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# Virtual Biotechnology Start-Up Model as Exclusive Network Innovation under Uncertainty

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***Abstract*--Virtual Biotechnology Start-up model has recently been created from venture capital's reluctance for investment. For example, Quanticel Pharmaceuticals was founded by a VC firm as a matchmaker; Versant Ventures, an established biopharmaceutical company as a would-be licensee; Celgene, and idea generating researchers of Stanford University, in San Francisco and La Jolla in November 2011. As a research question, is it possible to regard this type the same as open-source innovation like Arch2POCM, which seeks speed-up by preventing the overlap of the pre-competitive Research and Development cost? VBS is defined as a portfolio of real options in a process for commercializing life-science ideas until the milestone of Proof-of-Concept by partnerships among university, pharmaceutical company, and VC. Option-Games method is defined as an integrated methodology between real options and game theory, regarding the difference of real options with financial options as the limited exclusiveness. The objective of this paper is to examine, firstly, a theory on investment timing under uncertainty and competition, secondly the deterioration models of growth options at monopoly and perfect competition as both competitive extremes, and thirdly the implication of VBS model as social innovation at oligopolistic structure and sensitivity analysis. It is still necessary to analyze the incentive of non-profit R&D by Public Private Partnership.**

## I. INTRODUCTION

Virtual Biotech Start-up (VBS) model has been recently created from VC (Venture Capital)'s reluctance of investment due to unstableness of IPO (Initial Public Offering), patent cliff of blockbuster drugs in established pharmaceutical companies, and their gradually intensive competition with genetic drugs. For example, Quanticel Pharmaceuticals was founded by a match-making VC firm; Versant Ventures, an established biopharmaceutical company as would-be licensee; Celgene, and idea generating researchers of Stanford University, in San Francisco and La Jolla in November 2011. The biotechnology start-up's business is focused on the mono-cell genomic analysis of human cancers. There is another similar example of Warp Drive Bio founded by Harvard University and UCSF scientists at an option short position, Sanofi-Aventis as an option holder, and Third Rock Ventures and Greylock partners as deal brokers, in Boston in December of the same year.

Such VBS model is considered as a call option like the built-in investment exit that an established pharmaceutical or biotechnology company has a right to buy the biotechnology start-up, if they succeeded in the milestone as Proof-of-Concept (POC). As a research question, is it possible to regard this type almost the same as the open-source innovations like Arch2POCM or Sage Bionetworks that seeks speed-up by preventing the overlap of the pre-competitive Research and Development (R&D) costs?

As the main key words to the above research question, at first, the POC oriented virtual biotechnology start-up is defined as a portfolio of real options at a process of commercializing life-science ideas into the milestone of POC by partnerships between universities, pharmaceutical companies, and VCs, by considering entrepreneurs' ideas as the real options like investment opportunities. Secondly, Option-Games approach is defined as integrated methodology between real options and game theory, by regarding the inferior difference of real options to financial options as the limitations of exclusiveness and by valuing the flexible decision of irreversible investment under the uncertainty and market competitive structure. Thus this is a suitable approach to such D research question.

Objectives of this paper are consisted of firstly xamining the theoretical model on investment timing under uncertainty and competition, secondly comparing the deterioration models of growth options necessary to overcome the negative profits period at the monopoly and the perfect competition as both extremes of competitive structure, and thirdly evaluating the function of VBS model and its sensitivity analysis at the oligopoly as the midrange competitive structure, by option-games method in order to analyze new investment pattern in biotechnology start-ups under uncertainty and intensive fundraising competition.

## II. INVESTMENT TIMING OF BIOTECHNOLOGY START-UPS

### *A. The function of biotechnology start-ups*

Biotechnology start-ups have the comparative advantages at faster, cheaper, and smaller risk for transforming innovative ideas from basic life science at universities to the applied development toward niche markets than established pharmaceutical companies, which rather aim at mass-production of stable demanded drugs can do. However, the negative profits period for small firms is a financial abyss, because it takes more than 10 years from laboratory bench to government approval, and costs more than one billion US dollars for one medicine, and the average success probability is about a hundred-thousandth from the compounds in a laboratory to a medicine on the market. Then majority of US biotechnology start-ups are in the negative profits and their bankruptcy rate is also so high. One of the reasons why so many biotechnology start-ups can survive even without any drugs on the market is their dependency on the investors' evaluation about the project potential according to each smooth milestone success. Although technological achievements are constantly gained like nucleic acid, regenerative, and personalized medicines by long-term research, capital market has been subject to short-term fluctuation from unstable market factors as financial crises, advanced countries' deficits, and their aging populations.

