A signaling model for the defense acquisition system

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The purpose of this study is to analyze the efficiency of the defense acquisition system using the signaling model of the game theory. For this purpose, the defense acquisition system and characteristics of the defense industry were examined and a signaling model associated with the environment of the defense industry was set up. As a result of analyzing the efficiency of the defense acquisition system using this model, it was able to come up with an equilibrium strategy of the firm and the government, and the incentive system needed to revitalize R & D and production efficiency of the defense company. Based on these results, it will be possible to establish policies to enhance the defense industry's R & D and the defense system efficiency.

JEL Classification: C72, L51

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Ⅰ. Introduction

Global defense spending is estimated at $ 1,739 billion in 2017, 2.2% of global GDP. As shown in Table 1, defense expenditures of the world top 10 nations including the US and China account for 72.9% of the world's expenditure. Among these countries, China, Japan, and South Korea, which are three Northeast Asian countries, account for 17.9% of the world defense spending, which is $ 312.6 billion.

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When we can understand that defense spending indirectly expresses the degree of confrontation with neighboring countries, the security situation in Northeast Asia is considerably danger than other regions in the world. In addition, this indicator is expected to rise further reflecting direct and indirect spending by the US, Russia and North Korea.

[Table 1] SIPRI defense spending in 2017

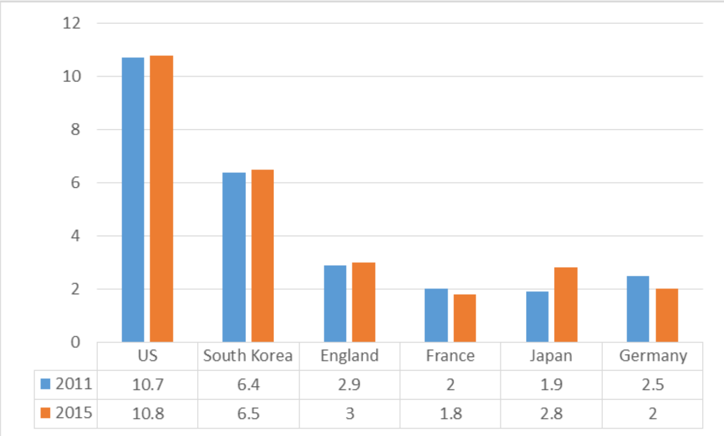
Rank	Country	Defense spending ($ 1 billion)	% of GDP	World Share (%)
1	US	610	3.1	35.0
2	China	228	1.9	13.0
3	Saudi Arabia	69.4	10.0	4.0
4	Russia	66.3	4.3	3.8
5	India	63.9	2.5	3.7
6	France	57.8	2.3	3.3
7	England	47.2	1.8	2.7
8	Japan	45.4	0.9	2.6
9	Germany	44.3	1.2	2.5
10	South Korea	39.2	2.6	2.3

Source: Data from the Stockholm International Peace Research Institute (SIPRI)

As shown in Figure 1, defense R & D share of major countries among the top 10 defense spending rankings is less than 3% except for US (10.8%) and South Korea (6.5%). This suggests that the R & D of the US and South Korea is being funded by the state, while the other countries are being led by the defense industry. Especially, in Korea, defense spending is relatively low compared to other countries, but the proportion of R & D is relatively high. Korea's defense R & D expenditure exceeded 3 trillion won in 2019, exceeding 6.7% of its defense budget, except for the US, which has a high defense cost. However, defense R & D investment is very low, less than 3% of defense sales. This has resulted in intensifying the government dependence of the defense industry and weakening its own competitiveness.

As a result of the research conducted by the Korea Development Institute (KDI) in 2016, 46 core technology competitiveness of the defense industry was 71.0% of the world's highest (100%). It can be seen how competitiveness weakened when Korean companies were reduced from 7 in 2015 to 4 in 2018 to the top 100 global defense companies announced by SIPRI.

[Figure 1] Defense R & D portion of the defense budget (%)



Source: Data from the OECD, government budget appropriations or outlays for R & D, Defense 2016 and SIPRI Military Expenditure database 2016

