RESIDUAL CLAIM, TECHNOLOGICAL BOUNDARY AND OPTIMAL INVESTMENT ARRANGEMENT: THEORETICAL MODEL AND CONTRACTUAL EXPLANATION

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Abstract: *The segmentation of residual claims, is one of the dynamic mechanism of defense R&D investment. Based on two dimensions of risk measuring and motivation designing, the contracts of defense R&D investment should be taken into an arrangement of division. In this paper, a mathematical model is set up to describe the nature of investment contract. Through arithmetic analysis, six key conclusions should be focused on, aiding to reveal the relations among the factors such as investment quota, effort coefficient, R&D yield, incentive effect and technological innovation. The further measuring on variables such as k, r and c indicates that both the specificity of defense R&D investment and hold-up behavior of military firms make it hard to break up k effectively. There exists a boundary where equilibrium of k and r should be located in the R&D projects with the highest intrinsic value, and the share of c should be accorded to the adjustment of r. By analyzing the variables δ and θ, it emphasizes the possibility of hidden dissipation of investment and the feasibility of step-by-step investment. Finally, some suggestions on the contract rights, contract forms, risk sharing, diversification of investment, technical boundary and management system of are put forward.*

Keywords: *residual claim, investment specificity, hold-up, investment boundary, implicit dissipation, technological innovation*

1. INTRODUCTION

The economic distribution is commonly performed by contract in the market. There are mainly three types of contracts according to the distribution forms, i.e. the wage contracts, the fixed contracts and the sharing contracts. For the wage contracts, the principal pays a fixed salary for the agent, possesses the rests and bears all risks. For the fixed contracts, the agent pays a fixed rent for the principal, possesses the rests and bears all risks. For the sharing contracts, the principal will pay a proportion of residues besides a definite sum of money. When analyzing the issues of agricultural production, Cheung (1969a, 1969b) points out that given a clear ownership, there will be no difference between the sharing contract and the fixed contract on the resource allocation, and the choice on the contractual form by both sides relies on the transactional cost and the attitude towards risk.

Essentially, the sharing contract can be regarded as a contractual mechanism for risk diversification (Cheung, 2000). This thought is profound for it has not only thrown down the traditional idea that the sharing contract produces efficiency loss, but revealed its function on the risk diversification. However, it does not consider the supervision cost and ignores the significance when the share-cropping plays an incentive role. By creating an initial efficiency-wage model, Stiglitz (1974) has modeled the thought of Cheung and considered that the ratio of the sharing does have an incentive effect on the labor. A technical process of which is to embed an effort coefficient into the production function and the utility function. The model analysis in this paper has referred to this paradigm.

The core of contract is to pursue for the residual claim for both sides. The so-called residual claim here means a claim for the residue when total revenue minus the fixed contract payment.

Thus, the allocation issue of residual claim has been the focus of the theory of firm. When explaining the corporate internally incentive mechanism (considering the supervision cost), Alchian & Demsetz (1972) emphasized the importance of residual claim on stimulating the supervisors. The reason why the defense R&D investment would adopt the sharing contract is that both the risk and incentive must be thought about. The long period and low success, as well as the multi-category-small-amount operating procedure, have together enhanced the cost and risk of defense industrial firms. Meanwhile, the irreversibility of investment demands the investor should pay a large sunk cost and request for a cost compensation inevitably. And the immeasurableness of the efforts of the firm makes the investment contract incomplete. When the outsider (for instance, the investor) lacks the incentive to supervise the firm, the problem of insider control that will not exist in a classical firm will emerge. Here, the insider control will bring about a huge residual loss, which ensures the existence and necessity of the arrangement of residual claim.

2. THEORETIC MODEL

2.1 Basic framework. In the defense R&D investment, we assume that the investor (I) owns the residual claim for R&D yield π of the military firm (F), which is mainly based on three aspects: Firstly, there will be uncertainties within the investment environment and investment project (here ε represents a random state), and the risks of investment result needs some compensation mechanism to smooth up. Secondly, the investment has a remarkable specificity, and a huge investment will result in a big cost viewed from the perspective of scale effect. Thirdly, the elasticity of rate of residual sharing or rate of return on investment (for I) can produce positive incentives, promoting the military firm to enhance its effect level of R&D (ω), here 1-r is the remaining share of F, and $\frac{\partial \omega}{\partial r} < 0$.

Consuming that both I and F have a fully defined utility function, the total revenue of defense R&D can be described as (ignoring the influence of tax) [1]:

$$\pi = \pi(\omega, k, \varepsilon) \tag{1}$$

Supposing that π is a monotonically increasing concave function of ω and k, and is an increasing function of ε, namely $\frac{\partial \pi}{\partial x} > 0$, $\frac{\partial^2 \pi}{\partial x^2} < 0$, here $x = \omega, k$, $\frac{\partial \pi}{\partial \varepsilon} > 0$.