Biotechnology start-ups basically utilize the flexibility to irreversible investments in the high-risk projects by staged milestone investments and a variety of suitable exit strategy (for example, out-license, partnership, Merger and Acquisition (M&A), and IPO) at each condition. But the value of growth options of biotechnology start-ups dependent on the exclusiveness of patents has gradually been difficult to expect reflecting so high payoffs in overcoming the non-profit period, due to the VC's investment reluctance from unstable IPO market, the patent cliff of blockbuster drugs of established pharmaceutical companies as licensees, and the market orientation to generic drugs. Thus as the option value of patents has been deteriorated by recent economic environment, the applied-research oriented biotechnology start-ups based on more exclusive network rather than open style are created as the VBS business model, to prevent the opportunity disappearing at existing value-chain. Therefore, the options-games approach seems suitable to analyze the investment decision in such VBS, since it deals with the limitation of exclusiveness in real options from a competition perspective.

*B. The shift from real options to option-games*

Biotechnology industry has often been studied from a network perspective as inter-organizational learning [16]. For example, in regional study area, local agglomeration is analyzed by focusing on scientists in biotechnology start-ups within a regional network with indices as status in firm and in science community or age [20]. The necessity of network formation for combining regional and global scientific community is advocated [12]. And regional incubator also needs such network forward survival and growth of biotechnology start-ups [17].

Secondary, a study group on R&D cycle in networking proposes a theoretical framework on radical and incremental innovations within an innovation cycle [5] and a pattern of exploration and exploitation networks by using the idea as "strength of weak ties" by Granovetter [4,7]. For example, the study of Gittelman and Kogut [6] focuses on biotechnology start-ups' function as mediator between universities and established pharmaceutical firms because of cultural difference to produce whether article or patent. And Stuart, Ozdemir, and Ding [21] analyze the middleman role of biotechnology start-ups in technology transfer chain between the basic science stage at universities and the manufacturing stage at established pharmaceutical firms, from a network perspective.

Thirdly, Wong [23] compares Asian three countries among South Korea, Taiwan, and Singapore and indicates that the biotechnology industry is different from IT industry in technological and economical uncertainties and more difficult for forming industrial policy. Pisano [15] more directly insists the biotechnology industry has the unique difficulty as the long-term initial negative profits period. If so, the role of star scientists can be more easily considered as "glue," in technology transfer network among the universities, small biotechnology firms, and established pharmaceutical firms, which have each different culture between the basic science and the commercialization, and during long-term and deep negative profits period [24].

This paper focuses on such problem as long-term negative profits period by using option-games approach, which integrates between real options and game theory. Real options approach has attracted attentions as an investment analytical method under uncertainty. The objective of business investment in biotechnology start-ups is regarded as the option value as potential during the period from the non-profits start to future growth of a company. The representative studies include the concept creation; Myers [13], the fundamental study; Dixit & Pindyck [3], and the practical guideline; Copeland and Antikarov [2]. Further, integrating it with game theory by focusing on the limited exclusiveness, the pioneering studies of option-games have the examples as Smit & Trigeorgis [19], and Kester [10]. On the other hand, the main practical studies are the game theoretical revision on business cycle at real-estate development; Titman [22], Grenadier [8], and the optimization studies at US off-shore oil rights between preemptive investing in exploitative mining and waiting for the information on oil well size by other companies' trial boring; Paddock, Siegel, & Smith [14], and Hendricks & Kovenock [9]. But there are very few option-games approaches on biotechnology start-ups. Then this paper focuses on option-games analysis on biotechnology start-ups.

*C. Timing option, uncertainty, and dividend*

The investment timing in business opportunity can be considered as a perpetual American call option of an asset with dividends or as an option to defer. In Fig. 1, when an underlying asset $V \geq V^*$ a critical value, Net Present Value (NPV) becomes equal or bigger than the option to defer $F$ as $NPV_N \geq V^* - I = F(V^*) \geq 0$, then the option exercise can become reasonable. On the other hand, if $V^* > V \geq I$, deferral becomes rational. That is, if an underlying asset value $V$ is bigger than the summation of an investment $I$ and a deferrable option $F$, it exceeds the investment critical value $V^*$. This deferrable option' curve $F(V)$ makes slower the investment by the expansion of $V^*$ with upward moving by the increase of volatility $\sigma$, or earlier it by the contract of $V^*$ with downward moving by the increase of dividend $\delta$. Therefore, there is a trade-off relationship between volatility $\sigma$ and dividend $\delta$ (see Fig.1).

The growth option of biotechnology start-ups that is based on patent exclusiveness has recently deteriorated the value and has reduced the market trading opportunities at the existing value-chain by VC's reluctance due to turmoil of IPO market and by licensees, large pharmaceutical companies' patent cliffs of blockbuster drugs and intensive competition with generic drugs.