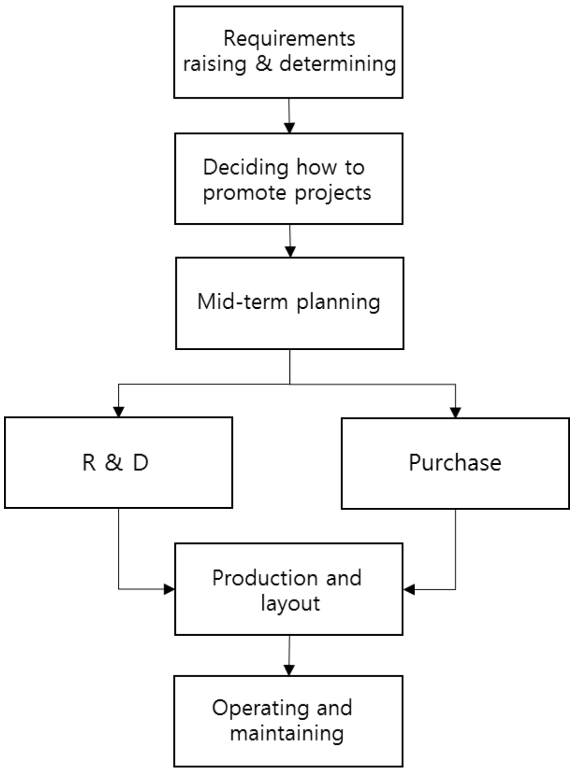
In order to increase the viability of the country in the military confrontation region, it is important to enhance the military power by the state-led initiative, but it is also important to emphasize that securing the competitiveness of the defense industry, which should use the defense budget efficiently and take the leading role in defense system production. In general, the defense industry is often a composite industry that includes defense systems as well as civilian systems. Therefore, in countries such as the South Korea where the economic scale is limited and dependence on exports is high, it is necessary to build a system to optimize the efficiency of the defense industry in order to improve the nation's industrial structure ecosystem and increase export of high value-added defense systems. In this study, in order to find out the possibility of constructing such a system, chapter II focused on the defense acquisition system and the characteristics of the defense industry mainly on research and development, and chapter III established the signaling model after examining the environmental factors of the defense industry. In chapter Ⅳ, the incentive system to improve the structure of the defense industry is analyzed as an optimization problem using the defined signaling model.

Ⅱ. Characteristics of the Defense Acquisition System

2.1. Defense Acquisition System

The acquisition of defense proceeds as a formal process as shown in Figure 2. In other words, if the demands and decisions are made by the ROK military (JCS, each military headquarters), the Defense Acquisition Program Administration (DAPA) will decide how to conduct the project (R&D or purchase). At the headquarters of the Department of Defense (D o D), a mid-term plan is drawn up in accordance with the project promotion method to obtain a budget, and the DAPA will promote the project with the budget obtained. During the project period, when the battle suit is judged in the test evaluation stage, it enters the mass production stage and supplies the defense systems produced to the ROK military.

[Figure 2] Defense Acquisition System Procedure



Source: Collecting data such as the Defense Planning and Management Basic Decree, the Defense System Generation Directive, and the Defense Management Regulations

The economic effects of the defense acquisition system are divided into national economic ripple effect, technology accumulation effect, import substitution effect and defense export effect as Baek Jae-ok, Park Soo-hyun, and Kim Sang-ho (2009) suggested. However, there is a lack of optimization and efficiency studies based on microeconomic theories and principles because most of the studies are analyzed with multiple regression analysis model using accumulated data and focused on macroscopic analysis through gathering expert opinions. Therefore, in this study, we try to derive market efficiency and incentive system based on optimization theory by game theoretical approach by dividing into two groups, namely, the Department of Defense (D o D), which acts as a representative group of consumers, and the defense industry that deals with R&D and production.

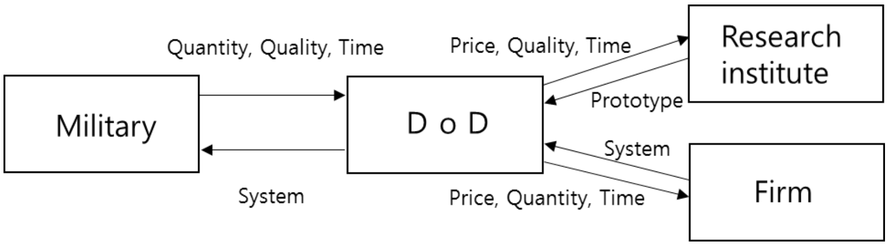
In connection with R&D, after 29 years of studying major companies in the United States, Baek and Jang (2016) said that high-quality companies have made remarkable achievements by investing actively in R&D to pursue performance improvement, but low-quality firms have not since it was difficult to create profits. Yacov Bar-shlomo (2016) emphasized the need to guarantee at least 8,000 units of production, because the cost of developing defense systems amounts from 8,000 to 10,000 times the unit price of the finished product.

2.2. Defense Industry

The concept of general defense acquisition is shown in Figure 3. The military proposes to D o D, including the quantity and performance of the weapon systems to be acquired and the time of acquisition. The D o D selects research institutes to conduct R&D within the allocated budget and conducts R&D. The requirements presented here are the total cost, the performance requirements, and the duration of R&D. The research institute conducts R&D, develops the tangible and intangible prototype and conducts test evaluations. If the test evaluates suitability for combat, the D o D will designate a defense contractor for the production. The negotiation and presentation with the defense industry are the price and quantity of the weapon system to be delivered and the time of delivery.