And ε obeys the normal distribution with mean of 0 and variance of σ^2, namely $\varepsilon \sim N(0, \sigma^2)$.

The arrangement of revenue sharing can be described as a form of piece wise linear contract[2]:

$$\pi_F = f + (1-r)(\pi - f - g) = \frac{\partial \pi}{\partial k}(1-r)k \tag{2}$$

$$\pi_G = g + r(\pi - f - g) = \frac{\partial \pi}{\partial k} k \tag{3}$$

Here, the functions f and g are respectively the fixed items in the investment contract. $\frac{\partial \pi}{\partial k}$ stands for a marginal benefit of investment. The Eq. (2) is a general expression on the income -determining terms in the three contract forms. Obviously in the wage contract, $r = 1$, while $r = 0$ in the fixed contact and $r \in (0,1)$ in the sharing contract.

According to Hart & Holmstrom (1987), the optimal contract under the condition of an information asymmetry and an assumption of risk neutral (a lack of understanding about ε and a high supervising cost): $f = 0$, $r = 0$. Namely, the firm holds the whole residual income, and the investor obtains a fixed earning. But in fact, there exist three constraint conditions making the optimal contract unenforceable. The first one is a lower bound. For whatever contract must at least provide the factor-owner with an original value, otherwise the latter will quit the contract (Cheung, 1983). For the investor, g may be too small to make up for the transaction cost; while for the military firm, $f = 0$ means there is no guarantee for a basic operating cost.

The second one is an incentive constraint. $r=0$ i.e. $\pi_G = g$, means that the investor will merely get a fixed income. If the investment is a kind of approximate market-pulling behavior, g will be even less likely than the opportunity cost of k, which will lead to an inadequate investment due to insufficient incentives. The third one is a risk constraint. The contract terms, technical strength and defense demand etc., will all pose an external impact on R&D, bringing about a unchangeable risk aversion for the military firm in many occasions. But the constraints in a fixed contract will make the military firm bear most of the risks. Thus, the extreme contractual arrangement with $f=0$ and $r=0$ doesn't evidently conform to the risk hypothesis for R&D investor. The only viable contractual solution is $0<f<\pi$, $0<r<1$.

Assuming that the investor is risk neutral[3], whose utility function is:

$$\mu_G = \pi - \pi_F = \pi - \frac{\partial \pi}{\partial k}(1-r)k \tag{4}$$

And its certainty equivalent income is equal to the random average income, that is:

$$E(\mu_G) = E(\pi - \frac{\partial \pi}{\partial k}(1-r)k) = \pi - \frac{\partial \pi}{\partial k}(1-r)k \tag{5}$$

Assuming that the utility function of military firm is $\mu_F = -\exp(-\rho\zeta)$, here ρ is the absolute risk aversion, ζ is the actual yield. If the military firm plays an effort level of ω, it will lower a (currency) cost of ω for the R&D project, and give rise to a negative utility of ψ(ω). Here ψ(ω) is a monotone increasing convex function of ω, that is for any $\omega > 0$ [4], $\frac{\partial \psi}{\partial \omega} > 0$, $\frac{\partial^2 \psi}{\partial \omega^2} > 0$.

To simplify the analysis, we assume that $\psi(\omega) = \frac{\tau}{2}\omega^2$, here $\tau > 0$ means an effort cost coefficient. ζ meets:

$$\xi = \pi_F - \psi(\omega) = \frac{\partial \pi}{\partial k}(1-r)k - \frac{\tau}{2}\omega^2 \tag{6}$$

Its certainty equivalent gain is:

$$E(\mu_F) = E(\xi) - \frac{1}{2}\rho(1-r)^2\sigma^2 = \frac{\partial \pi}{\partial k}(1-r)k - \frac{\tau}{2}\omega^2 - \frac{1}{2}\rho(1-r)^2\sigma^2 \tag{7}$$

For any sharing contract with a two-dimensional vector of (f, r), the military firm will choose an optimal effort level ω to maximize the utility function:

$$\underset{\omega}{Max}\; E(\mu_F) = \frac{\partial \pi}{\partial k}(1-r)k - \frac{\tau}{2}\omega^2 - \frac{1}{2}\rho(1-r)^2\sigma^2 \tag{8}$$

Give Eq. (8) a first derivation:

$$\omega = \frac{(1-r)k}{\tau}\frac{\partial^2 \pi}{\partial k \partial \omega} \tag{9}$$

Eq. (9) implies a conclusion: because $\frac{\partial^2 \pi}{\partial k \partial \omega} > 0$, there is a positive relationship between k and ω, meaning that the defense investment has a positive incentive on the military firm.