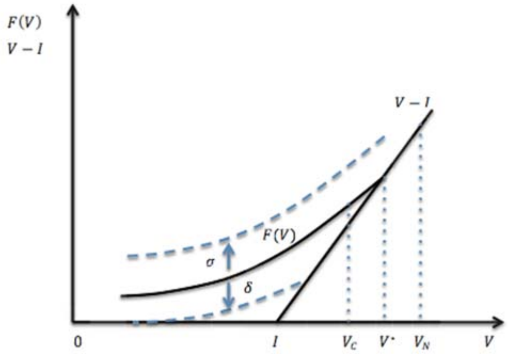


Fig. 1 Critical Value of Timing Option and Risk/Dividend

## III. GROWTH OPTION AND COMPETITION: FROM MONOPOLY TO PERFECT COMPETITION

Then if evaluating the growth-option value as biotechnology start-ups' business opportunity as enough high, the competitive structure can be defined as the monopoly, for example, because of the aggressive VC investment reflecting robust IPO market and the strong in-license demand by established pharmaceutical companies that have abundant fund by keeping the patents of blockbuster drugs and avoiding competition with generic drugs. On the other hand, if valuating it very low, such structure can be defined as the perfect competition structure, because of economic strictness of VC and large pharmaceutical companies.

### *A. Growth option value and competitive structure*

We here use the binomial evaluation method for path treatment at the decision tree tools, while handling the timing or deferrable option to decide the optimal investment timing based on the potential of new projects as biotechnology start-ups. If assuming the revenue loss from deferring the business start as the dividend, the optimal timing will be determined as the dynamic point between the opportunity loss by additional defer and the contribution by uncertainty reduction.

### *B. Competitions and value deterioration of growth option*

We examine the important points of discrete-time model of dividend, for impact comparison of investment deferral on the difference of value deteriorating tendencies of growth option at both extreme poles of monopoly and perfect competition, by referring the model of Smit & Ankum [18]. First of all, we define the expected net Cash Flow (CF) as return for investment at a time point, in discrete time, as the summation of the capital cost as periodical return to investors and the expected excess profits based on the business advantage, by following equation:

$$\overline{CF}_t = I \cdot r + \overline{EP}_t \quad t = 1,2,3,\cdots,\infty \quad (1)$$

where $\overline{CF}_t =$ the expected net CF at t, $I =$ the investment CF, $r =$ capital cost at rate, $\overline{EP}_t =$ the expected excess profits at $t$, $I \cdot r =$ annual opportunity cost of investment at going concern, and $t =$ a time point.

In monopoly, as it is possible to assume that there is no deterioration from competition, in new project value as the expected excess profits, the value of timing (or deferrable) option can be equal to that of call option for a stock with dividend. The dividend rate is, during the period between time points, $t$ and $s$, path independent at binomial model as following:

$$\delta_{t,s} = \frac{r}{1+r} = \delta_t \quad t = 1,2,3,\cdots\infty \quad (2)$$

On the other hand, as in perfect competition the continual new entry is possible, the expected net CF declines from initial positive value and finally converges into the capital cost at the going-business bottom line. Therefore, the dividend rate in perfect competition can be assumed as follows:

$$\delta_{t,s} = \frac{I \cdot r + \left[1 - \frac{e^{-d}}{(1+r)}\right]\left[FV_{t,s} - (1+r)I\right]}{FV_{t,s}} \quad t = 1,2,3,\cdots,\infty \quad (3)$$

where $FV_{t,s} =$ the future value at a future time point s from a perspective of present time point $t$. The first term of numerator is the annual capital cost to investors, and the second term is the excess profits at each condition. If biotechnology industry approaches to the long-term equilibrium point through exponential function $e^{-d}$ with decline rate $d$, the excess profits will finally disappear.

### *C. Numerical calculation: investment timing strategy and excess profits*

As the assumption for numerical calculation for option valuation at each competitive market, capital cost $r = 0.15$, annual up ratio of underlying asset at binomial process $u = 1.25$, and its down ratio $d = 0.8$. From $u = 1/d = e^{\sigma\sqrt{\Delta t}}$ as the model characteristic, if assuming $\Delta t = 1$ year, volatility as risk scale $\sigma = 22.314\%$. And risk free rate $r_f = 0.05$.

Otherwise, while from the innovation the expected excess profits at the end of initial year $\overline{EP}_1 = 30$, the value is supposed to deteriorate exponentially at annual rate 0.30 by market entry from perfect competition. And another assumptions are eternal operation even after M&A and the investment for starting business $I = 1000$.

1) Monopoly

Here we examine the rationality of option exercise during 2-year period. First of all, at the exclusive condition in monopoly, assuming the expected net CF which consists of the capital cost from (1) and the excess profits is possible as constant, the present business value is calculated as following:

$$V_0 = \sum_{i=1}^{\infty} \frac{\overline{EP}_i + r \cdot I}{(1+r)^i} = \frac{\overline{EP}_1 + r \cdot I}{r} = \frac{30 + 0.15 \times 1000}{0.15} = 1200 \quad (4)$$

At the binomial model of product demand behavior, the business value can be calculated with multiplier from the product of an asset change ratio times the ratio after dividend deduction. Thus, the mid position value of the underlying asset at time point 2 is, from (2), $V_{ud} = V_{du} = 907.3$. That is, both paths of up to down and down to up lead the same value, and produce the reconnected node as Fig. 2.