In terms of defense industry characteristics, Kim et al. (2012) emphasized the creation of a competitive environment, the use of civilian technology in the defense industry, and strengthening civil-military compatibility, because the defense industry is characterized by both monopolistic and regulated industries, a high proportion of fixed costs, and technology-intensive industries.

[Figure 3] Defense acquisition concept



In connection with the monopolistic nature of the defense market, Bagwell and Riordan (1991) found that high-quality firms generally prefer high prices, while low-quality firms prefer the same price as marginal cost and prefer mass production.

In terms of game theoretical market analysis, Daughety and Reinganum (2007) argue that in imperfect competitive oligopoly markets, there exists separating equilibrium that high-quality firms signal high prices, while low-quality firms take a mixed strategy and if the number of competitors increases, low-quality firms lose market dominance by converging prices to marginal costs. In addition, Basso and Figueroa, Vasquez (2016) found that it is more effective to use the price mechanism to the firm whose marginal cost continues to increase and to use quantity mechanism to the firm whose marginal cost continues to decrease in order to regulate monopolistic firms under asymmetric information.

Ⅲ. The environment of defense industry and signaling model

3.1. The environment of defense industry

The military, which plays a role of consumer concept, ask D o D, acting as agents, to know the quantity and performance of weapon systems, and when to acquire a defense system. The D o D decides to acquire weapons systems through R&D in order to enhance its core technology by activating its R&D. Therefore, in order to publicize the research institute to be responsible for R&D, proposals including research cost, performance, and research period will be announced.

The research institutes will take a public offering by submitting a proposal to the D o D, the D o D will review the proposals of each institution and then select R&D agency. At this time, the selection criterion is whether the required performance can be developed within the specified study period and the research expense limit. If the conditions are met, the D o D will ultimately designate the institution that proposed the lowest research cost as the preferred negotiation target.

Firms selected as R&D institutions will conduct R&D within the research period to produce prototypes, and the D o D conducts test evaluations on prototypes. When the result of the test evaluation is judged as battle suitability, the R&D project of the research institute is terminated.

When the research and development are over, the D o D will select firms to be in charge of production. To do this, the quantity, delivery period, and price of the weapon system are announced. The firm conducts negotiations with the D o D, finally, firms that offer procurement within the deadline and offer the lowest price will be awarded. The selected firm produces the weapon system and supplies it to the deadline within the delivery period, thus completing the acquisition of the defense system.

3.2. Basic model

3.2.1. Firm

There are two types of firms: those producing high quality (H) and those producing low (L) quality. The quality $(Q_i = H\ or\ L, i = 1, 2)$ follows a uniform probability distribution from $\mathrm{u}[0, 1]$ and is defined as $0 \leq \mathrm{L} \leq \mathrm{H} \leq 1$. The cost companies invest in order to meet the standards set by D o D can be divided into the common cost (C_i) and the specialized cost (F_i). A firm knows its common costs and specialized costs, but it is assumed that competitors and D o D do not know it. A common cost is expressed as a function of quality $\mathrm{C}(Q_i{:}\,\delta)$ as a cost commonly required by all companies to achieve quality (Q_i). δ as a parameter representing the technical difficulty for achieving quality Q_i, which means that the cost for achieving quality is increased as δ is increased. That is, even if it is the same Q_i, if δ is large, the cost and the marginal cost become large. It is assumed that C_i increases as Q_i

increases and also marginal cost for Q_i increases.

$$\frac{\partial C_i}{\partial Q_i} > 0,\ \frac{\partial^2 C_i}{\partial Q_i^2} > 0,\ \frac{\partial C_i}{\partial \delta} > 0,\ \frac{\partial^2 C_i}{\partial \delta^2} > 0 \tag{1}$$

Specialized cost (F_i) is inversely proportional to the level of core technology holdings, which is a differently applied cost depending on the level of the company to achieve the required quality Q_i and$F_H > F_L$. That is, the higher the skill level, the lower the specialized cost, and the lower the skill level, the higher the specialized cost.