At this moment, what the defense investor would solve is:

$$\underset{s.t.\; r \to \text{Eq. (9)}}{Max}\; E(\mu_G) = \pi - \frac{\partial \pi}{\partial k}(1-r)k \tag{10}$$

Clearing up the first-order condition[5] based on Eq. (9), we will get (on account of 0<r<1, the interior point solution exists):

$$r = 1 + \frac{\partial \pi}{\partial \omega}\frac{\partial \omega}{\partial r}\tau \Big/ \left[(\frac{\partial^2 \pi}{\partial k \partial \omega})^2 k^2 + \rho\tau\sigma^2 \right] \tag{11}$$

Adding it to Eq. (9):

$$\omega = -(\frac{\partial \pi}{\partial \omega}\frac{\partial \omega}{\partial r})\frac{\partial^2 \pi}{\partial k \partial \omega}k \Big/ \left[(\frac{\partial^2 \pi}{\partial k \partial \omega})^2 k^2 + \rho\tau\sigma^2 \right] \tag{12}$$

2.2 Some deductions. From Eq. (9), we can get:

Proposition-1: $\frac{\partial \omega}{\partial (1-r)} = \frac{k}{\tau}\frac{\partial^2 \pi}{\partial k \partial \omega} > 0$ indicates that in the investment contract, to increase the share of residual claim of military firm will benefit to reduce the risk of moral hazard under asymmetric information, stimulate the initiative and creativity of military firm engaged in the defense R&D.

Proposition-2: $\frac{\partial (1-r)}{\partial \tau} = \frac{\varpi}{k} \Big/ \frac{\partial^2 \pi}{\partial k \partial \omega} > 0$ indicates that the bigger effort cost coefficient τ, the more the share of residual claim required by the military firm for its effort level ω.

Because of the risk of defense R&D, the military firm will inevitably require a certain cost compensation or expected return.

Proposition-3: $\frac{\partial\omega}{\partial\tau}=-\frac{(1-r)k}{\tau^2}\frac{\partial^2\pi}{\partial k\partial\omega}<0$ and $\frac{\partial^2\omega}{\partial\tau^2}=\frac{2(1-r)k}{\tau^3}\frac{\partial^2\pi}{\partial k\partial\omega}>0$ indicate that in the

contractual arrangement, the investor should fully think about such a possibility: a bigger τ will lead to a lower effort efficiency of military firm, which is a multiplicative decrease[6].

From Eq. (11), we can get:

Proposition-4:

$$\frac{\partial(1-r)}{\partial\rho}=\frac{\partial\pi}{\partial\omega}\frac{\partial\omega}{\partial r}(\sigma)^2\Big/\left[(\frac{\partial^2\pi}{\partial k\partial\omega})^2k^2+\rho\tau\sigma^2\right]^2<0$$ and

$$\frac{\partial(1-r)}{\partial\sigma^2}=\frac{\partial\pi}{\partial\omega}\frac{\partial\omega}{\partial r}\rho^{2}\Big/\left[(\frac{\partial^2\pi}{\partial k\partial\omega})^2k^2+\rho\tau\sigma^2\right]^2<0$$

indicate that the stronger tendency to avoid risk for the military firm, the greater uncertainty within the external environment of defense R&D, as well as the greater risk the investor will bear, resulting in a lower percentage of return for the military firm. In this case, the incentive mechanism will be out of order. By this time ($\pi_F\to f$), namely the fixed contract regardless of the R&D efficiency will be superior to the incentive contract based on the residual claim. On the contrary, for $\sigma^2\to 0$, in order to reduce the uncertainties within the external environment of defense R&D, the incentive effect will be more obvious in the linear contract (Eq. (2)).

Proposition-5:

$$\frac{\partial(1-r)}{\partial k^2}=\frac{\partial\pi}{\partial\omega}\frac{\partial\omega}{\partial r}(\frac{\partial^2\pi}{\partial k\partial\omega})^2\tau\Big/\left[(\frac{\partial^2\pi}{\partial k\partial\omega})^2k^2+\rho\tau\sigma^2\right]^2<0$$

indicates that the greater is the investment, the bigger is the residual claim scale of the investor asks for. Namely, the less is the profit share of the military firm, and the less is the efforts input. Therefore, there undoubtedly exists an equilibrium solution of k and r in the optimal contractual arrangement, which will be analyzed in the third part.

From Eq. (12), we can get:

Proposition-6:

$$\frac{\partial\omega}{\partial\sigma^2}=\frac{\partial\pi}{\partial\omega}\frac{\partial\omega}{\partial r}\frac{\partial^2\pi}{\partial k\partial\omega}k\rho\Big/\left[(\frac{\partial^2\pi}{\partial k\partial\omega})^2k^2+\rho\tau\sigma^2\right]^2<0$$

indicates that the smaller is the risk of R&D project, the easier it guarantees an effective output, and the higher is the enthusiasm of the military firm. To avoid a loss caused by a misguided decision-making, the military firm tends to choose a normal investment project with a lower market risk. And thus, the R&D project focuses mainly on the level such as a blind imitation or a tracking innovation, giving rise to a low-level repetition of research achievements, a low contribution rate technological progress acts on the generation & transformation of fighting capacity, as well as the coexistence of the shortage & redundancy of the R&D achievements.

