Game Theory on Tesla: The Automobile Industry Analysis on Strategic Cooperation among Competitors

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Abstract

In this paper, we mainly study the cooperation among competitors specifically and how it affects all the companies in the automobile industry. Based on the two-stage dynamic game theory and two-part tariff theory, we construct a game theory model to analyze the details of Tesla-Daimler AG Cooperation (2018) and Tesla-Toyota Cooperation (2021) in terms of contract payments, Nash Equilibrium, strategic payoffs and ceasing time for the contract.

1 Introduction

Nowadays, the business enterprises in the business world work not just as an individual but mostly cooperate together as a cooperation chain, in which to fight against other chains in the industry, even if the cooperated companies are strict competitors in some aspects. In this cooperation, given different strategic objectives and operations, the profits that the players maximize within cooperation exceeds the initial profits, instead of zero-sum game like the price loser or winner in Bertrand Competition, in which price-winner win all the profit and loser obtains nothing.

1.1 Vertical Cooperation and Horizontal Cooperation

With respect to this cooperation, Brandenburger and Nalebuf (1996) provided that the cooperation can be divided into two terms: vertical and horizontal. As for vertical cooperation, it normally occur within supply chain where upstream firms like suppliers vertically cooperates with downstream firms like retailers. In the supplier-retailer case, a *strategic complement* emerges for the increase needs of products in retailer market triggers the increase of production for supplier. For example, the success of Dell Inc. can somehow benefits AMD company, because more sales on Dell computers acquire more needs on AMD computer chips; AMD can also design more complicated and functional chips to promote the evolvement of Dell computers through more R&D on software and hardware, which directly promote the competitive advantage of Dell computers and further increase the sales of Dell.

Nevertheless, horizontal strategic cooperation mostly emerges in high-tech or high barrier industry. Given the shortage of budgets on R&D investment and restrictions on fixed assets' management, challenges can hardly be handled by individual firms, such as high variable costs on unit production, pressures on R&D department and compulsory start-up payments. Though an innovation yields an intensive competitive advantage in the market, it's not always a good choice to implement all the R&D work or technology inventions for one individual firm, because it's unpredictable for the research time and sometimes failures exist.

Based on limited and scarce resources of individual company, a firm better strategically cooperates with other companies in this industry that yields competitive advantages, and create its own version of products through *learning by doing*. For example, DangDang.com used to be an offline book store in China. During the 6 years' cooperation with Amazon, DangDang accumulate books to accumulate profits for Amazon, while Amazon provide advanced online platform for DangDang. In this process, DangDang gradually operates an online book store through learning by doing in the Amazon-DangDang cooperation, which largely reduces the time that DangDang innovates a system by itself to enter the online market. So, based on different strategic objectives (profit, technology, operation model, etc.), firms might agree to construct a temporary cooperation with their competitors. Nonetheless, this cooperation would continue until one firm achieve its objective or the profit obtained is higher than that within cooperation through *learning by doing*. Hence, several concerns exist on this cooperation: *the premises and timing of cooperation, the details of cooperation contract, the Nash Equilibrium and best responses, the payoffs and outcomes of all the firms in the industry after cooperation, and proper timing for ceasing cooperation.*

1.2 Horizontal Cooperation on US Automobile Market

In this paper, we specifically quantify the horizontal cooperation effect in a oligopoly market, in which competitors with large market share and great frame cooperate with those low-cost firms to reduce their marginal cost through *learning by doing*, while the low-cost firms also increase their profits through the contract payments. The case in the American Automobile industry raises greatly from 2018 to 2021. A study (Gnyawali, 2020) shows that automobile emission accounts for 45% of greenhouse gas (GHG) in the United States in 2020, while the GHG is 91% constituted of exhaust fumes provided by petrol-power automobiles, which suggests a necessary innovation on the power system of automobiles.