From the assumption of going concern, even if the backward-induction method is impossible, the valuation of deferrable option is possible, by supposing an American call option as compound option consisted of each annual European-call-option, and using Black-Scholes-Merton formula for underlying assets with dividend [1, 11]. Then, the present-time option value $C_0^* = 200$, by using the hedge-portfolio method.

Behavior of underlying asset

| | | |
|---|---|---|
| | | Vuu= 1417.769 |
| | Vu= 1304.348 | Vud= 907.3724 |
| Vo= 1200.00 | | |
| | Vd= 834.7826 | Vdu= 907.3724 |
| | | Vdd= 580.7183 |

Option value

| | | |
|---|---|---|
| | | Cuu= 417.7694 |
| | Cu= 304.3478 | Cud= 23.42305 |
| Co= 200 | | |
| | Cd= 12.39315 | Cdu= 23.42305 |
| | | Cdd= 0 |

Option selection Policy

| | | |
|---|---|---|
| | | Invest |
| | Invest | Defer |
| Invest | | |
| | Defer | Defer |
| | | Defer |

Fig. 2 Binomial Lattice Model: Monopoly

That is, the decision at $C_0^*$ means $NPV = 200$ with investment is bigger than business stop 0 at time point 0 or the value of option to defer 166.27, then the investment decision, as immediate exercise of option, is reasonable. In Fig.2, as option selection policy at binomial path of underlying assets, the investment decision nodes include $V_0$, $V_u$, $and\ V_{uu}$, otherwise the decision to keep alive option to defer is rational for remaining nodes.

2) Perfect competition

Based on the assumption of deterioration of the excess profits with negative exponential function due to the excessive free entry into the decreasing VC capital market as the perfect competition, the numerical calculation of binomial model of the underlying assets at time point 0 is following:

$$V_0 = \sum_{i=1}^{\infty} \frac{\overline{EP}_{i-1} e^{-d(i-1)t} + r \cdot I}{(1+r)^i} \approx 1073.31 \quad (5)$$

With dividend $\delta_{0,1} = 0.1458$ during the period [0, 1] using (3) and binomial change ratio of risk assets, the underlying asset increased after one period can be calculated as $V_u = 1145.99$.

Behavior of underlying asset

| | | |
|---|---|---|
| | | 1204.516 |
| | 1145.994 | 770.8905 |
| 1073.317 | | |
| | 733.4362 | 872.3095 |
| | | 558.2781 |

Option value

| | | |
|---|---|---|
| | | 204.5164 |
| | 145.9941 | 3.579656 |
| 84.68782 | | |
| | 17.5823 | 33.04891 |
| | | 0.227044 |

Option selection Policy

| | | |
|---|---|---|
| | | Invest |
| | Invest | Defer |
| Defer | | |
| | Defer | Defer |
| | | Defer |

Fig. 3 Binomial Lattice Model: Perfect Competition

Because the dividend of $V_d$ is smaller than $V_u$ based on path dependency, as the mid-position values at time point 2 of binomial lattice model $V_{du} = 872.30 > V_{ud} = 770.89$, then these can not be a reconnected node as Fig. 3. Further, with option valuation by Black-Scholes-Merton formula and hedge portfolio method, finally the present option value $C_0^* = 84.68$.

Thus, at the present decision as $C_0^*$, the value of option to defer 84.68 is the biggest, comparing with business stop 0 or investment $NPV = 73.31$ at time point 0, then keeping alive this option with deferring the investment is recommended. As calculation results in Fig.3, the option selection policy is the same with that of monopoly, except $C_0$.

In monopoly and perfect competition as both extreme poles of competition at binomial-process model with the dividend (penalty for deferring), first of all, monopoly can keep the exclusive excess profits like the financial option. Then the decision is identifiable to invest if a favorable condition, or to defer if an unfavorable condition. On the other hand, in perfect competition, the decision strategy is bipolarized as more quick investment than deterioration speed of the excess profits, or more prudent investment to wait until enough large opportunity appears if anyway to prevent rival from entering into the market is impossible. The investment incentives also exponentially deteriorate in pace with the decrease of a dividend as a penalty of deferring.

Then in order to make clear the difference of development cost for innovation, it can be rational to make progress the innovative biotechnology drug by VBS model or to flexibly decide the investment in development of neglected or generic drug by the later mainly open-source model after adjusting the condition of demand and technology sources.

## IV. PARTNERSHIP-STYLE VIRTUAL BIOTECH START-UPS: OLIGOPOLISTIC MARKET

### *A. Option-games analysis of oligopolistic market*

For much faster investment strategy rather than deterioration speed of growth option caused from severe VC market, the partnership among more closed relationship players is indispensable rather than that among open ones. This partnership is equivalent to the oligopolistic market in the competitive structures between the monopoly and the perfect competition. If focusing on the duopoly for simplification, two companies' investment timings depend on combinations between each other's strategies.