3. THE OPTIMAL CONTRACT ARRANGEMENT

The second part is mainly to measure mathematically about the internal relation among the variables of the defense R&D investment.

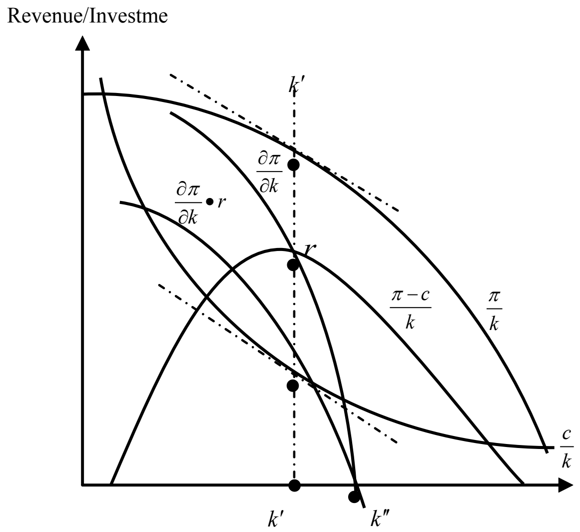

Figure-1. Graphic Description of Contract Arrangement of Defense R&D Investment

The third part will give a further analysis on Eq. (2) and (3).

We will introduce a two-dimensional coordinate system to diagrams the relevance of k, r and c, so that we can obtain an optimal contractual arrangement of the defense R&D investment on the two dimensions of both revenue sharing and cost compensation.

3.1 Diagrammatizing. The key variables in the graph explained:

- $\frac{\pi}{k}$ means the average revenue of the R&D investment of military firm.
- *c* means the R&D input of military firm (except of the investment itself), including the plants, equipments, labor inputs, etc. Assuming that all the R&D input (except of the investment) c must be borne by the military firm (Later we will relax the conditions) and remain unchanged, so $\frac{c}{k}$ can be regarded as a quotient of the non-investment and investment, or a necessary ratio of the complementary cost to the investment k, which is manifested as a hyperbola convex to the origin in mathematics.
- The vertical dimension between the curve $\frac{\pi}{k}$ and $\frac{c}{k}$ defines the curve $\frac{\pi - c}{k}$, i.e. net revenue per investment.
- $\frac{\partial \pi}{\partial k}$ means the marginal revenue of R&D investment. When c is fixed, $\frac{\partial \pi}{\partial k}$ decreases with the increase of k, namely $\frac{\partial^2 \pi}{\partial k^2} < 0$.
- The contractual arrangement on residual sharing of the investment revenue: On the marginal, the investor asks for $\frac{\partial \pi}{\partial k} r$, and the military firm gets the rest $\frac{\partial \pi}{\partial k}(1 - r)$.

The every moving-up of the curve $\frac{c}{k}$, will cause the responding moving-up of the curve $\frac{\pi}{k}$.

The former means the marginal cost of non-capital increases with a constant rate (the marginal cost of factors remains the same). The latter shows that the marginal revenue of added non-capital input increases with a diminishing rate. When the marginal distance is equal for the both curves, the marginal revenue will equal the marginal cost of the R&D investment (the two virtual tangents parallel), so the marginal revenue curve $\frac{\partial \pi}{\partial k}$ will intersect both the average revenue curve $\frac{\pi}{k}$ and net revenue per unit curve $\frac{\pi - c}{k}$. This moment the balanced investment assigned to military firm is k', and the balanced revenue sharing rate r equals the ratio of $\frac{\pi - c}{k}$ (or $\frac{\partial \pi}{\partial k}$) and $\frac{\pi}{k}$, which can describe the residual sharing $\frac{\partial \pi}{\partial k} r$ of the investor.

3.2 Investment division: a balanced measuring of k and r. By definition, the R&D revenue of military firm $\frac{\partial \pi}{\partial k}(1 - r)$ will change with k. If this revenue is not less than that coming from the R&D activities, as long as $\frac{\partial \pi}{\partial k} > 0$ and c remains constant, the military firm has have an incentive to continue the defense R&D, and improve the utilization efficiency of investment as much as possible. On the other hand, in order to achieve a maximum revenue, the investor will require a higher sharing ratio r which enhances the curve $\frac{\partial \pi}{\partial k} r$, until the R&D revenue of military firm equals its non-R&D possible revenue. Actually, r is not the sole relevant variable affecting the residual sharing of the investment contract. when investigating the agricultural tenancy agreements, Cheung (2000) points out that If the tenant market as a buyer is unceasingly subdivided, that is to say, the landlord offers his farming lands to different peasants to obtain a maximal rent, he will not has an incentive to sign a long term contract only with the same tenant farmer.