To ameliorate and modify the automobiles' power system and make cost reduction on per unit automobile production, electronic devices substitute the fuel systems in physical effectiveness. As it shows that, for automobile power systems, 94% of electronic energy can be transformed into kinetic energy, while the same amount of fuel energy can only yield to 23% kinetic energy (Kodama, 2018), which indicates a large cost reduction and effectiveness promotion for electronic power system on automobiles. The Tesla-Daimler AG Cooperation in 2018 and Tesla-Toyota Cooperation in 2021 are based on this background, in which both Daimler and Toyota want to minimize their costs on power systems through cooperating with Tesla and apply *learning by doing* theory. Hence, we try to analyze this cooperation contract through horizontal cooperation theory, and solve the following issues through game theory in this paper: [1] Estimate the contract payments, which includes fixed payment and marginal payment; [2] Predict the possible payoffs of each company within cooperation in each stage; [3] Quantify the horizontal cooperation effect on other automobile firms (eg. Volkswagen, FAW, etc.) in the market; [4] Figure out the ceasing time for the cooperation contract by evaluating the trade-off of *learning by doing* and contract payments cost.

2 Literature Review

2.1 Cooperation Theory

Given high-tech or high barrier oligopoly market, Brandenburger and Nalebuf (1996) indicated that a horizontal cooperation mostly emerges, while this temporary compliment always provide the reduction on marginal cost. While Bengtsson and Kock (1999) raised a more complicated and narrow relationship of cooperation, in which firms would tackle with complex relationships with its competitors in different stages. For example, Amazon would only cooperate with DangDang on online platform but compete in book sales in some senses, while DangDang reduce its cost by *learning by doing* process and terminate their cooperation in its mature stage. Moreover, Pathak et al. (2019) theoretically and qualitatively analyze the emerge and expiration of horizontal cooperation among firms in a supply chain with time or stage changes, while supply chain finance can operate within this cooperation to maximize the cash flows within the cooperation.

2.2 The Effect of Learning and Horizontal Cooperation on Cost Reduction

Concerning the high-tech and high-barrier market, horziontal cooperation enables enterprises to obtain and utilize the resources necessary for innovation through sharing, which avoids huge and high-risk investments on R&D and promote the enthusiasm and productivity of innovation (Sampson, 2013). On the other hand, Nagarajan and Sosic (2014) implemented a quantitative method to evaluate and investigate the alliance among competitors within a certain market. Nevertheless, this study only covers the two engaged enterprises in the cooperation but neglects the possible effects of the cooperation that affects other firms outside of the cooperation in the market. Also, Granot and Yin (2016)'s study add a time baseline on the previous studies and make a complement on the calculation of cost, which further considering the negotiation cost and opportunity cost on the contract payments. Zhang and Frazier (2019) also developed a more advanced model on calculating specific parts of contract payments under monopoly market, but only emphasizes and concerns cooperation decisions based on monopoly pricing, instead of possible first degree price discrimination to maximize the total profit in each decision stage.

3 Model of Horizontal Cooperation Game

In this model, we consider 4 main parties existed in the automobile market: Tesla, Daimler, Toyota and other automobile companies.

3.1 Model Assumptions

[1] Suppose Firm 1 (Tesla) earns the fixed contract payment and marginal payment per unit produced in the contract, and it provides outsourcing service of electronic power system (or directly proffers the components of system) to Firm 2 (Daimler) and Firm 3 (Toyota) which have high marginal cost when producing electronic power system at present.

[2] Although high marginal cost exists in the production of electronic power system for Firm 2 (Daimler) and Firm 3 (Toyota), they still have significant market share in the automobile market, which means that the only objective they need to achieve in this model is to *reduce marginal cost through learning by doing*.

[3] Firm 4 includes companies outside of the cooperation like Volkswagen and FAW, who process the R&D and promote and innovate their power system by themselves. Regarding specific analysis, Firm 4 includes n specific firms: $\{Firm4_1, Firm4_2, Firm4_3, ..., Firm4_n\}$, we apply horizontal summation on some objective functions like demand curve functions to obtain a group function.

[4] Suppose complete and perfect information shares in the whole automobile market, hence all the companies know each action in all the stages.

[5] With respect to the automobile series and power systems, to simplify the model, we assume that each firm only sell one brand of car, and each car has only one electronic/fuel power system.

3.2 Model Formulation

Firstly, we try to figure out the demand curve and profit function for each firm. Assume the total market size of automobile as m, the product differentiation of firm j with respect to firm i as γ_{ij} $(i \neq j)$, the fixed payment, marginal payment and negotiation fee of cooperation contract as ψ, υ and n respectively, the price, quantity, marginal cost of power system and profit as p, q, c and Π respectively, the decision variable as $\xi \in \{0, 1\}$.

