \neq ac + \beta \mu \) and \( k \neq \frac{\omega^2(1+\alpha)}{2\omega_c} \), when \( k > \frac{\omega_c}{a} \), with the increase of profit distribution coefficient \( \lambda \), technology suppliers increase their revenue share by seeking agency relationship cooperation with agents, so as to further stimulate the promotion enthusiasm of agents and help technology suppliers improve their own
revenue. However, when \( k < \frac{a^2}{\sigma} \), with the increase in profit distribution coefficient \( \lambda \), the agent chamber of commerce sought to adjust the existing promotion scope, so as to reduce the overall market scale. Therefore, the increase of \( \lambda \) will put the technology suppliers at a disadvantage in the cooperative relationship.

Then, we continue to compare the optimal profits of technology suppliers in Models 3 and 1 and analyze the impact of the price discount coefficient \( r \) on their difference \( (\pi_m^\ast - \pi_m^1) \). The specific results are as follows:

\[
\frac{\partial (\pi_m^\ast - \pi_m^1)}{\partial r} = \frac{a^2(r^2 + 2a^2r + a^2 + \alpha_1 r + \beta r + 1 + \lambda_1)}{kr^2 (r^2 + \alpha_1 + \beta r + 1)}
\]

(16)

Similarly, from formula (16), it is easy to know that on the premise of \( k \neq \frac{a^2(2-r)}{2\sigma} \), when \( 0 < \tau < \max \left\{ \frac{\alpha c}{a c - \alpha c + \beta u}, \frac{\alpha c}{a c - \beta u} \right\} \), with the increase of the profit distribution coefficient, the profit income of the technology supplier in Model 3 and the optimal profit value in Model 1 will gradually decrease, that is, the technology supplier will not bring additional profits to itself if it continues to give the agent a large price discount.

On the premise of \( \frac{\alpha c}{a c - \alpha c + \beta u} > 0 \), that is, \( k < \frac{a^2c}{a c - \alpha c + \beta u} \), when \( 0 < \tau < \min \left\{ \frac{\alpha c}{a c - \alpha c + \beta u}, \frac{\alpha c}{a c - \beta u} \right\} \) or \( \tau > \max \left\{ \frac{\alpha c}{a c - \alpha c + \beta u}, \frac{\alpha c}{a c - \beta u} \right\} \), with the increase of the price discount coefficient, the profit income of technology suppliers in Model 3 and the optimal profit value in Model 1 will gradually expand, that is, when the price discount coefficient is adjusted within a higher value or a lower range, it can stimulate the increase of market demand and make technology suppliers profit. In addition, when \( k > \frac{a^2c}{a c - \alpha c + \beta u} \), it can be consistent with the conclusion above only when the conditions \( \tau > \max \left\{ \frac{\alpha c}{a c - \alpha c + \beta u}, \frac{\alpha c}{a c - \beta u} \right\} \) are met.

Finally, let us make a parameter analysis on the difference between the optimal profits of agents in Models 2 and 3. Here, we focus on the impact of the profit distribution coefficient \( \lambda \) on the difference. The relevant solution results are as follows:

\[
\frac{\partial (\pi_m^3 - \pi_m^2)}{\partial \lambda} = \frac{k(2a^2c^2 + 3a^4 \lambda - a^3 ak(1 + 5 \lambda))(a - ac + \beta u)^2}{(2ak + a^2(1 + \lambda))^3}
\]

(17)

\[
\frac{\partial (\pi_m^3 - \pi_m^2)}{\partial \lambda} = \frac{k(4a^2c^2 + a^2(3 - 6 \lambda)) + 2a^4(4 + 5 \lambda))(a - ac + \beta u)^2}{(2ak + a^2(1 + \lambda))^3}
\]

(18)

Through formula (17), we can obtain the stagnation point of the difference under the profit distribution parameters \( \lambda \), and the result is:

\[
\lambda^* = \frac{ak(a^2 - 2ak)}{3a^4 - 5a^2 ak}
\]

(19)

Combined with formula (18), on the premise of \( k \neq \frac{a^2(1+\lambda)}{2a} \) and \( a \neq ac + \beta u \), we assume that \( \lambda = \frac{a^2(1+\lambda)}{2a} \) \( \frac{1}{10a^2 ak - 8a^2 k^2 - 4ak^2 a^2} \), where \( \lambda > 0 \), the following proposition can be obtained:

**Proposition 4** When \( \lambda^* > \lambda^* \), \( \lambda^* \) is the minimum difference value between the optimal profits in agent Models 2 and 3. In the interval \( (\lambda, \lambda^*) \), the profit difference value will gradually decrease with the increase of \( \lambda \), while in the interval \( (\lambda^*, +\infty) \), the profit difference value will gradually increase with the increase of \( \lambda \); when \( 0 < \lambda^* < \lambda^* \), it is the maximum difference value between the optimal profits in agent Models 2 and 3. In the interval \( (0, \lambda^*) \), the profit difference value will gradually increase with the increase of \( \lambda \), while in the interval \( (\lambda^*, \lambda^*) \), the profit difference value will gradually decrease with the increase of \( \lambda \).