According to the contract theory, such one-to-many relationship is in essence a kind of filtering mechanism. For once the number of buyers increases, the available allocation amount must be reduced, which demands to lower the ratio of the lease, in order to prevent that the buyer should quit the contract[7]. However, the reduction of the lease rate will decrease the final revenue of the seller. Therefore, a trade-off exists in the both.

In terms of the defense R&D investment, if the investment k is split for many military firms and we assume that all the r is equal, there will be several vertical investment boundaries k'k' in the figure. Compared with a sole military firm, the curve $\frac{\partial \pi}{\partial k}$ will move up, but due to a deducing investment quota for sole military firm, the marginal expected revenue of the investor, $\frac{\partial \pi}{\partial k} r$, will inevitably decrease.

Moreover, once the line k'k' continues to shift to the left, r will eventually become very low (at this time, a undersized investment k' can't meet the fund demand of defense R&D, neither bring forth a scale effect of output.), thus reduce the total investment revenue. Another explanation that there is seldom contract term of investment division in practice, could be due to the properties of the investment itself, namely the investment-specific has an internal stimulation on the investment boundary. According to Klein (1978), et al., the investment-specific is something that once used to other realms, its marginal productivity will be close to zero. Actually, the defense R&D investment is not less than a sort of relationship-specific investment in the Williamson's sense (1975). That is, the investment specially used for the military firm to carry through the defense R&D, whose economic intuition is quite simple: because of the uncertainty of the R&D revenue π, as well as the difficulty in measuring the performing cost, once one party invests on a project with a high investment-specific, he will objectively be faced up with the opportunistic hold-up from the other party (military firm).

The hold-up is a function of decision-making right λ of military firm[8], such as account manipulating, investment eroding, and even the power rent-seeking[9].

In other words, the degree of investment-specific will give rise to a non-efficiency consequences.

As for the investor, he will pay an additional follow-up governance cost when lending the investment, especially when the technical strength θ and effort degree ω of the buyer (military firm) are both small, the adverse selection and moral hazard occur easier and the regulation becomes more difficult[10].

The better transmission the defense R&D acts on the fighting capacity, the higher investment-specific of the investment, and the more tendency for the investor to disperse risks by expanding the investment boundary.

The expansion modes is mainly to diversify the invests and projects, but it also brings about an increase of the transaction cost.

Particularly as for the former, the three important variables θ, ω and λ, are difficult to be clearly defined in the contract.

3.3 The investment interval: measuring the point of intrinsic value. As a supplement to the investment division, we analyze here the investment interval. From the definition and the graphic we get:

$$\frac{\partial \pi}{\partial k} = \frac{\pi - c}{k}\bigg|_{k = k'} \tag{13}$$

At the peak of curve $\frac{\pi - c}{k}$, the marginal investment revenue is equal to the average net investment revenue, which is a basic principle of the firm theory. According to the theory, the line k'k'' is a reasonable interval of the investment.

While the radical difference between the contract theory and the cost theory when adjudging the investment interval lies in that, the latter only aims at the firm itself, while the former includes two participants, whose purposes do appreciably differ.

Therefore, the investment interval k'k'' will likely withdraw to be an equilibrium point k'.

Three points here should be explained:

(1) The military firm is more inclined to the investment k'', which is more than the equilibrium investment k', for $\frac{\partial \pi}{\partial k} = 0$ meets the condition of revenue maximization. (2) Based on the same reason, the investor will control the investment at k', and loan the rest investment k'' - k' to other firms in the same contract terms. (3)The investor cannot control the investment below the level k', for when r is given, the opportunity cost when the military firm accepts the investment may be higher, lacking of the incentive to continue the R&D project.

For the sharing contract, how to make the financing scale k and the net investment revenue $\frac{\pi - c}{k}$ of military firm reach to an equilibrium?

The investment must be used on the R&D projects with the highest intrinsic value, and the input of military firm must be fully taken into account. As long as the market is flowing and competitive, the investor does not need to grasp at the technological input and innovation of the military firm, for the competitiveness of the freely flowing capital can lead to an effective contractual arrangement. Obviously, if the intrinsic value ($\frac{\pi - c}{k}$) of R&D project is low, the irrational impulse when the military firm absorbs investment will easily lead to a high k or a small c. In this case, $\frac{\pi - c}{k}$ will less than the average interest rate of the market, which is obviously unfavorable for investor. What the investor can do is either to loan the investment to other military firms, or to invest other R&D projects. On the other hand, if what the military firm obtains from the sharing contract is less than the opportunity revenue from other economic project, he will choose voting with feet and seeking for another investor with more favorable terms (a higher k and a lower $\frac{\pi - c}{k}$).