Especially in the competition of starting new business, early market monopolizing enables to defend the business value in addition to coping with uncertainty.

### *B. Extensive game analysis*

If annotating $I =$ Investment, and $D =$ Deferral, Investment means option exercise with its payoff $= V_{t,s} - I$, Investment Deferral means option holding with its value $C_{t,s}$. In an extensive game between two companies with symmetry competitive ability, even if without the information on the game condition at maturity date, it is possible to get the solution by Sub-game Perfect Equilibrium.

Thus, at competitive symmetry option-games, it is necessary to respectively consider, firstly the Cournot Nash equilibrium solution considering excessive and complementary competition if both companies invest simultaneously, secondary the Stackelberg equilibrium solution if the game is sequential between leader and follower, and thirdly Nature's selection, dividend $\delta's$ opportunity cost, and option valuation by Black-Scholes-Merton formula for assets with dividend and discounted expected value by hedge portfolio method.

This kind game tree enables to optimize the trade-off between the flexible treatment to uncertainty and the preemptive choice to rival.

### *C. Numerical calculation*

For evaluating two-stage extensive duopolistic game with competitive symmetry, the assumptions are the underlying asset at time point 0, $V_0 = 100$, investment $I = 50$, risk adjusted interest rate $k = 0.15$, risk free interest rate $r_f = 0.05$, binomial process's underlying asset up ratio $u = 1.25$, its down ratio $d = 0.8$, investment Cournot game's competitive coefficient $\nu = 0.5$, Stackelberg equilibrium leader's market share $\theta = 0.525$, and unit time period $= 1$ year. If so, these equations produce volatility $\sigma = 0.2231$, risk neutral probability $p = 0.5555$, and annual dividend $\delta = 0.1304$.

With these parameters, the game tree is built as Fig. 4. That is, 'Nash equilibrium' as sub-game perfect equilibrium shows, first of all, both companies; A and B, defer {D, D} at time point 0. If nature N1; as uncertainty is favorable; u, both companies will invest, then the payoff at time point 1 becomes (4.34, 4,34). On the other hand, if N1 is unfavorable; d, both will defer {D, D}. Further if next nature N2 is favorable; u, both players defer again {D, D}, payoff at time point 2 is (5.24, 5.24) by keeping each option alive. Otherwise, if N2 is d, both repeatedly defer, then payoff at time point 2 becomes (0, 0). Thus the payoff at time point 1 is (2.77, 2.77) as the discounted expected values from both conditional payoffs at time point 2. Furthermore, the discounted expected values, then backward inducted from both payoffs at time point 1, or overall payoff at time point 0 by adopting this sub-game perfect equilibrium strategy is (3.47, 3.47).

However, this Nash Equilibrium solution falls into prisoners' dilemma. Much better, 'Pareto optimal' strategy shows follow as: after both players defer {D, D} at time point 0, if N1 is d, both re-defer {D, D}, this part is the same with the above strategy. But if N1 is u, one player, for example, A invests, and the other B defers. Further if N2 is u, B invests, and if N2 is d, B defers again. As the result, this strategy's total payoff at time point 1 can improve into (7.05, 3.23). In this case, if in order to re-distribute this improved payoff, there is a social function to smartly coordinate the roles between leader and follower, both players' summed (or entire society's) payoffs have the potential to ameliorate.

Then in VBS model, further sophisticated coordinating function is needed as social innovation for total optimization.

## V. SENSITIVITY ANALYSIS

Here we try sensitivity analysis on each model in monopoly, perfect competition, and duopoly to test robustness of the above results. First of all, in a Monopoly model, as Fig.5 the option value $F$ increases if both parameters time horizon $T$ and volatility $\sigma$ go over the thresholds. It can be understood that both volatility and time horizon have the same variation characteristics with the case of financial option.

Next, in Perfect Competition model as the opposite side in competition structure, while as Fig.6 the variation connection of volatility $\sigma$ with the increase of real option value $F$ is the same, the added value deterioration rate $D$, which is used in the negative exponential function, has the tendency of a little more expanding at both high and low extremities than in the middle of the deterioration rate axis. This has the relationship with bipolarization of decision speed on commitment value as the faster investment decision than deteriorating speed and the more prudential decision to confirm favorable condition based on declining of opportunity cost.