With regard to the inverse demand functions,

$$q_i = m - \Sigma_j \gamma_{ij} p_j - p_i \tag{1}$$

Specifically, concerning all the firms in Firm 4, we apply horizontal summation to form an inverse demand function for Firm 4 ($k = 1, 2, ..., n$), $-4k$ represents all the other companies in Firm 4 except for Firm $4k$),

$$q_{4k} = m - \Sigma_{-4k}\gamma_{(4k,-4k)}p_{-4k} - p_{4k} \tag{2}$$

$$q_4 = \Sigma_k q_{4k} \tag{3}$$

Then, we calculate the profit function of Firm 1,

$$\Pi_1 = (p_1 - c_1)q_1 + \Sigma_{j=2}^{3}[\psi_j + (\upsilon_j - c_1)q_j - n_j]\xi \tag{4}$$

With respect to Firm 2, 3 and 4, the profit functions are slightly different. To help evaluating the *learning by doing* effect, we assume the time from issuing contract as t, and λ as learning rate, which represents the marginal cost reduced for per unit of time.

$$\Pi_j = p_j q_j - (c_j - \lambda_j t_j)q_j(1-\xi) - (\psi_j + \upsilon_j q_j + n_j)\xi \tag{5}$$

To be specific, $\xi = 0$ represents the firm produces the system by itself no matter never joining the cooperation or ceasing the contract, while $\xi = 1$ represents that cooperation contract is in process. So, it very much help to judge the time for ceasing the contract for Firm 2 and Firm 3.

$$\Pi_{j,\xi=0} = p_j q_j - (c_j - \lambda_j t_j)q_j \tag{6}$$

$$\Pi_{j,\xi=1} = p_j q_j - (\psi_j + \upsilon_j q_j + n_j) \tag{7}$$

After calculating the inverse demand functions and profit functions, we'll apply two-part tariff theory (first-price discrimination) to help determine the fixed contract payment and marginal contract payment for cooperation.

Firstly, Firm 1 will occupy all the consumer surplus of Firm 2 and Firm 3 as fixed contract payment. Assume that Π_j^b as Firm j's ($j \in \{2,3\}$) profit before issuing the cooperation contract, Π_j^a as Firm j's profit after cooperation, and bargaining power of Firm j as μ_j ($\mu_j \in (0,1)$). We can roughly estimate the reservation price as Π_j^b and actual price as $\Pi_j^a - n_j$.

$$\Pi_j^a = \Pi_{j,\xi=0},\ \Pi_j^b = \Pi_{j,\xi=1} \tag{8}$$

$$\psi_j = \mu_j(\Pi_j^a - n_j - \Pi_j^b) \tag{9}$$

Regarding the marginal payment υ_j of the contract, Firm 1 should set the price at the maximum social welfare. Hence, we first apply horizontal summation on the inverse demand curves of Firm 2 and Firm 3.

$$q_2 = m - \gamma_{12}p_1 - \gamma_{32}p_3 - \gamma_{42}p_4 - p_2 \tag{10}$$

$$q_3 = m - \gamma_{13}p_1 - \gamma_{23}p_2 - \gamma_{43}p_4 - p_3 \tag{11}$$

$$Q = q_2 + q_3 \tag{12}$$

According to Equation (10), (11) and (12), we obtain the total inverse demand curve for Firm 2 and Firm 3,

$$Q = 2m - 2(\Sigma_{j=2}^{3}\gamma_{1j}p_1 + \Sigma_{j=2}^{3}\gamma_{4j}p_4) - (1+\gamma_{23})p_2 - (1+\gamma_{32})p_3 \tag{13}$$

Let $Q = c_1$, suppose the electronic power system is β ($\beta \in (0,1)$) times automobile price p_1, and we obtain the marginal payment in the cooperation contract.