3.4 The separability of c: an idea for cost sharing. The cost of defense R&D (not investing cost) can be shared by the investor and the military firm. Here, $\frac{c}{k}$ stands for a merged cost. When the curve $\frac{\pi}{k}$ and $\frac{c}{k}$ are both given, the curve $\frac{c}{k}$ minus this segmental cost of the investor will lie in a lower area, while the curve $\frac{\pi - c}{k}$ is higher (not drawn up). By this time, r will be higher and the curve $\frac{\partial \pi}{\partial k} r$ will move up at the same speed, while the equilibrium investment k' will keep constant. Certainly, the peak of a higher curve $\frac{\pi - c}{k}$ will shift to the left of the dotted equilibrium line k'k'. While this has nothing to do with the choice of investment scale, for it will result in a lower sharing rate r. From Eq. (13) and the basic definition, we can easily deduce:

$$r = \frac{\partial \pi}{\partial k} \Big/ \frac{\pi}{k} = \frac{\pi - c}{k} \Big/ \frac{\pi}{k} = (\pi - c)/\pi \Big|_{k = k'} \qquad (14)$$

Eq. (14) shows that in order to effectively use resources, the sharing of cost c can be adjusted according to the revenue sharing rate r.

This conclusion has an important policy meaning: Whether the investor asks the military firm for more input and less profit (lower r), or the investor himself pays more cost and asks for a higher r, he will invest in some way as provided an investment maximization. The above analysis provides a sort of means for the contractual design of the defense R&D investment: the military firm doesn't need to own the total input for the R&D project, while he can cooperate with the investor or the third party when lacking of the input, by means of joint developing, technology importing and practicing joint venture. From the perspective of capital market, the military industrial groups relies on the asset restructuring, merger& acquisition and industrial integration, as well as introducing diversified capital and operation mechanism, which will be the largest investment opportunity for the military industry listed companies in the future.

4. FURTHER THINKING: EMBEDDING PARAMETERS

According to the neo-classical optimal growth theory, the traditional production function $Y = Y(K, L)$ includes two independent variables, and the technical progress is always regarded as a Harrod neutrality. The benefit of doing this is that it seldom causes any additional difficulty when analyzing, but at the same time it ignores explaining the origin of technological progress. Within the defense R&D, the technological progress or innovation is a transitional factor, for its ultimate goal should be to enhance the productivity and transform the generation mode of fighting capacity. As mentioned before, the defense R&D is a dynamically progressive process, whose technology is an input for the follow-up phases. For the investor, it is appropriate that the technology θ of defense R&D be regarded as an important reference. To make up for such a loss, it is necessary to make the technology endogenetic. The Learning by Doing model by Arrow (1962) regards that the investment is a measuring of Doing (here interpreted as the defense R&D) and Doing leads to Learning (technological progress). Shell (1966) has proposed a model to prove that the accumulation of knowledge (technology) depends obviously on the resource endowments of the invention activities (defense R&D). We here put forward a simplified formula for an endogenous θ based on Shell's model:

$$\dot{\theta}(t) = (1 - r(t)\ \pi(t) - \theta(t)$$

$$\dot{k}(t) = r(t)\pi(t) - \frac{\partial \phi}{\partial \lambda} k(t) \tag{15}$$

Eq. (15) has processed technically for three sides: Firstly, describing the relation between the technology and capital input and the revenue π within a dynamic framework. Secondly, reflecting the time effect of investment sharing rate r, which mainly considers that the defense R&D investment may be multi-stage and continuous, and there exists a possibility revising the terms of contract for both parties. So the determination of r is dynamic.

Thirdly, the imbedding of erosion coefficient φ(λ) is to measure the implicit dissipation of investment. Here, $\phi(\lambda) \in (0,1)$, $\frac{\partial \phi}{\partial \lambda} > 0$. The military firm has the information superiority upon decision-making. Once the freedom λ increases, namely the investor cannot guarantee the validity of investment on regulating, the military firm will occupy and erode the investment, resulting in an investment dissipation with $\frac{\partial \phi}{\partial \lambda} k$.

5. CONCLUSIONS

5.1 The free exiting mechanism for the investor should be an option in the contract. The defense R&D investment contract can be considered as a kind of implicit long-term one for both participants[11]. Presently, the identity of investor is strictly limited. Most of the time, the paternalism of government will lead to a under use of the investment, and the behavior restriction of defense R&D tends to soften. One immediate consequence of the soft budget constraint is that the military firm is inclined easily to have a moral hazard syndrome, such as abusing investment, encroaching capital, misreporting profit and loss and malignant subsidizing, therefore the rights of the investor cannot be effectively protected.