Since firms' research costs are the sum of common costs and specialized costs, they can be expressed as follows.

$$C_i(Q) = C(Q_i : \delta) + F_i \tag{2}$$

Let us suppose that the price ($P_i,\ i = 1, 2$) proposed by firms to win a bid can take into account various factors, but presents a strategy with a linear function proportional to the specialized cost for ease of analysis. And we assume $0 < P_L < P_H \leq 1$ then, the research expenses proposed by each firm can be expressed as follows.

$$P_i = a_i \cdot F_i + k_i\ (a_i,\ k_i\ is\ constant) \tag{3}$$

In this cost mechanism, each firm presents the best research cost to the D o D, and the D o D selects the lowest research cost firm as the research institute. If the output is X, then the profit of the companies can be expressed as follows[1].

$$\pi_i = \left(P_i - C(Q_i : \delta)\right) \cdot X - F_i \tag{4}$$

A firm of type H must have a bid (P_H) lower than that (P_L) of a firm of type L in order to win a bid for production. In case of the opposite, H-type firm is eliminated,

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[1] Kim and Nam (2018) define the profit of the firm as $\pi_i = b_i - f_i - C(R : \gamma)$ in a study on the "defense acquisition bidding system for R & D". Here, b_i represents the bid price, f_i represents the cost specific to each company, and $C(R : \gamma)$ represents the cost commonly applied to all companies to develop a product having γ performance with difficulty.

so in order to win the bid, the following should be established.

$$P_H < P_L = a_L \cdot F_L + k_L \;,\;\; so \;\; \frac{P_H - k_L}{a_L} < F_L \tag{5}$$

Therefore, the expected profit of the firm of type H ($\mathrm{E}\pi_H(P_H)$) can be obtained as follows.

$$\mathrm{E}\pi_H(P_H) = \int_{\frac{P_H - k_L}{a_L}}^{1} \big((P_H - C(Q_H:\delta)\big) \cdot X - F_H) dF_H = \frac{\big((P_H - C(Q_H:\delta)\big) \cdot X - F_H)(a_L - P_H + k_L)}{a_L} \tag{6}$$

In general, assuming that a firm is neutral to risk, each firm will set a bid to maximize its own profit. Therefore, it can be expressed as follows.

$$max_{P_H}(\mathrm{E}\pi_H(P_H)) = max_{P_H} \frac{\big((P_H - C(Q_H:\delta)\big) \cdot X - F_H)(a_L - P_H + k_L)}{a_L} \tag{7}$$

Therefore, the first condition for obtaining the bid that maximizes the expected profit of H type firm is obtained as follows.

$$a_L - P_H + k_L - P_H + C(Q_H:\delta) \cdot X + F_H = 0 \tag{8}$$

At this time, the optimal bid for a firm of type H is as follows.

$$P_H = \frac{a_L + k_L + C(Q_H:\delta) \cdot X + F_H}{2} \tag{9}$$

In the same way, the optimal bid for a firm of type L is obtained by the following method.

$$P_L = \frac{a_H + k_H + C(Q_L:\delta) \cdot X + F_L}{2} \tag{10}$$

In equation (3), since $P_H = a_H \cdot F_H + k_H$, $P_L = a_L \cdot F_L + k_L$, so $a_H = a_L = \frac{1}{2}$ and the following equation holds.

$$k_H = \frac{1}{2}(k_L + \frac{1}{2} + C(Q_H:\delta) \cdot X) \tag{11}$$

$$k_L = \frac{1}{2}(k_H + \frac{1}{2} + C(Q_L:\delta) \cdot X) \tag{12}$$

Therefore, it can be seen that $k_H = k_L = \frac{1}{2} + C(Q:\delta) \cdot X$, and the firm's equilibrium bid is determined as follows.

$$P_i^* = \frac{1}{2}F_i + \frac{1}{2} + C(Q_i : \delta) \tag{13}$$

In the equation (13), the firm presents both the common cost and the specialized cost for obtaining the quality when presenting the bid, and it can be understood that the priority is placed on the common cost in particular.

And then the equilibrium profit is as follows.

$$\pi_i^* = \left(P_i^* - C(Q_i : \delta)\right) \cdot X - F_i = \left(\frac{1}{2}F_i + \frac{1}{2}\right) \cdot X - F_i \tag{14}$$

In equation (14), the firm's profits are influenced by firm-specific specialized costs and output. In particular, since production is an important factor in relation to profits, it is important to consider the initial production volume setting as well but minimize the variation during the business process.

From the standpoint of firms, it can be concluded that it is also essential to increase production through the expansion of overseas export as well as domestic export market to increase production.

In order to increase the core technology level of the firm, it is necessary to revitalize R&D and optimize R&D cost through various methods such as reduction of development cost through domestic and overseas joint development and mutual exchange through core technology modularization policy.

From a D o D perspective, it is necessary to attract investment in R&D to increase specialized costs for R&D. Therefore, it is necessary for the D o D to grant incentives for R&D, or to consider policy rewards such as price compensation related to R & D achievements.

