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Game-theoretic Analysis for the Trade-Off Between R&D and Marketing in Chinese Cosmetic Market

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ABSTRACT

A booming economy nurtured a bunch of new local brands in the Chinese cosmetic market, and Perfect Diary has stood out as a top player. However, it did more aggressive marketing than its international counterpart L'Oréal, which mainly focused on R&D. The mechanism behind their strategy making is worth studying. Therefore, this paper applies game theory and models the competition between two typical players as a static game and an infinitely repeated game to account for their actions and search for another possible outcome. Marketing effect, R&D effect, and discount rates of future payoffs are factors influencing players' preferences. The result turns out that both games have an equilibrium: the static game ends up in a marketing war, while the repeated game has a pleasant equilibrium where both players adopt the anonymous grim trigger strategy, conditional on large discount rates. Furthermore, limited R&D capability and a strong marketing effect will make the equilibrium lame in the repeated game.

Keywords: *Chinese cosmetic market, Game theory, Marketing, R&D, Discount rates.*

1. INTRODUCTION

1.1. Background

Due to the rapid development of China's economy in recent decades, the life quality of Chinese people has been significantly improved. The standard for a satisfactory life is not just limited to eating well or wearing cool, the magnitude of consumption of non-essential items like cosmetics also counts. In terms of population, generation Z, who are eager to pursue individuality and show their beauty, have gradually become the main consumer cohort in China's cosmetic market. Plus, China has long been an OEM for developed countries, thus its production technology and process management related to the cosmetic industry have become mature in recent years. All these factors allow new domestic brands to enter this market, which has been dominated by foreign cosmetic companies before. Since 2016, numerous domestic brands have been created. After 5 years, Perfect Diary is taking the lead among domestic brands and threatening to replace the cosmetic tycoon - L'Oréal.

However, it is worth noting that Perfect Diary and L'Oréal achieved success in different paths. Perfect Diary made full use of digital marketing by implementing KOL marketing strategy and omnichannel distribution, with a focus on affordable products. On the contrary, L'Oréal was aimed at the luxury market and renowned for intense R&D. Although they are different, both companies are well aware of the fact that R&D is the source of profits and marketing is a necessity to attract customers. Hence, they have to face a common problem now: the trade-off between R&D and marketing investments.

There are many effective methods to describe the competitive relationship and trade-off between the different options. Game theory is one of the most efficient ways, and it is widely used in related research in economics. As a result, the static model and dynamic model in game theory will be used in the following pages.

1.2. Related Research

Many scholars have studied how marketing and R&D affect the company and market. Amir et al.

investigated the AJ model and concluded that more research and development is beneficial to consumers and society as a whole [1]. Yang et al. believed that strategic innovations that increase the value of products or services can help win the competition and create new markets [2]. However, the performance of Chakravarty et al. library results showed that reducing R&D can increase stock expectations in 2011 [3]. The research results of Li et al. also showed that advertising is very important in the traditional supply chain and more useful for maintaining long-term customer relationships [4, 5]. Both being very important ways for companies to enhance their value, how to deal with the trade-off between marketing and R&D has always been a difficult problem. Shin et al. mentioned in their research that leaders benefit more from marketing investment, while followers benefit more from R&D investment [6]. Therefore, the best strategy is difficult to formulate. As a result, this research is significantly valuable to provide some suggestions for finding the best strategy.

In the era of rapid economic development in China, more opportunities for entering the Chinese beauty market arose [7]. Li et al. found that Perfect Diary has established a good reputation in a short time and surpassed European and American brands by focusing on product quality and moderate marketing in recent years [8]. That's why Perfect Diary is indeed a subject worth studying.

1.3 Objective

This paper selects two typical companies in the Chinese market as the research subjects - Perfect Diary from China and L'Oréal from Europe. The former is marketing-oriented, while the latter is R&D-oriented. The proposed model tries to illustrate how they vie for market share by a trade-off between R&D and marketing investments and to figure out the condition to make them invest more in R&D instead of getting stuck in a dismal marketing war.