The tenancy theory points out that, as long as the land owner has the power to decide whether to maintain the original contract, the tendency of declined revenue of tenant farmer under the share-cropping could be suppressed. This implies that, a contractual term of free exiting endowing for the investor (potential threat could also work) would guarantee a sound performance of military firm who would maintain a soaring zeal, thus reducing a potential investment dissipation. Therefore, as a hedging mechanism, the right to exit for the investor should be a clause of the contract.

5.2 A full consideration on the feasibility of segment-based investment. From another perspective to interpret the moral hazard syndrome of military firm, the investment-specific of defense R&D investments leads to a high opportunity cost of one-time investment, and increases the risk of investor.

The implicit contract between the investor and military firm will evolve into an insurance contract. Especially when the former cannot take an effective anti-hold-up step against the opportunism of the latter, the self-enforcing of military firm could not be institutionally guaranteed. That is to say, the investment-specific increases the probability of the moral hazard of military firm, and weakens the feasibility of the exiting of investor. As a complementary mechanism of the above exiting, a one-time investment of the contractual term may be rewritten as a segment-based investment given a unconspicuous transaction cost, whose purpose includes: (1) weakening the investment-specific; (2) increasing the negotiable room for revising r; (3) reducing the information asymmetry. In this case, a positive incentive mechanism for military firm could be enforced, and the exiting term could also be an internal constraint for the self-enforcing of military firm.

5.3 On the basis of revenue sharing, establishing risk sharing mechanism of defense R&D. A feasible way is to add an escape clause into the iron-sheet contract, namely the revenue π or sharing rate r is allowed to be discounted at some special intervals (such as a structural technical bottleneck on the R&D project, a rapid increase of input c caused by the market change etc.) so that the residual sharing range of fixed contract could be flexibly adjusted. Of course, this kind of liability exemption should pay the costs, which is a sort of compensation mechanism against the risks investor bears (for instance, the investment may not be able to be recouped.) According to the implicit contract theory, Eq. (2) and (3) can respectively be rewritten as $\pi_F = f + (1-r)(\pi - f - g) - I$ and $\pi_G = g + r(\pi - f - g) + I$, here I is the insurance expenses. That is to say, when I>0 under the unfavorable natural conditions (a remarkably fluctuant ε), the military firm will pay additional insurance expense besides the quota for the investor, which is an opportunity cost for lowering the loan k when the failure of R&D project leads to a capital chain rupture. In the capital market, the diversification of insurance expenses could effectively reduce the systemic risk of portfolio.

5.4 Enlarging the capital market for defense industry, improving the mechanism of diversification of the main investors on defense R&D. According to the investigation and analysis of authoritative research institutions around the world, the R&D investment in China belongs to a below-average level on the overall size. In terms of the investment structure, the own input of firm is low and the market is still in its infancy, while the central finance lacks of a stable growth mechanism. In the field of defense science and technology, the problems that the aggregate investment is insufficient and the capital structural is imbalanced are more serious. The significance of introducing private capital is not only to solve the capital problem, but more to introduce the market-oriented operation mechanism. By using of the capital market, the military firm can broaden the financing channels, optimize the capital structure, reduce the system risk of the R&D. At the same time, the capital market can also provide the military firm with a leverage for merger and acquisition, helping it to carry out the horizontal integration. In 2007, the instructions for the non-public sectors of the economy participating in the construction of science and technology industry of national defense has clearly pointed out that, encouraging all kinds of social capital to enter into the military firms through acquisitions, asset replacement, joint venture etc., promote quality resources concentration, thus promoting the concentration of quality resources. Therefore, if we can make full use of the defense policies of science and technology development, increase and optimize the scale and structure of R&D investment relying on the capital market actively, a stable dependence between the two sides of investment could be established, and the zeal and consciousness for innovation of military firm could also be aroused, all of which could contribute to build a long-standing mechanism for a benign development of defense R&D. Technically, an investment boundary should be reasonably divided: The R&D project with core technology must be invested by the competent department of defense because of its high customization.

While those projects with a low customization, could be stripped out and handed to the third investor so as to greatly reduce the governance cost of the investor.

5.5 Broadening the technological boundary of defense R&D, establishing the defense innovation system based on a military-civilian sharing and integration. To achieve a military-civilian integration and to place the defense R&D upon the whole national strategy of both economy and science and technology, is a common policy choosing among the main developed countries in the world. Over the years, the science and technology industry of national defense of China has gathered powerful R&D capacities, and massively accumulated scientific and technological achievements which can be transferred into civilian use. On the other hand, the realm of civilian scientific research has possessed a strong foundation, and the strengths of many civil technologies have exceeded that of the traditional military realms. However, owing to the overall pattern of a military-civilian segmentation that cannot be fundamentally broken through, it is difficult for the civilian scientific research and industrial fields to radiate and permeate technologically into the military fields. What we should do at the present focused on: (1) effectively integrating the R&D projects between military and civilian, making full use of the resources of national scientific research, avoiding the regional segmentation and redundant construction; (2) strengthening the intervention and support of the key technology in defense R&D, choosing few major strategic products as a breakthrough, promoting the integration and innovation of major technological achievements, driving the rise and development of the high-tech defense industry; (3) actively carrying out the government purchasing policies, effectively reducing the preliminary market risks of high-tech products, creating a predictable market for the defense R&D.