Theorem 1 The total cost of a firm consists of a common cost (C_i) and a specialized cost (F_i). The firm knows its own common costs and specialized costs but assumes that the D o D and competitors do not know. Assuming that the pricing strategy taken by the firm is a linear function of specialized cost ($P_i = a_i \cdot F_i + k_i$), the common cost and the specialized cost follow a uniform probability distribution of u$[0, 1]$,

(ⅰ) The optimal bid for a firm is $P_i^* = \frac{1}{2}F_i + \frac{1}{2} + C(Q_i\colon\delta)$,

(ⅱ) The firm's expected profit is $\pi_i^* = \left(P_i^* - C(Q_i\colon\delta)\right)\cdot X - F_i = \left(\frac{1}{2}F_i + \frac{1}{2}\right)\cdot X - F_i$

3.2.2. D o D

In terms of the quality and price of the system developed and produced by the firm, the utility of the D o D can be defined as follows[2].

$$U_i = w\frac{Q_i^{1-\theta}}{1-\theta} - \frac{P_i^{1-\gamma}}{1-\gamma} \quad where \quad w,\theta,\gamma > 0 \quad \text{and} \quad \theta,\gamma \neq 1 \qquad (15)$$

Here, $Q_i(Q_i = H\ or\ L)$ represents the numerical value of the quality level according to the firm's type in terms of the monetary value. $P_i(P_i = P_H\ or\ P_L)$ represents the price level negotiated by the D o D according to the type of firm. For a generally valid analysis, we assume that $H > P_H$, $L > P_L$. D o D utility increases as quality increases, but decreases as prices rise. θ,γ are a parameter indicating the degree of D o D risk aversion to the quality and price of the acquired system, and w is a constant indicating the preference weight satisfying the D o D quality.

Let $\theta = \gamma$[3], we will solve the problem of P_i that optimizes U_i and then use the equation that satisfies the first condition as follows.

$$max_{P_i} U_i = w\frac{Q_i^{1-\theta}}{1-\theta} - \frac{P_i^{1-\theta}}{1-\theta}, \quad \text{s.t} \quad P_i = Q_i + I_i \qquad (16)$$

In Equation (16), the D o D sets the price (P_i) including the compensation for quality improvement of the firm. That is, $P_i = Q_i + I_i$ is assumed where I_i is the

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[2] Griebeler and Wagner (2017) set the utility of the government as $U_t = \frac{C_t^{1-\theta}}{1-\theta} + w\frac{G_t^{1-\gamma}}{1-\gamma}\ where\ \theta,\gamma,w > 0\ and\ \theta,\gamma \neq 1$, taking into account the per capita consumption of the worker (C_t) and the expenditure of the government (G_t). θ,γ is the risk aversion to consumption and government spending, and w is the preference weight for the government spending.

[3] If we assume $\theta \neq \gamma$, it becomes difficult to obtain a valid solution any more.

investment compensation index. Then, to obtain the value for P_i, we obtain $w(P_i - I_i)^{-\theta} - P_i^{-\theta} = 0$, the first condition that optimizes U_i and we obtain P_i that optimizes this formula as follows.

$$P_i^* = \frac{w^{\frac{1+\theta}{\theta}}}{1-w^{\frac{1}{\theta}}} \cdot I_i \tag{17}$$

As a result of equation (17), the optimal utility of the D o D can be obtained as follows.

$$U_i^* = [\left(w^{\frac{1+\theta}{\theta}} + w^{\frac{1}{\theta}}\right)^{1-\theta} - w^{\frac{1-\theta^2}{\theta}}] \cdot (\frac{I}{1-w^{\frac{1}{\theta}}})^{1-\theta} \tag{18}$$

The optimal price index offered by the D o D to the firm is affected by the compensation price and the preference weights that satisfy the quality. Therefore, the higher the compensation price, the higher the price. In the case of investing in the quality improvement of the firm, the D o D can understand not only the compensation for R&D but also the tendency to keep compensatory measures by increasing the price in the production stage.

In addition, it can be seen that the utility of the government can be enhanced through the price compensation as well as the R&D promotion.

Theorem 2 The utility function of the D o D can be expressed as a linear function of the quality index Q_i and the price index P_i. Assuming that Q_i and P_i are indices following uniform probability distribution of u[0, 1], and $P_i = Q_i + I_i$ then,

(i) The D o D's optimal price index is $P_i^* = \frac{w^{\frac{1+\theta}{\theta}}}{1-w^{\frac{1}{\theta}}} \cdot I_i$

(ii) The optimal utility of the D o D is $U_i^* = [\left(w^{\frac{1+\theta}{\theta}} + w^{\frac{1}{\theta}}\right)^{1-\theta} - w^{\frac{1-\theta^2}{\theta}}] \cdot (\frac{I}{1-w^{\frac{1}{\theta}}})^{1-\theta}$