Proposition 4 proves to us that under certain constraints, there will be a maximum or minimum value for the profit difference between agents in Models 2 and 3 in different numerical ranges, that is, agents can make revenue judgments in advance according to the change of profit distribution coefficient \( \lambda \) of technology suppliers, so as to select a more suitable marketing mode.

**Numerical analysis**

Based on the results of the model analysis in the previous section, in this section, we will analyze the influence of each parameter on the decision variables and the choice of mode strategies for both sides of the decision more intuitively by means of numerical simulation. In this way, we set the value of each parameter as \( p_1 = 1; \lambda = 0.5; \gamma = 1.5; \tau = 0.3; \sigma_1 = 0.3; k = 2.0; \sigma = 0.15; c = 0.7; C_1 = 0.01 \). Combined with the decision function and profit function of the decision object in each mode, according to the relevant solution results, we will first explore the impact of technology depreciation cost \( c \) on decision variables related to technology suppliers in Model 1.

From Fig. 2, we can clearly see that, as technology depreciation cost \( c \) increases, the official sale prices of technology providers will be steadily increased, and the promotion level will drop steadily. From this, we can see that when cost \( c \) increases over time, technology providers choose to raise prices to ensure stable revenue for their technology products. Meanwhile, when \( c \leq 0.95 \), technology providers will phase out positive market promotion as costs increase; when \( c > 0.95 \), technology vendors will progressively scale down the scope of their existing markets as costs increase.

Next, we will explore the impact of technology depreciation cost \( c \) and price sensitivity factor \( a \) on the profitability of technology providers in Model 1.
Fig. 2 The Impact of $c$ on decision variables $p_{m}^{1}$ and $\theta_{1}^{1}$

From Fig. 3, we can easily know that when the technology depreciation cost and the price sensitivity factor are comparatively small or high, the technology provider’s profit is higher compared to the parameter range. This also shows that when both the cost $c$ and sensitivity factor $\alpha$ are comparatively small, technology suppliers can obtain higher market demand and higher profits per unit of technology product sold. When both the cost $c$ and sensitivity factor $\alpha$ are comparatively high, technology providers will be incentivized to raise the official market selling price to make more profits from the limited market.

Then, we will explore the effects of changes in the relevant parameters in Models 2 and 3 on the firm’s decision variables and profits in turn.

Figure 4a shows the impact of $\lambda$ on the decision variables related to technology supply and agents in Model 2, while Fig. 4b shows the impact of $\lambda$ on the profits of the two firms. From Fig. 4, we can see that as the profit-sharing factor $\lambda$ increases, the official sale price and marketing incentives of

Fig. 3 The Impact of $c$ and $\alpha$ on the profit of technology suppliers

Fig. 4 The effect of $\lambda$ on the decision variables and profit of each enterprise
technology suppliers gradually increase, while their revenue decreases. And with the improvement of $\lambda$, the agent marketing enthusiasm is decreasing, but its profits will gradually increase. This illustrates that the improvement of $\lambda$ will stimulate technology providers to work harder on market promotion to a certain extent, but the opposite agents are caught in a state of inert promotion and sitting on their earnings. When $\lambda > 0.5$, the profit gains for agents will be greater than for technology providers.

Similarly, Fig. 5a shows the effect of $\tau$ on technology supply and agent-related decision variables in Model 3, while Fig. 5b represents the effect of $\tau$ on the profits of the two enterprises. From Fig. 5, we can easily know that, when $\tau < 0.3$, the official sale price and the level of promotion of both companies have gradually decreased, while the revenue of technology suppliers has been losing money and the profit of agents has continued to decrease. And when $\tau > 0.3$, both enterprises’ decision variables and technology suppliers’ profits change in a similar trend, both showing a sharp decline and then stabilizing. The profit value of the agents, on the other hand, changed from a loss to a gain and then slowly decreased, during which its profit value once exceeded that of the technology providers. This also shows that when the price discount $\tau$ is small, it benefits the agent. And as the price discount $\tau$ increases, technology providers tend to gain more than agents.

Then, we will explore the selection interval of the optimal model of the technology provider under the variation of the profit-sharing factor $\lambda$ and the price discount factor $\tau$.

From Fig. 6, we can see that with the growth of the profit-sharing factor $\lambda$ and the price discount factor $\tau$, the mode choice of technology providers is divided into four regions. When $\tau < 0.28$ and $\lambda > 0.07$, technology providers select Model 1 of direct official sale for the highest profit gain; when $\tau < 0.28$ and $\lambda < 0.07$, or $\tau > 0.93$ and $\lambda$ below a certain linear trend, the optimal model for technology providers is Model 2, that is, to seek agency relationships with agents; in addition to the above range of parameter adjustments, the technology providers’ choice of Model 3 means the highest return when it comes to reseller relationships with agents. Thus, it is clear that when the price discount is comparatively high, it will stimulate the market and expand the market demand so that the profit income of technology suppliers increases. However, when the price discount is comparatively small and its stimulation of consumer demand is insufficient, and the profit distribution coefficient will play a key role at this time. When the profit distribution coefficient is comparatively high and the proportion of technology supplier profits received is comparatively small, the direct official sales become the optimal solution. However, when the profit distribution coefficient is comparatively low, the technology supplier will prefer agent cooperation.