2. METHOD

This study first models the competition between Perfect Diary and L'Oréal as a static game, where both players only care about short-term interests. Then the model is extended to an infinitely repeated game so that future payoffs may sway both players' strategies.

2.1. Static Game

Two markets are taken into consideration: a low-end market and a luxury one. Each market has only one player - Perfect Diary as player 1 in the former, and L'Oréal as player 2 in the latter. Both have to choose either of the following actions as their operation strategy: aggressive marketing with no R&D denoted by A, or incremental marketing with intense R&D denoted by I. At the same time, they have to set prices, p_1 and p_2 respectively for the chosen action, without knowing the opponent's choice. Their demand takes the form of $1 - p_1$ and $1 - \frac{p_2}{2}$, but may change according to the actions both players take. Specifically, if players choose the same, marketing doesn't work. Otherwise, whoever chooses A will take away some customers from his rival, who chooses I. We use λ to represent this marketing effect. When a player chooses I, his demand curve will shift upright, and that leads to an increase of μ to the demand. It is assumed that players have different R&D capabilities, so there will be μ_1 (for player 1) and μ_2 (for player 2) [9]. A premise is set to indicate a strong marketing effect: $\lambda > \mu_2 > \mu_1 > 0$. The payoffs for players are revenues they made, whose forms in each possible outcome are listed in Table 1.

2.2. Infinitely Repeated Game

In this game, the players, actions, and payoff functions are all the same as the static one, but there will be more elements. First, both players have their discount rate of future payoffs, denoted by δ_1 and δ_2 respectively. Both δ_1 and δ_2 fall between 0 and 1. Second, both players adopt the anonymous grim trigger strategy. The strategy works as below: If a player adopts this strategy, he will choose I in the first period and will still do so in later periods only when both players choose I in the previous period. Should either player deviate to A at some point, he will choose A forever after that deviation period. Osborne has proved in the case of prisoner's dilemma that the strategy profile in which both players adopt anonymous grim trigger strategy is a subgame perfect Nash equilibrium when δ_1 and δ_2 satisfy certain conditions [10]. The model in this paper also tries to find the proper discount rates of both players to keep them at an equilibrium state.

Table 1. The payoff functions of both players

Action	A	I
A	$p_1 \times (1 - p_1)$, $p_2 \times \left(1 - \frac{p_2}{2}\right)$	$p_1 \times (1 - p_1 + \lambda)$, $p_2 \times \left(1 + \mu_2 - \frac{p_2}{2} - \lambda\right)$
I	$p_1 \times (1 + \mu_1 - p_1 - \lambda)$, $p_2 \times \left(1 - \frac{p_2}{2} + \lambda\right)$	$p_1 \times (1 + \mu_1 - p_1)$, $p_2 \times \left(1 + \mu_2 - \frac{p_2}{2}\right)$

Here an explanation is offered on the assumption that payoff functions remain the same in every single period. The reason why players have to invest consistently in R&D to keep that μ in the demand function in any single period is to meet customers' expectations of new products. Involvement in intense R&D lets out a signal that the player is trying to make some surprises, which exactly suits the taste of new generation customers. They may not show loyalty to any particular brand and just give a shot at something new. For players, they hope to develop those adventurous customers into regular ones. This is the underlying assumption behind a constant R&D effect rather than a cumulate one.

2.3. Simplifications in the Method

There are several simplifications made in the model to capture the main idea without sacrificing generality. First, costs are not involved. Second, the marketing effect is the same no matter which player is doing aggressive marketing. This is reasonable because, in the current Chinese cosmetic market, which features the prevalence of the Internet, the essence of marketing is to appear as many times as possible and to appear everywhere so that the brand can take up a place in people's minds. Since the Internet has really leveled the playing field for incumbents and potential challengers to do marketing, and customers gradually view the overwhelming marketing as homogeneous, this simplification might be an illustration of the situation. Third, both marketing and R&D are set to influence demand directly. Fourth, only two players are involved.

3. RESULTS

3.1. Static Game

The model is a little bit different from a standard static game, as players have two decisions to make in a single stage: an action and a price. Although the actions are supposed to be simultaneous, there exists a hidden reasoning process where they should be done in order. That is, players should derive the accurate payoff with certain prices and then apply the best response method. Therefore, the first step is to set the optimal prices for each action.