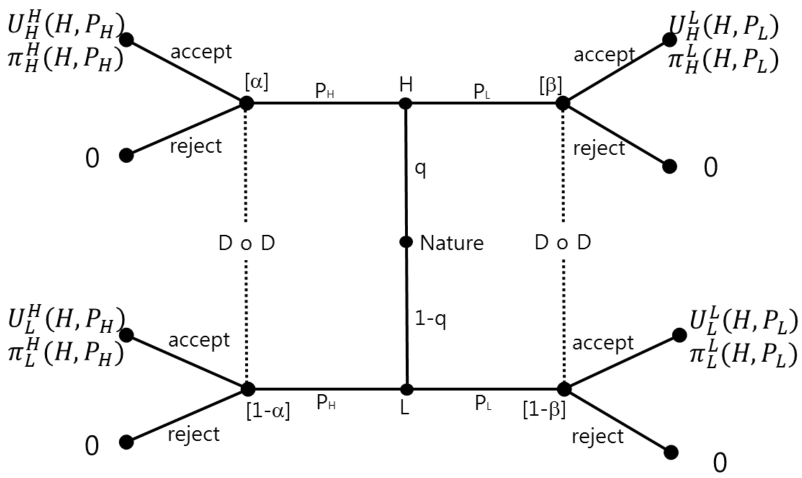
Ⅳ. Analysis of the efficiency of the defense acquisition system

In the previous chapter, we analyzed the individual equilibrium of firm and D o D. However, since the market is generally balanced by the interaction between producers and consumers, we will analyze the optimization problem using the signaling model of game theory in terms of efficiency of the defense acquisition system. In this model, the player is D o D and defense firm in charge of the defense industry, and type is quality. When a firm presents a signal of price according to the type of quality, the D o D takes an action on the purchase based on the signal of belief and price according to the type of firm. As a result of D o D action, the payoff of D o D utility and profit of the firm is determined.

4.1. Timing

The timing of the game is carried out in conjunction with the environment of the defense industry. In particular, since the D o D has no prior information on the type of firm, it is necessary to derive a Perfect Bayesian Equilibrium(PBE) under the incomplete information that judges the type of firm based on the signal of price as in Figure 4 (Game extensive form) and selects its strategy.

[Figure 4] Game extensive form



1) Nature chooses the type (t_i) of the firm from a set of possible types $t_i =$

[L, H]. The probability that a firm's type will be selected is q_i, and $q_i > 0$, $\sum_{i=1}^{2} q_i = 1$.

2) The D o D makes announcements to select companies to take charge of R&D and production, and after proposing its type, the firm proposes a proposal containing the total cost (P_i).

3) The D o D confirms the total cost of project (P_i) submitted by the firm and concludes a contract for R&D and production responsibility with the firm that submitted the lowest project cost.

4) The compensation for the negotiation result is determined by the utility function (U_i) of the D o D and the profit function (π_i) of the firm.

4.2. Equilibrium of the defense acquisition system

Let us derive a Perfect Bayesian Equilibrium of the defense acquisition system consisting of bilateral negotiations between the D o D and firm under incomplete information. In general, the two equilibria of pooling and separation equilibrium can be derived.

4.2.1. Pooling equilibrium

This equilibrium is the case where all parties involved in the negotiations, regardless of type, present a high price or a low price. First, let's look at the case of high prices. At this time $q = 0.5$ and the D o D's prior belief α is 0.5 by Bayesian law. To achieve this equilibrium, D o D must accept higher prices regardless of type and refuse if lower prices are offered. In this case, when a high-quality firm is awarded, the utility (U_H^H) of D o D and profit (π_H^H) of the firm are as follows.

$$U_H^H = w\frac{H^{1-\theta}}{1-\theta} - \frac{P_H^{1-\gamma}}{1-\gamma} \quad (19)$$

$$\pi_H^H = \left(\frac{1}{2}F_H + \frac{1}{2}\right) \cdot X - F_H \quad (20)$$

If a low-quality firm is awarded, the utility (U_L^H) of the D o D and the profit (π_L^H)

of the firm are as follows.

$$U_L^H = w\frac{L^{1-\theta}}{1-\theta} - \frac{P_H^{1-\gamma}}{1-\gamma} \tag{21}$$

$$\pi_L^H = \left(\frac{1}{2}F_L + \frac{1}{2}\right) \cdot X - F_L \tag{22}$$

However, in order to satisfy this equilibrium, if a high-quality or low-quality company deviates from a low price, the D o D must reject the firm's proposal, so the following conditions must be met.

$$\beta\left(w\frac{H^{1-\theta}}{1-\theta} - \frac{P_L^{1-\gamma}}{1-\gamma}\right) + (1-\beta)(w\frac{L^{1-\theta}}{1-\theta} - \frac{P_L^{1-\gamma}}{1-\gamma}) \leq 0 \tag{23}$$

Here we assume that $\theta = \gamma$, and equation (23) is summarized as follows.

$$\beta \leq \frac{P_L^{1-\theta} - L^{1-\theta}}{H^{1-\theta} - L^{1-\theta}} \tag{24}$$

Here, β is the prior belief of the D o D and $\beta \geq 0$, $H > L$, so $P_L^{1-\theta} \geq L^{1-\theta}$ must be satisfied. This implies that for a pooling equilibrium that presents a high price, the price index of a low-quality firm should be higher than the value of a lower quality index. In other words, D o D's prior belief in low-quality companies has a price priority over quality.