From Fig. 7, we can see that as the profit-sharing factor $\lambda$ and the price discount factor $\tau$ grow, the choice of the agent’s optimal solution is similarly divided into four regions.
0.07 < τ < 0.34, or τ > 0.73 and λ are above a certain linear trend, the optimal mode for agents is Model 2; while in other parameter ranges, technology providers have the highest profit gains when they choose Model 3. As a result, it is easy to see that technology providers need to pay attention to the size of the adjustment speed when formulating relevant price adjustment strategies in order to prevent chaos in the entire market system.

Conclusion

Based on the development status of green technology, combined with the relevant technical marketing experience in other fields, this paper builds three models of technology marketing based on the Stackelberg game between technology suppliers and agents and builds a dynamic system model based on one of three models. Then, we make a comparative analysis on the solution results of the model and further observe the impact of each parameter on enterprise decision variables, profits, and the choice of optimal mode scheme through numerical simulation. Based on this, we draw the following conclusions:

(1) In the two models based on supplier and agent cooperation, under certain conditions, there exists the maximum or minimum value of agent profit difference within the scope of the different numerical values, that is, the agent can choose a more suitable marketing model for themselves based on the change of the profit distribution coefficient of technology suppliers as to determine their earnings ahead of time.

(2) The level of price discount will determine whether the technology supplier chooses to cooperate with agents on commission, while the level of profit distribution coefficient will determine whether the technology supplier chooses direct official sales. When the price discount is comparatively high, technology suppliers give priority to cooperating with agents on commission; when the price discount is comparatively low, mode selection should be determined according to the level of profit distribution coefficient. When the profit distribution coefficient is comparatively high, technology suppliers choose direct official sales instead of cooperating with agents.

(3) Technology suppliers need to control the speed at which they adjust their prices. When the price adjustment speed of technology suppliers is too high, it will affect the market stability and lead to the bifurcation of decision variables, making it difficult for decision-makers
to make reasonable decisions. If the price adjustment speed of technology suppliers is stable in a certain area, the stability of the whole system can be maintained. Hence, the policymakers should be very careful when they regulate the market.

The current research in this paper is limited to the game competition between a single technology supplier and a single agent. In the future, the game scenes between multiple technology suppliers will be further explored to enrich the content of this paper.

Appendix

Optimal profit of technology supplier in Model 1:

\[ \pi^1_m \approx -\frac{k(a - ac + \beta u)^2}{2(a^2 - 2ak)} \]  

\[ (20) \]

Optimal profit of technology supplier and agent in Model 2:

\[ \pi^2_m = \frac{-4C_1ka - 2ak(c - u\beta)(1 + \lambda) + k(c - u\beta)\lambda(-1 + \lambda) + a^2(1 + \lambda)(2C_1(1 + \lambda))}{-4ka + 2a^2(1 + \lambda)} \]

\[ \pi^2_g = \frac{4ak^2(a - ca + u\beta)\lambda + 6a^2k(c - u\beta)\lambda^2 + 2k^2a(-4C_1a + (c - u\beta)^2\lambda - a^4(3k\lambda^2 + 2C_1(1 + \lambda)^2) + a^2k(8c\lambda(1 + \lambda) + \lambda(2ka - 3(c - u\beta)^2\lambda))}{2(-2ka + a^2(1 + \lambda))^2} \]

Optimal profit of technology suppliers and agents in Model 3:

\[ \pi^3_m = \frac{(ak\tau + a^2(c - ct) + k\tau(-ac + \beta u))^2}{2k\tau(a^2(-2 + \tau) + 2ak\tau)} \]  

\[ (21) \]

\[ \pi^3_g = \frac{(-1 + \tau)(-a^2c + k(a + ca + u\beta)\tau)(-3a^2k(-1 + \tau) + 3a^2k(c - u\beta)(-1 + \tau)\tau - 2ak^2a\tau^2 + 2k^2a(c - u\beta)\tau^2 + a^2c(-1 + \tau)(1 + 2\tau))}{2k\tau^2(a^2(-2 + \tau) + 2ak\tau)^2} \]

Acknowledgements We thank the reviewers and associate editor for their careful reading and helpful comments on the revision of the paper.

Author contribution Meihong Zhu, Xiao Li, and Li Zhao: thesis architecture design, writing the original draft. Xinliang Wang: supervision and project administration. Li Zhao, Xiao Li: reviewing, preparing final draft, and formatting. Meihong Zhu, Xinliang Wang: investigation, validation, programming and calculation, and editing. Li Zhao, Xinliang Wang: methodology and experimental calculations.

Funding The research was supported by the Innovation Fund of Tianjin University.

Data availability Supplementary data to this article will be provided upon request.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Data availability Not applicable.

Conflicts of interest The authors declare no competing interests.

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