Let's start with player 1. It is assumed that he forms a belief about player 2: choose A with probability α (α∈ [0,1]), and I with (1-α), so that he sets prices under the same criterion. The expected payoffs of A and I are calculated to determine the optimal prices for each action. By putting them in the revenue formula, the payoff matrix can be obtained in Table 2.

$$E(\mathrm{A}) = \alpha p_1(1-p_1) + (1-\alpha)p_1(1-p_1+\lambda) \quad (1)$$

$$\frac{\partial E(\mathrm{A})}{\partial p_1} = 1 - 2p_1 + (1-\alpha)\lambda = 0 \quad (2)$$

$$p_1^*(\mathrm{A}) = \frac{1+(1-\alpha)\lambda}{2} \quad (3)$$

$$E(\mathrm{I}) = \alpha p_1(1+\mu_1-p_1-\lambda) + (1-\alpha)p_1(1+\mu_1-p_1) \quad (4)$$

$$\frac{\partial E(\mathrm{I})}{\partial p_1} = 1 + \mu_1 - 2p_1 - \alpha\lambda = 0 \quad (5)$$

$$p_1^*(\mathrm{I}) = \frac{1+\mu_1-\alpha\lambda}{2} \quad (6)$$

Next, best response method is used to determine Nash equilibrium.

Proposition 1: A is a dominant strategy for player 1.

Proof: Given that player 2 plays A,

$$\frac{1-[(1-\alpha)\lambda]^2}{4} - \frac{(1+\mu_1-\alpha\lambda)[1+\mu_1-(2-\alpha)\lambda]}{4}$$

$$= \frac{1-(1+\mu_1-\lambda)^2}{4} > 0 \quad (7)$$

or

$$\frac{1-[(1-\alpha)\lambda]^2}{4} > \frac{(1+\mu_1-\alpha\lambda)[1+\mu_1-(2-\alpha)\lambda]}{4} \quad (8)$$

Given that player 2 plays I,

$$\frac{[1+(1-\alpha)\lambda][1+(1+\alpha)\lambda]}{4} - \frac{(1+\mu_1)^2-(\alpha\lambda)^2}{4}$$

$$= \frac{1}{4}[(1+\lambda)^2 - (1+\mu_1)^2] > 0 \quad (9)$$

or

$$\frac{[1+(1-\alpha)\lambda][1+(1+\alpha)\lambda]}{4} > \frac{(1+\mu_1)^2-(\alpha\lambda)^2}{4} \quad (10)$$

The result shows that player 1 prefers (A, A) to (I, A), and (A, I) to (I, I). Therefore, A is a dominant strategy for him.

Table 2. The payoff matrix for player 1 with an arbitrary belief

Action	A	I
A	$\frac{1-[(1-\alpha)\lambda]^2}{4}$	$\frac{[1+(1-\alpha)\lambda][1+(1+\alpha)\lambda]}{4}$
I	$\frac{(1+\mu_1-\alpha\lambda)[1+\mu_1-(2-\alpha)\lambda]}{4}$	$\frac{(1+\mu_1)^2-(\alpha\lambda)^2}{4}$

Table 3. The payoff matrix for player 2 with an arbitrary belief

Action	A	I
A	$\frac{1-[(1-\beta)\lambda]^2}{2}$	$\frac{(1+\mu_2-\beta\lambda)[1+\mu_2-(2-\beta)\lambda]}{2}$
I	$\frac{[1+(1-\beta)\lambda][1+(1+\beta)\lambda]}{2}$	$\frac{(1+\mu_2)^2-(\beta\lambda)^2}{2}$

For player 2, the analysis is quite similar. He forms a belief about player 1: choose A with probability β ($\beta \in [0,1]$), and I with $(1-\beta)$. Then, optimal prices are derived as Equations (11) and (12) illustrate, and the payoff matrix can be obtained in Table 3. Since Table 2 and Table 3 have quite symmetric structures, A should be a dominant strategy for player 2.

$$p_2{}^*(\mathrm{A}) = 1 + (1-\beta)\lambda \quad (11)$$

$$p_2{}^*(\mathrm{I}) = 1 + \mu_2 - \beta\lambda \quad (12)$$

Both players will realize the fact that A is the optimal choice for themselves and their rivals after such logical reasoning. Ultimately, (A, A) will be the stable outcome and their price settings will be consistent with it. The final payoff matrix will end up in Table 4. Therefore, the pure strategy pair (A, A) is the stable Nash equilibrium in this game.