Let's look at the case of pooling at a low price. At this time, the D o D's belief β is 0.5 by the Bayesian law. In order to achieve this equilibrium, D o D should accept lower prices regardless of the type and refuse higher prices. In this case, when a high-quality firm is awarded, the utility (U_H^L) of the D o D and the profit (π_H^L) of the firm are as follows.

$$U_H^L = w\frac{H^{1-\theta}}{1-\theta} - \frac{P_L^{1-\gamma}}{1-\gamma} \tag{25}$$

$$\pi_H^L = \left(\frac{1}{2}F_H + \frac{1}{2}\right) \cdot X - F_H \tag{26}$$

If a low-quality firm is awarded, the utility (U_L^L) of the D o D and the profit (π_L^L) of the firm are as follows.

$$U_L^L = w\frac{L^{1-\theta}}{1-\theta} - \frac{P_L^{1-\gamma}}{1-\gamma} \tag{27}$$

$$\pi_L^L = \left(\frac{1}{2}F_L + \frac{1}{2}\right) \cdot X - F_L \tag{28}$$

However, in order to satisfy this equilibrium, a firm of a high quality or low quality should not deviate to offer high price, so the following conditions must be met.

$$\alpha\left(w\frac{H^{1-\theta}}{1-\theta} - \frac{P_H^{1-\gamma}}{1-\gamma}\right) + (1-\alpha)(w\frac{L^{1-\theta}}{1-\theta} - \frac{P_H^{1-\gamma}}{1-\gamma}) \leq 0 \tag{29}$$

Here we assume that $\theta = \gamma$, and equation (29) is summarized as follows.

$$\alpha \leq \frac{P_H^{1-\theta} - L^{1-\theta}}{H^{1-\theta} - L^{1-\theta}} \tag{30}$$

Here, α is the prior belief of the D o D and $\alpha \geq 0, \mathrm{H} > \mathrm{L}$, so $P_H^{1-\theta} \geq L^{1-\theta}$ must be satisfied. This means that for a pooling equilibrium that offers a lower price index, the price of a high-quality firm should be higher than the value of lower quality.

On the other hand, when we compare the utility of the D o D and the profit of the firm, we can see that the D o D's utility ($U_H^L = w\frac{H^{1-\theta}}{1-\theta} - \frac{P_L^{1-\gamma}}{1-\gamma}$) of equation (25) is the highest and the profit of the firm is $\pi_H^L = \left(\frac{1}{2}F_H + \frac{1}{2}\right) \cdot X - F_H$. Therefore D o D prefers a pooling equilibrium signaling a low price regardless of the type of firms. Especially, the utility of the D o D is the maximum utility when purchasing the highest quality product at the lowest price, and it can be seen that firm's profits are influenced by individual investment and production volume of firm investing in R&D irrespective of equilibrium[4].

4.2.2. Separating equilibrium

Two separating equilibrium can be considered. First, high-quality firms offer high prices, and low-quality firms offer low-cost prices. At this time, the D o D's prior belief α is 1 by the Bayesian law, and β is 0. The D o D accepts the high price offered by the high-quality firm by prior belief and accepts the low price offered by

[4] If we assume $\theta = \gamma$, U_H^L is greater than U_H^H, U_L^L, U_L^L since $\mathrm{H} > \mathrm{L}$ and $P_H > P_L$.

the low-quality firm as well. If a high-quality firm is awarded, the utility of the D o D and the profit of the firm are equal to Eq. (19), (20), and if the low-quality firm is awarded, the utility of the D o D and the profit of the firm are equal to Eq. (27), (28). However, in order for this balance to be established, it is necessary not to show the price of the high-quality firm, and the low-quality firm should not offer a high price. However, as shown in Eq. (19), (20) and (27), (28), the profits of firms are the same. Therefore, the company may deviate from the equilibrium. If a firm deviates, it will be a problem, so D o D regulations are needed to prevent deviations. For regulations to prevent deviation, when a firm bid, only the initial bidding content is recognized, or if the actual content differs from the bid content, it is necessary to restrict the bidding in the future and impose a fine.