$$\upsilon_j = \beta\left(\frac{m}{\Sigma_{j=2}^{3}\gamma_{1j}} - \frac{\Sigma_{j=2}^{3}\gamma_{4j}}{\Sigma_{j=2}^{3}\gamma_{1j}}p_4 - \frac{(1+\gamma_{23})p_2 - (1+\gamma_{32})p_3 - c_1}{2\Sigma_{j=2}^{3}\gamma_{1j}}\right) \tag{14}$$

According to Equation (9) and (14), we achieve the first objective in 2.1, in which we obtains the fixed payment and marginal payment of the cooperation contract. In the next step, we need to determine the effect of cooperation for all the companies in the market and how they make decisions. Hence, we construct an optimization scenario problem $\mathbb{S}(\xi_2, \xi_3, \xi_4)$ shown as follows.

$$\max\ \Pi_i\ i \in \{1,2,3,4\} \tag{15}$$

$$\text{s.t. Equation } (4), (5), (9), (14) \tag{16}$$

By solving $\mathbb{S}(\xi_2, \xi_3, \xi_4)$ with KKT condition, we analyze the Tesla cooperation case through a two-step dynamic game as follows.

Stage1 Cooperation Decision. Firstly, take Firm i as an example, it determines that whether it cooperates with Tesla ($\xi_i = 0$ represents no cooperation, 1 represents opposite choice). Also, in this optimization problem, there are totally four different integrations for as follows,

$$(\xi_2, \xi_3, \xi_4) = \{(00, 0), (0, 1, 0), (1, 0, 0), (1, 1, 0)\} \tag{17}$$

Stage2 Pricing Decision. With respect to the integrations in Step 1, each firm determines its pricing strategy through $\mathbb{S}(\xi_2, \xi_3, \xi_4)$ while gratifying Equation (4) and (5), which transforms into a dynamic simultaneous game under complete and perfect information.

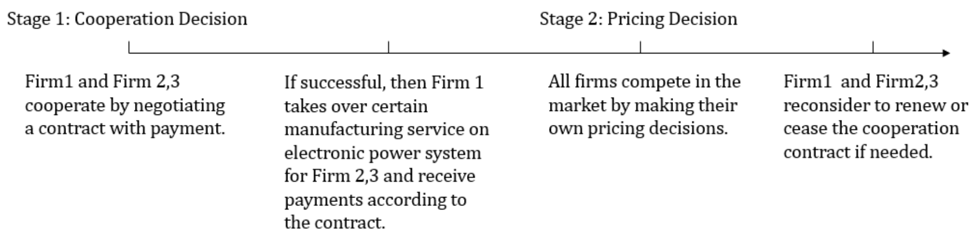

Figure 1: Sequence of Events.

Ultimately, we analyze the proper ceasing time for Firm 2 and Firm 3. In this case, the proper timing for Firm 2 and 3 is when $\Pi_{j,\xi=0}$ is not less than $\Pi_{j,\xi=1}$, and we further obtain,

$$t_j \geq \frac{c_j}{\lambda_j} - \frac{\psi_j + \upsilon_j q_j + n_j}{q_j \lambda_j} \tag{18}$$

According to Equation (18), we find the minimum time for Firm 2 and Firm 3 to cease the cooperation contract and develop its own electronic power system is $\frac{c_j}{\lambda_j} - \frac{\psi_j + \upsilon_j q_j + n_j}{q_j \lambda_j}$.

4 Conclusion and Result

In this paper, we mainly study the Tesla-Daimler AG Cooperation in 2018 and Tesla-Toyota Cooperation in 2021. In these cooperations, we analyze four objectives through game theory and two-part tariff theory with respect to the details of cooperation contract, including contract payments estimation (i.e. fixed payment, marginal payment and negotiation cost within cooperation), Nash Equilibrium and payoffs prediction, effects of all the firms in the market and proper ceasing time of contract.

According to the model analysis in section 3, we find the optimal fixed payment and marginal payment for per unit electronic power system exist, when fixed payment takes over all the consumer surplus of Daimler and Toyota while marginal payment reaches the marginal cost of the per unit system in which maximize the total social welfare. Moreover, through Equation (9) and (14) in section 3, we find that when the product differentiation γ_{ij} of product j with respect to product i increases, both fixed payment and marginal payment decrease for high marginal cost firms like Daimler and Toyota, which conforms our economic intuition. Also, if the bargaining power of the high marginal cost firm is more intensive (i.e. bargaining power can somehow derives from market share, capitals, goodwill, etc.), the related payments decrease as well.