Table 4. The final payoff matrix

Action	A	I
A	$\frac{1}{4},\frac{1}{2}$	$\frac{1+2\lambda}{4},\frac{(1+\mu_2-\lambda)^2}{2}$
I	$\frac{(1+\mu_1-\lambda)^2}{4},\frac{1+2\lambda}{2}$	$\frac{(1+\mu_1)^2-\lambda^2}{4},\frac{(1+\mu_2)^2-\lambda^2}{2}$

3.2. Infinitely Repeated Game

Still, this subsection starts with player 1. In the equilibrium state, since everyone chooses I, player 1 should set the optimal prices under the belief that player 2 will always choose I, as shown in Equations (13) and (14). Form the payoff matrix as Table 5, and the sum of equilibrium payoffs in all periods is calculated in Equation (15).

$$p_1{}^*(\mathrm{A}) = \frac{1+\lambda}{2} \quad (13)$$

$$p_1{}^*(\mathrm{I}) = \frac{1+\mu_1}{2} \quad (14)$$

$$\text{Equilibrium payoff} = \frac{(1+\mu_1)^2}{4}\sum_{i=0}^{\infty}\delta_1{}^i = \frac{(1+\mu_1)^2}{4(1-\delta_1)} \quad (15)$$

Table 5. The payoff matrix for player 1

Action	A	I
A	$\frac{1-\lambda^2}{4}$	$\frac{(1+\lambda)^2}{4}$
I	$\frac{(1+\mu_1)^2}{4}-\frac{\lambda(1+\mu_1)}{2}$	$\frac{(1+\mu_1)^2}{4}$

In the deviation period, optimal prices are the same as the equilibrium state. The outcome goes (A, I), so the deviation payoff is $\frac{(1+\lambda)^2}{4}$. However, outcomes in the following periods will be (A, A) forever and optimal prices should change as player 2 shifts his action. It's easy to derive that $p_1{}^*(\mathrm{A}) = \frac{1}{2}$ and the payoff in the (A, A) cell becomes $\frac{1}{4}$. The sum of deviation and punishment payoffs is shown in Equation (16).

$$\frac{(1+\lambda)^2}{4} + \frac{1}{4}\delta_1 + \frac{1}{4}\delta_1{}^2 + \frac{1}{4}\delta_1{}^3 + \cdots = \frac{(1+\lambda)^2}{4} + \frac{\delta_1}{4(1-\delta_1)} \quad (16)$$

The deviation is not profitable if and only if

$$\frac{(1+\mu_1)^2}{4(1-\delta_1)} \geq \frac{(1+\lambda)^2}{4} + \frac{\delta_1}{4(1-\delta_1)} \quad (17)$$

or

$$\delta_1 \geq \frac{(1+\lambda)^2-(1+\mu_1)^2}{\lambda(\lambda+2)} \quad (18)$$

Similarly, optimal prices can be derived. Then, the payoff matrix is formed in Table 6. Nash equilibrium condition is shown as Inequation (21) and the value range of δ_2 is given by Inequation (22).

$$p_2{}^*(\mathrm{A}) = 1 + \lambda \quad (19)$$

$$p_2{}^*(\mathrm{I}) = 1 + \mu_2 \quad (20)$$

Table 6. The payoff matrix for player 2

Action	A	I
A	$\frac{1-\lambda^2}{2}$	$\frac{(1+\mu_2)^2}{2}-\lambda(1+\mu_2)$

I	$\frac{(1+\lambda)^2}{2}$	$\frac{(1+\mu_2)^2}{2}$

The deviation should not be profitable if and only if

$$\frac{(1+\mu_2)^2}{2(1-\delta_2)} \geq \frac{(1+\lambda)^2}{2} + \frac{\delta_2}{2(1-\delta_2)} \quad (21)$$

or

$$\delta_2 \geq \frac{(1+\lambda)^2-(1+\mu_2)^2}{\lambda(\lambda+2)} \quad (22)$$

Before the conclusion, there should be illustrations on the validity of Inequations (18) and (22).