The following separating equilibrium is the case where a high-quality firm presents a low price and a low-quality firm presents an expensive one. At this time, the D o D's prior belief α is 0 by the Bayesian law, and β is 1. The D o D accepts the low price offered by the high-quality firm by prior belief and accepts the high price offered by the low-quality firm as well. If a high-quality firm is awarded, the utility of the D o D and the profit of the firm are equal to Eq. (25), (26), and if the low-quality firm is awarded, the utility of the D o D and the profit of the firm are equal to Eq. (21), (22). However, in order for this equilibrium to be established, it is necessary not to show the price of the high-quality firm, and the low-quality firm should not offer a high price. However, as shown in Eq. (25), (26) and (21), (22), the profits of corporations are the same. Therefore, the company may deviate from the equilibrium. If a firm deviates, it will be a problem, so D o D regulations are needed to prevent deviations. But here are some things to consider. In other words, if a high-quality firm presents a low price, the answer to this can be judged to be inappropriate because high-quality firms always aim for high prices as the result of research by Daughety and Reinganum (2007). It is also necessary to consider the reaction of the D o D. In other words, if a high-quality firm presents a low price, it is reasonable to accept it from the standpoint of a risk-neutral D o D, but it is more reasonable to reject it when a low-quality firm presents an expensive price. Therefore, there is no equilibrium in this situation.

Theorem 3 In the case of a signaling game in which the D o D and the defense firm play a role player and the type is a quality. When a company presents a signal of a price ($P_i,\ i = 1, 2\ and\ P_i = P_H\ or\ P_L$) according to the type of quality ($t_i,\ i = 1, 2\ and\ t_i = H\ or\ L$), the firm takes action on whether or not to purchase by the prior belief and the price signal. Assuming that the D o D's utility and firm's profit are determined as a result of D o D action.

(ⅰ) Regardless of the type of firms, there is a pooling equilibrium that signals both high and low cost. In order for high-priced equilibrium to exist, the constraint of $\beta \leq \frac{P_L^{1-\theta} - L^{1-\theta}}{H^{1-\theta} - L^{1-\theta}}$ must be satisfied in order to prevent a high-quality firm or a low-quality firm from offering a low price. In order for low-priced equilibrium to exist, the constraint of $\alpha \leq \frac{P_H^{1-\theta} - L^{1-\theta}}{H^{1-\theta} - L^{1-\theta}}$ must be satisfied in order to prevent a high-quality firm or a low-quality firm from offering a high price.

(ⅱ) There is a separating equilibrium that high-quality firms offer high prices and low-quality firms offer low-cost. At this time, the profit of the firm is the same regardless of the type, so there is a possibility of deviation. Therefore, bidding regulation is necessary to prevent deviations. Separating equilibrium in which high-quality firms offer low prices and low-quality firms offer high prices does not exist when considering the results of Daughety and Reinganum's study (2007) and the D o D's risk-neutral position.

Ⅴ. Conclusion

The defense industry is a national infrastructure industry, and it is necessary to revitalize R&D and to improve the efficiency of the defense market. However, too much research and development by the nation led to a decrease in the self-sustaining power of the firm and a weakening of the will to research and development. Therefore, in this study, we applied the signaling model considering the optimization problem of the firm and the D o D and the bilateral interaction in order to present the incentive system considering the characteristics of the defense industry system.

In general, for profit-oriented firms, assuming a pricing strategy of a linear function, the profit of the firm is influenced by the output and the firm's own specialized cost. Therefore, the government needs R&D incentives or price compensation policies to promote R&D. And firms need to make efforts to increase exports and to develop and utilize core technologies to expand production volume.

The utility of the D o D was analyzed in terms of the quality and price of the defense system. As a result of the analysis, the utility of the D o D was affected by the compensation paid to the firm's research and development and the preference weight that the D o D satisfied with the quality. Therefore, it is required to encourage R & D by firms through compensation and to make compensatory efforts through price policy at the production stage.

There have been established and modeled a signaling model to analyze the interactions in which the D o D and firm become players, quality becomes a type, and a price becomes a signal. As a result of the analysis, there is a pooling equilibrium in which companies offer both high and low prices. There was a strategy of high-quality firms offering high prices and low-quality firms offering low prices. In order for the pooling equilibrium to exist, a restriction on the D o D's prior belief was needed to prevent the deviation of the firm. In order for the separating equilibrium to exist, bid regulations and institutional supplement were needed to prevent deviation of low-quality companies.

This study can be applied to establish the policy to promote the efficiency of the defense acquisition system and promote the research and development of the defense industry in the future. However, there is a need to further analyze the competitive market in which more firms are participating and to present the efficiency and complementarities of the multistep negotiation process.

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