| A | B | Payoff A | Payoff B | N1 | A | B | Payoff A | Payoff B | N2 | A | B | Payoff A | Payoff B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | I | 0 | 0 | | | | | | | | | | |
| I | D | 2.5 | 1.713288 | u | | I | 3.59375 | 1.630435 | | | | | |
| | | | | | | D | 3.59375 | 3.238115 | | | | | |
| | | | | | | | | | u | | I | 5.166016 | 6.120038 |
| | | | | | | | | | | | D | 5.166016 | 3.993923 |
| | | | | | | | | | d | | I | 3.30625 | −14.0832 |
| | | | | | | | | | | | D | 3.30625 | 0 |
| | | | | d | | I | 2.3 | −16.9565 | | | | | |
| | | | | | | D | 2.3 | 0 | | | | | |
| | | | | | | | | | u | | I | 3.30625 | −14.0832 |
| | | | | | | | | | | | D | 3.30625 | 0 |
| | | | | | | | | | d | | I | 2.116 | −27.0132 |
| | | | | | | | | | | | D | 2.116 | 0 |
| D | I | 1.713288 | 2.5 | u | I | | 1.630435 | 3.59375 | | | | | |
| | | | | | D | | 3.238115 | 3.59375 | | | | | |
| | | | | | | | | | u | I | | 6.120038 | 5.166016 |
| | | | | | | | | | | D | | 3.993923 | 5.166016 |
| | | | | | | | | | d | I | | −14.0832 | 3.30625 |
| | | | | | | | | | | D | | 0 | 3.30625 |
| | | | | d | I | | −16.9565 | 2.3 | | | | | |
| | | | | | D | | 0 | 2.3 | | | | | |
| | | | | | | | | | u | I | | −14.0832 | 3.30625 |
| | | | | | | | | | | D | | 0 | 3.30625 |
| | | | | | | | | | d | I | | −27.0132 | 2.116 |
| | | | | | | | | | | D | | 0 | 2.116 |
| *D* | *D* | *3.474378* | *3.474378* | u | *I* | *I* | *4.347826* | *4.347826* | | | | | |
| | | | | | I | D | 7.065217 | 3.238115 | | | | | |
| | | | | | | | | | u | | I | 41.01563 | 6.120038 |
| | | | | | | | | | | | D | 41.01563 | 3.993923 |
| | | | | | | | | | d | | I | 6.5 | −14.0832 |
| | | | | | | | | | | | D | 6.5 | 0 |
| | | | | | D | I | 3.238115 | 7.065217 | | | | | |
| | | | | | | | | | u | I | | 6.120038 | 41.01563 |
| | | | | | | | | | | D | | 3.993923 | 41.01563 |
| | | | | | | | | | d | I | | −14.0832 | 6.5 |
| | | | | | | | | | | D | | 0 | 6.5 |
| | | | | | D | D | 4.808526 | 4.808526 | u | I | I | 9.073724 | 9.073724 |
| | | | | | | | | | | | D | 12.02741 | 3.993923 |
| | | | | | | | | | | D | I | 3.993923 | 12.02741 |
| | | | | | | | | | | | D | 5.241793 | 5.241793 |
| | | | | | | | | | d | I | I | −12.1928 | −12.1928 |
| | | | | | | | | | | | D | −10.3025 | 0 |
| | | | | | | | | | | D | I | 0 | −10.3025 |
| | | | | | | | | | | | D | 0.017989 | 0.017989 |
| | | | | d | I | I | −15.2174 | −15.2174 | | | | | |
| | | | | | I | D | −13.4783 | 0 | | | | | |
| | | | | | | | | | u | | I | 26.25 | −14.0832 |
| | | | | | | | | | | | D | 26.25 | 0 |
| | | | | | | | | | d | | I | 16.8 | −27.0132 |
| | | | | | | | | | | | D | 16.8 | 0 |
| | | | | | D | I | 0 | −13.4783 | | | | | |
| | | | | | | | | | u | I | | −14.0832 | 26.25 |
| | | | | | | | | | | D | | 0 | 26.25 |
| | | | | | | | | | d | I | | −27.0132 | 16.8 |
| | | | | | | | | | | D | | 0 | 16.8 |
| | | | | | *D* | *D* | *2.773435* | *2.773435* | u | I | I | −12.1928 | −12.1928 |
| | | | | | | | | | | I | D | −10.3025 | 0 |
| | | | | | | | | | | D | I | 0 | −10.3025 |
| | | | | | | | | | | *D* | *D* | *5.241793* | *5.241793* |
| | | | | | | | | | d | I | I | −25.8034 | −25.8034 |
| | | | | | | | | | | I | D | −24.5936 | 0 |
| | | | | | | | | | | D | I | 0 | −24.5936 |
| | | | | | | | | | | *D* | *D* | *0* | *0* |