Proposition 2: There exists $\delta_1 \in (0,1)$ and $\delta_2 \in (0,1)$ such that Inequations (18) and (22) hold.

Proof: With the premise $\lambda > \mu_2 > \mu_1 > 0$, it's easy to obtain

$$\frac{(1+\mu_1)^2-(1+\mu_1)^2}{\lambda(\lambda+2)} < \frac{(1+\lambda)^2-(1+\mu_1)^2}{\lambda(\lambda+2)} < \frac{(1+\lambda)^2-(1+0)^2}{\lambda(\lambda+2)} \quad (23)$$

and

$$\frac{(1+\mu_2)^2-(1+\mu_2)^2}{\lambda(\lambda+2)} < \frac{(1+\lambda)^2-(1+\mu_2)^2}{\lambda(\lambda+2)} < \frac{(1+\lambda)^2-(1+0)^2}{\lambda(\lambda+2)} \quad (24)$$

That is,

$$0 < \frac{(1+\lambda)^2-(1+\mu_1)^2}{\lambda(\lambda+2)} < 1 \quad (25)$$

and

$$0 < \frac{(1+\lambda)^2-(1+\mu_2)^2}{\lambda(\lambda+2)} < 1 \quad (26)$$

Inequations (25) and (26) justify the existence of certain δ_1 and δ_2 . In other words, whether this equilibrium can hold depends on players' attitudes towards future payoffs.

In conclusion, the strategy profile in which both players adopt the anonymous grim trigger strategy is a Nash equilibrium if Inequation (18) and (22) hold. It's also a subgame perfect equilibrium because the sequence of outcomes in the subgame following any history except (I, I) is ((A, A), (A, A), (A, A), …), and nobody can gain more by deviating in any single period.

4. DISCUSSION

4.1. Static Game

The equilibrium (A, A) indicates a marketing war, which is not desirable. Unluckily, there's no other way out as A is always a dominant strategy for both players, regardless of their beliefs. This comes down to the premise about the relationship between the marketing effect and the R&D effect. To be more specific, the inequation $\lambda > \mu_2 > \mu_1 > 0$ guarantees the dominance of action A.

However, (A, A) can be an efficient equilibrium if μ_2 doesn't reach a certain threshold. The structure of the ultimate payoff matrix is almost identical to the prisoner's dilemma. This classic example ends up with an inefficient equilibrium where both players choose to defect (The action "A" plays the role of "defect" in the proposed model). What's different here is that the relationship between the payoffs of (A, A) and (I, I) is flexible.

Proposition 3: The static game has an efficient equilibrium if the following condition holds:

$$\mu_2 < \sqrt{\lambda^2 - 1} - 1 \quad (27)$$

Proof: Inequation (27) leads to $\frac{1}{2} > \frac{(1+\mu_2)^2-\lambda^2}{2}$, which means player 2 prefers (A, A) to (I, I). With $\mu_2 > \mu_1$, it's natural that $\mu_1 < \sqrt{\lambda^2 - 1} - 1$. That leads to $\frac{1}{4} > \frac{(1+\mu_1)^2-\lambda^2}{4}$, which is to say player 1 prefers (A, A) to (I, I) as well. Therefore, an efficient equilibrium can be achieved with surprisingly low R&D effects or an especially strong marketing effect.

What does the efficient equilibrium bring about? When the whole industry suffers from a lack of R&D, companies will be stuck in fierce marketing competition and they feel comfortable with it in the short term. However, it is a crisis for customers because they will never be able to enjoy high-quality products. Eventually, companies cannot have a profitable long-term development.