5.6 Strengthening the supervision on the defense R&D, deepening the flexible management system of military firm. The variable λ has two sides. From the perspective of a large-scale cooperation for the defense R&D, the military firm must be provided with considerable freedoms to realize an independent innovation.

Nonetheless, a bigger λ is easily inclined to account manipulation and investment erosion. The lower is the disobeying ability of military firm, the greater is the power authorized by the contract. The key issue lies in an information asymmetry. Given a moderate informational cost, the investor could screen the technical qualification θ and supervise the non-productive rent-seeking, thus giving rise to a Pareto improvement. The 17th CPC National Congress has put forth a purpose of changing the mode of fighting capacity generation, required that the development of defense R&D should aim at high-end orientation of technology, diversification of varieties, integration of performance, rapidness of logistical support, etc. Therefore, as for the military firm, the traditional manufacturing industry based on mechanization, standardization, large-scale and replication has no longer adapted itself to the changes in the new situation, and has to adopt the flexible and elastic management mechanism on the aspects such as R&D project management, production management, financing management and etc., in order that the management innovation be a strong adhesive for both technology innovation and investment appreciation.

Notes

[1] In the model of Zhang (1993), the technical efficiency parameter θ and decision freedom coefficient λ together with ω and k, are all the important variables for measuring π. Considering that this article is mainly to discuss the incentive effects for the different division rate r on ω, as well as the relation between r and k. So the function can be simplified as the two-dimensional variable form only including ω and k. Besides, the traditional production function $Y=Y(K,L)$ only analyzes two input factors K(k) and L(ω), this article will follow this paradigm.

[2] Holmstrom & Milgrom (1987) gives the conditions making a linear contract turn to an optimal one. Besides of assuming an absolute risk aversion ρ, they have thought meanwhile about a dynamic model selecting an effect variable ω in a continuous time.

[3] We assume the client is a rational investor who has a promising strategic investment plan, which is reasonably considered as an assumption with a good degree of fitting.
[4] Simply, we assume that in the range of relevant effort equilibrium, ω is strictly positive. For the analysis of ω≤0, someone can refer to Jean Tirole (2004).

[5] Previously, we have analyzed $\frac{\partial\omega}{\partial r}<0$,

and thus Eq. (1) can be also described as π=π(ω(r),k,ε).
[6] On account of the technical parameter θ of defense R&D (discussed in the fourth part of this article), the relation of the three variables

is: $\frac{\partial\omega}{\partial\theta}<0$, $\frac{\partial\tau}{\partial\theta}>0$ (for $\frac{\partial\psi(\omega)}{\partial\theta}>0$), which can

be referred to the definition on the optimal regulation scheme by Jean Tirole (2004).
[7] Certainly, this relates essentially to the issues of enforcing and exiting towards the contract, which will be specially analyzed later. Telser (1980) regards that why the enforcing of contract can be a problem is mainly due to a counter-measuring behavior for a certain (or some) signing parties under the condition of a great supervising cost and asymmetric information, thus inevitably giving rise to a cheating or a breaching. At this point, the best punitive measure for the other party of contract is to suspend the contract relationship, that is, to exit. Of course, there also exists a possibility of existence for the seller. The related classic literatures include Coase (1937), Cheung (1969), Williamson (1985), Kornai (1993) etc.
[8] The decision-making freedom of defense R&D λ, refers to an authority on determining what and how to research and development restrained by the resources such as technical strength, investment amount, defense policy, etc. Here, $\lambda\in[0,1]$.
[9] Including increasing the on-the-job consumptions for the interior personnel in the military firm, thus inflating the non-productive cost; or once the R&D project is in the red, the profit will be misrepresented; or invest for the non-R&D project. The above will be discussed in the fourth part, or one might as well refer to Zhang (1995). In addition, the profound analysis about the issues such as the richness of behavior space and the forms of the contract, can be seen in Holmstrom (1987).
[10] Actually, among the related documents about the agency problem, the variables θ and ω are always used as describing the adverse selection and moral hazard, and we assume ordinarily that they are one-dimensional. The further discussion can be referred to Tirole (2004).
[11] The contractual relationship (whether it's an investment contract or an agency contract) discussed here is implicit for that there exist some unobserved variables among them, such as the effort degree of military firm, the emphasis degree of investment efficiency etc. All these variables cannot be written into an explicit contract because of their un-recognition. The related documents about implicit contract include Baily (1974), Gordon (1974), Azariadis (1975) etc.

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