Fig. 4 Nash Equilibrium and Pareto Optimum at Competitive Symmetrical Duopoly

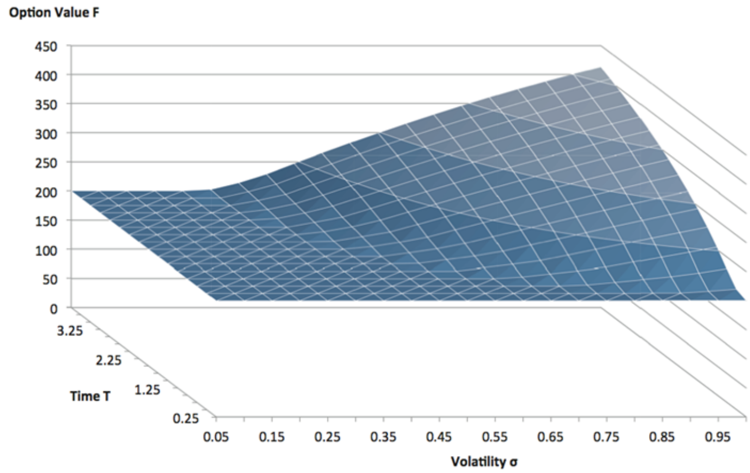


Fig.5 Sensitivity Analysis on Option Value in Monopolistic Model

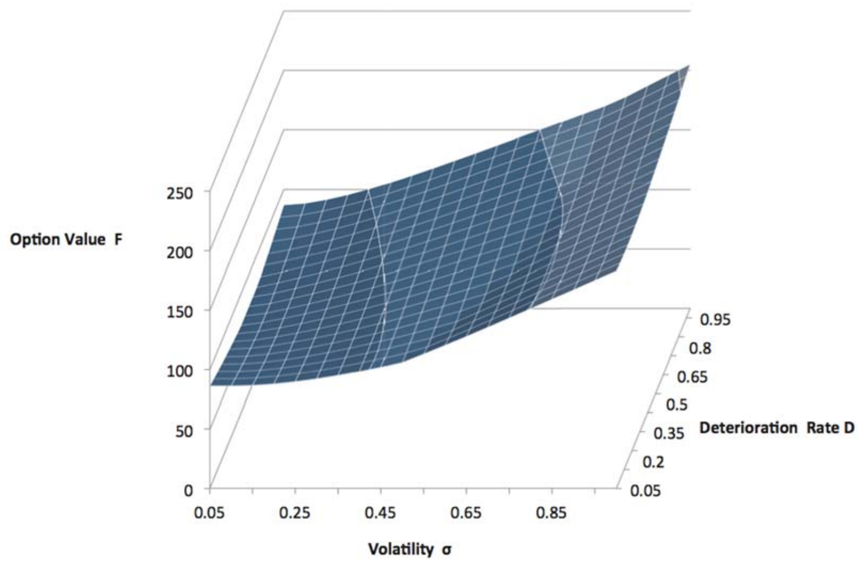


Fig.6 Sensitivity Analysis on Option Value in Perfect Competition Model

And, in duopolistic model, under this parameter assumption, the strategic profile is equal to unconditionally $\{D,D\}$ in first period, is equal to $\{I,I\}$ if first state of nature $N_1=\{u\}$ $(\{I,I\}: if\ N_1=\{u\})$, and is equal to $\{D,D\}$ regardless of second state of nature $N_2=\{u\}\,or\{d\}$ if first state of nature $N_1=\{d\}$ $(\{D,D\}: if\ N_2=\{u\}\,or\{d\};\ if N_1=\{d\})$. However, under the same parameter assumption, Pareto optimal solution is the same strategic profile with the second above strategic profile, that is, $\{D,D\}$ regardless of $N_2=\{u\}\,or\{d\}$ if $N_1=\{d\}$ $(\{D,D\}: if\ N_2=\{u\}\,or\{d\};\ if N_1=\{d\})$, and is $\{I,D\}\,or\{D,I\}$ $if\ N_1=\{u\}$ $(\{I,D\}\,or\{D,I\}: if\ N_1=\{u\})$. Thus the sum of both players' NPVs is larger than that of strategic profiles at Nash equilibriums. This Nash equilibrium solution is constant and not related with the size of volatility $\sigma(0\le\sigma\le 1)$ as a parameter, and is also constant within a range of WACC (Weighted Averaged Cost of Capital) $r$: $0\le r<0.1727$ as another parameter. At the sensitivity analysis of the Nash equilibrium in these both ranges, while the NPV increases with the both values of parameters of volatility $\sigma$ and opportunity scale: WACC $r$ as Fig.7, both parameters have also a trade-off relationship. And within this range of both parameters, as a result, the NPV of Pareto optimum is always higher than the of Nash equilibrium as Fig.8.