4.2. Infinitely Repeated Game

The conditional equilibrium brings some hope to the industry. It can be achieved due to a long-lasting punishment for deviation in the form of profit decrease, but whether it's easy to keep is another issue. A larger μ leads to a lower discount rate requirement, which means a tech expert faces a harsher punishment if he does aggressive marketing, and thus is inclined to invest in R&D. On the opposite, the tech neophyte player with a smaller μ is more likely to break the equilibrium unless he waits patiently enough for the investment to pay off. On top of the technological factor, a strong marketing effect will make it harder for both players to resist the temptation of deviation.

It's worth noting that the equilibrium prices of both players get higher than those in the static game. Player 1 sets the price at $\frac{1+\mu_1}{2}$ rather than $\frac{1}{2}$ and player 2 sets it at $1 + \mu_2$ rather than 1. If the R&D effect accumulates and drives demand higher and higher in every single period, the optimal price would experience a continual increase in consequence. The price rise is backed up by R&D activities like quality improvement or ingredient upgrades. It will lay a solid foundation for an entry into the high-end market, which could be a promising choice for corporate development and a boost to brand image especially for a company like Perfect Diary is currently targeting the low-end market.

4.3. A Real-Life Test of the Model

This subsection refers to available data to test the proposed model and tries to reach some practical implications. In 2020, the weighted average cost of capital (WACC) was 7.3% for L'Oréal and approximately 20% for Perfect Diary, according to their annual reports. With Equation (28), it's easy to derive the values δ_1 and δ_2 . That is, δ_1 = 93.20%, δ_2 = 83.33%.

$$\delta_i = \frac{1}{1+WACC_i}, i = 1,2 \tag{28}$$

Even though λ and μ remain unknown, the result is enough to shed light on why Perfect Diary pooled its resource in marketing. With a fragile technology foundation, Perfect Diary was already hindered by a high threshold. As a young player, Perfect Diary had a large WACC that constraint it from caring about a far-away future and forced it to deliberate over any investment. Considering the cost and the risk, it was natural to choose marketing. On the contrary, L'Oréal could afford some failures on R&D with a relatively small WACC, not to mention its strong R&D capacity.

Hopefully, Perfect Diary is carrying out some plans on enhancing its R&D level in 2021 as it is securing its position in China and clarifying its business model. If things go well, the cooperative equilibrium may be in store.

5. CONCLUSION

This paper applies game theory to explore the satisfactory operation strategies for two typical players targeting different customers in the Chinese cosmetic market. The competition between them is first modeled as a static game and then extended to an infinitely repeated game. Considering factors like marketing effect (λ), R&D effect (μ), and the discount rate of future values (δ), some inspiring conclusions are obtained.

The static game has a gloomy Nash equilibrium where both players choose aggressive marketing with no R&D, yet it can be efficient if both R&D effects do not reach a certain threshold. This is a major difference between the static model and the classic prisoner’s dilemma.

In the repeated game, the strategy profile in which both players adopt the anonymous grim trigger strategy is a subgame perfect Nash equilibrium if their discount rates of future payoffs are large enough. It’s easier for the company that does better in R&D to follow the equilibrium, but harder for the one that does worse to do so. When the marketing effect becomes stronger, companies must be patient enough to adhere to the equilibrium. Financial indicator WACC is also included in the analysis to indicate the reasons behind players’ actual strategies. A large WACC results in an inclination towards marketing.

There are some managerial implications for future strategy making. First and foremost, commitments benefit both companies in the long term. Profit increase is apparent, and companies end up with a higher price owing to R&D effects. The price rise will prepare companies for entry into the high-end market. Second, without commitments in advance, small companies had better start from conducting good marketing to survive the inchoate phases when R&D is not affordable or quite rewarding.

There are also insights into policymaking. The government needs to play the role of market regulation and supervision. It should support companies in the gloomy industry with adequate resources to make sure that they are willing to do R&D under a specific discount rate. What's more, the government is supposed to set several limitations on marketing behavior and force the payoff of marketing down. This helps lower the threshold of discount rates to keep companies at the status of equilibrium.

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