Regarding the effects for the Daimler and Toyota, through *learning by doing* effect, we find that the marginal decreases with time; while solving problem $\mathbb{S}(\xi_2, \xi_3, \xi_4)$ with KKT condition, Firm 4, in which consists of all the other firms outside of the cooperation, decreases its profit due to increasing quantity of high-market-share firm (Tesla, Daimler, Toyota) and decreasing product differentiation (because all the firms are prone to improve the electronic systems that lead a decrease of differentiation). At the same time, there is a tendency of strategic substitute for Firm 4 with Firm 1,2,3, where Firm 4 produces less and less in the long period and further deteriorate their profits.

Hence, it might be rational for all the firms in Firm 4 to construct the business strategic alliances with each other instead of processing the R&D by themselves in the automobile industry.

With regard to the ceasing time, as we analyzed in Equation (18), only when the marginal cost of Daimler and Toyota decreases through *learning by doing* effect until their profit by producing by themselves overwhelms than that within the cooperation, they would terminate the contract. In addition, compared with Daimler (2018) and Toyota (2021), we notice that the former firm obtains a significant First-Mover Advantage, not only because the time of learning by doing is greater than the latter one, but also a more intensive decrease on product differentiation between Tesla and Daimler leads a higher profit. To be more specific and further testifying our conclusion, we figure out the financial reports of 2020-2021 series automobiles for the 3 firms in the midterm of 2021 which compares Tesla Model X, Daimler Smart C with Toyota RAV4.

Table 1: Comparison among 2020-2021 series of Tesla, Daimler and Toyota

Index	Tesla Model X	Daimler Smart C	Toyota RAV4
Quantity sold in mid-2021	22576	3876	4523
E-power System cost per unit (USD)	3000	7500	16000
Automobile price (USD)	48760	25780	33650
Profits (USD million)	5876.5	2238.4	650.9
Year of Cooperation	-	3	1

Through Table 1 above, we find that, even if Toyota RAV4 has a higher price and higher sales in contrast with Daimler Smart C, Daimler Smart C obtains a higher profit given less electronic power devices, which results from a longer year of cooperation with Tesla. Also, with the year of cooperation increases, there is a lower product differentiation between Tesla model X and Daimler Smart C in terms of power system, which has been testified in Equation (5) and (9) that this decrease leads a lower cost and higher profit. In this case, when a proper horizontal cooperation exists, the earlier entry of the player in the market, the higher profit it earns.

References

[1] Brown. (1996). Co-opetition: Adam M. Brandenburger and Barry J. Nalebuff New York: Doubleday, 1996 [Review of Co-opetition: *Adam M. Brandenburger and Barry J. Nalebuff New York: Doubleday, 1996*]. *Public Relations Review*, 22(4), 394–396. Elsevier Inc.

[2] Gnyawali, & Park, B.-J. (Robert). (2020). Transportation's roles in reducing U.S. greenhouse gas emissions. *Research Policy*, 40(5), 650–663.

[3] Kodama, 2014, & Shibata, T. (2018). Research into ambidextrous RD in product development - new product development at a precision device maker: a case study. *Technology Analysis Strategic Management*, 26(3), 279–306.

[4] Bengtsson, & Kock, S. (1999). Cooperation and competition in relationships between competitors in business networks. *The Journal of Business Industrial Marketing*, 14(3), 178–194.

[5] Pathak, Wu, Z., Johnston, D. (2019). Toward a structural view of cooperation in supply networks. *Journal of Operations Management*, 32(5), 254–267.

[6] Sampson. (2013). RD Alliances and Firm Performance: The Impact of Technological Diversity and Alliance Organization on Innovation. *Academy of Management Journal*, 50(2), 364–386.

[7] Nagarajan, Sosic, G. (2014). Stable Farsighted Coalitions in Competitive Markets. *Management Science*, 53(1), 29–45.

[8] Granot, Yin, S. (2016). Competition and Cooperation in Decentralized Push and Pull Assembly Systems. *Management Science*, 54(4), 733–747.