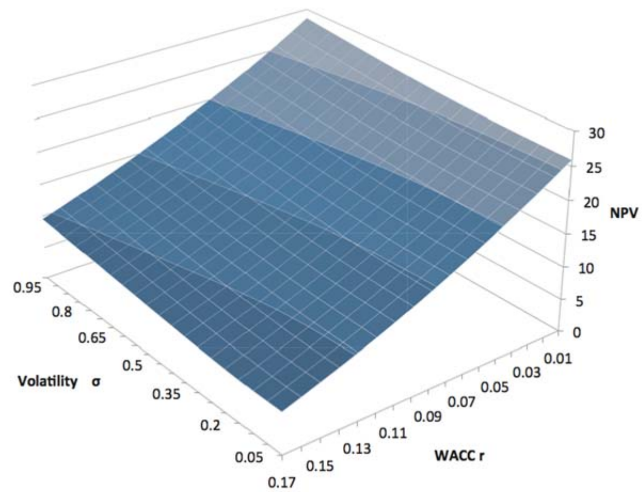


Fig.7 Sensitivity Analysis on Summed NPVs of Both Players in Nash Equilibrium

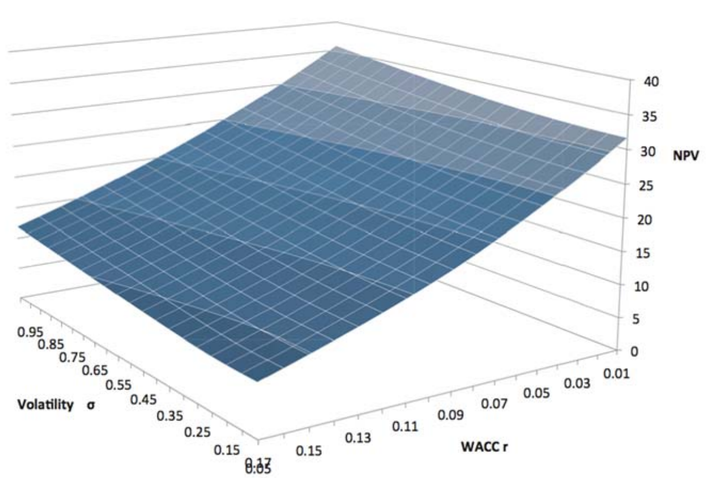


Fig.8 Sensitivity Analysis on Summed NPVs of Both Players in Pareto Optimum

Thus, by sensitivity analysis, the monopolistic and perfect competition models make clear the continual changing surface and each change rate as the slope of the NPV with parameter movement in 3 dimensional figures, and make easy strategic conception for investment decisions. Especially, in the Monopolistic model, we can observe the thresholds of starting increase of NPV with each shift of Time Horizon and Volatility as parameters. On the other hand, in the Perfect Competition model, this model is useful for a guideline of decision speed bipolarization against deterioration of NPV under uncertainty. And, in the Duopolistic model, these Nash equilibrium solutions lead confirmation of effective field boundary with parameter axes and make possible the field comparison between this Nash equilibrium and the Pareto optimum.

## V. CONCLUSION

NPV (Net Present Value) as an investment criterion has a disadvantage for business valuation, facing with a trade-off as rapid decision under uncertainty. While option theory is effective at this condition, real options approach is different from financial option theory in the limit of exclusiveness.

This paper examined the impacts of the uncertainty and competition on the invest timing. First of all, investment opportunity on monopoly is exclusive as same as financial option. Then you have to defer at unfavorable condition and immediately invest at favorable condition. On the other hand, the deferral in perfect competition means the deterioration of the expected returns from rival entrance. The lack of exclusiveness indeed cannot deny the incentive of more swift investment than the deterioration speed. But if it is impossible to avoid rival entrance leading to the accelerated deterioration on the dividend as an opportunity cost from deferring, the incentive of prudential investment increases after making sure the favorable condition under uncertainty. As the result, there is a possibility of a dichotomy as the rapid opportunity search with initial innovativeness or the prudential investment deferral until sure favorable condition.

Oligopoly is located in mid-range between monopoly and perfect competition. In symmetrical oligopoly under uncertainty, it is rational for both players to invest if business value is enough high, or for both to defer the investment if the value is low. However, if avoiding the excess competition and investing after coordinating both the roles between leader and follower and the redistribution of synergistic effect returns by social systematic innovation, the summation of both players' performance can improve.

And sensitivity analysis on the above three models can make clear robustness and sustainable field boundary of gained solutions. Additionally, three-dimensional figures in NPV and parameters are expected to make easy strategic decision.

Thus as social innovation, it is highly possible to develop the innovative drugs by Virtual Biotech Start-ups model, and to do neglected drugs by open-network model. That is, Virtual Biotech Start-up model needs strategic partnership for Pareto optimization for escaping from prisoners' dilemma due to excessive rivalry, with investment risk-hedge against uncertainty among relatively closed players rather than open source in oligopolistic market structure, to prevent deterioration of growth option. Thus, this paper contributes to explain the suitable innovation targets of each model as the open network or the closed Virtual Biotech Start-ups by using option-games analysis on irreversible investment under uncertainty and competition as the main implication.

However, it is still necessary to analyze the incentive of non-profit research and development investment by open source, virtual network, and PPP (Public Private Partnership). And measurement of practical parameter is also needed as future challenges.

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