Effects of the Anticommons on R&D: The Case of University Corporation in Japan

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Abstract

Patentability of basic research together with complementarity between basic research and commercialization development leads to the problem called "anti-commons" where assigning exclusive rights of a resource to more than one entity reduces usage of the resource. Transition from (not-for-profit) National University to (profit-seeking) University Corporation in Japan may actualize a nightmare of the anti-commons in product innovations of some fields such as biotechnology. This paper, using a two-stage patent race model, shows that we need more expenditure on basic research to compensate for negative effect of the anti-commons on R&D: as a consequence of the transition to University Corporation, (1) interim expected profits of firms evaluated at the beginning of the commercialization stage become less than half, (2) ex ante expected profits of firms evaluated at the beginning of the basic research stage decrease if total expenditures on basic research under National University is less than twice that under University Corporation, and (3) for social welfare to increase, total expenditure on basic research must increase in the case where consumer surplus is high relative to total revenue from patents and there is a small number of firms competing in the development stage.

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1 Introduction

Private ownership in resource implies that a person or agent is given both usage and exclusion rights. The conventional commons problem emerges as more than a single person or agent is assigned usage rights. When more than one person is assigned exclusion rights to a resource and these rights are simultaneously exercised, the resource is underutilized, in contrast to overutilization of resource in the conventional commons problem. In the shift from socialist to market institutions in Russia, several "de facto" owners of a building were allowed to exercise exclusion rights and to charge rents individually. One had to pay all the owners these rents, each of which may have been small but the sum of which was extremely high. As a result, no one was willing to rent a room so that the building was almost empty.[1] Heller (1998) calls this phenomenon "the tragedy of the anticommons". Buchanan & Yoon (2000), pointing out symmetric aspects between the conventional commons and the anticommons problems, present a formal model of "the tragedy of the anticommons".

A warning on the anticommons problem in R&D was made by Heller & Rosenburg (1998) and Shapiro (2001). When upstream and downstream technologies are complementary to each other to produce a new product and each technology is patentable and possessed by different parties, price of the new product becomes high and its consumption ends up being small. A typical case is a new drug that is produced based on knowledge of DNA sequences. A research company finds a fraction of DNA sequences and gets its patent, while a pharmaceutical company, using a finding of the DNA fraction, develops a new drug which is also patentable, but fails to capture all the revenue from the new product that the pharmaceutical company would earn if knowledge of DNA sequences is free of charge.[2] When basic research and development of a new product are technologically complementary to each other and both patentable, the anticommons problem arises and incentive to develop a new product deteriorates. Furthermore if many research companies get patents of many different parts of DNA sequences and new drugs are produced only based on more than one part of DNA sequences, the anticommons problem and its effect on incentive to develop new drugs will be more serious.

Although the anticommons problem reduces incentive to develop new products, it raises incentive to do basic research (and obtain its patent) compared with the case where basic research is public good, i.e., not patentable. As Heller & Rosenburg (1998, p. 700) point out, it has not been examined which effect of incentive dominates. This paper is the first attempt to analyze total effects of the anticommons on R&D in the context of the transition of National University to University Corporation in Japan.

The anticommons problem has never been a serious problem so far in Japan.

[1]There is an implicit assumption in this example: the building is only one available in a nearby area so that competition among buildings does not work.

[2]There is still a controversy about whether basic research should be patentable or not. However, the de fact trend is that patent claims of basic research such as findings of DNA sequences by many research firms have become their vested interests.

This is because National Universities[3], receiving more than three quarters of total fund devoted on basic research in Japan (Kneller (2003, p. 357)), has been and is the only entity capable of doing basic research and under severe regulations in Japan. Since researchers in National University are civil officials, they had been eventually prohibited from earning incomes by selling their (public funded) inventions until recently.[4] Firms engaged in developing new products were able to use results of basic research achieved by National University for free or at a small amount of donation paid to individual researchers for their inventions.[5] Results of basic research have been almost public goods in Japan. There has been no cause of the anticommons problem so far.

However, the situation is changing. National University is about to become one of Independent Administrative Entities, called University Corporation, in 2004. Each of University Corporation takes responsibility for its administration including financial accounts to some extent, while it is allowed to earn incomes from its inventions. Subsidy to each of University Corporation is no longer guaranteed. University Corporation is under strong pressure to manage efficiently and earn incomes from the outside. Actually the Ministry of Education[6] has encouraged universities to obtain patents of their inventions and engage in cooperative research activities with private firms through establishing Technology License Office for the past few years. The transition of National University to University Corporation implies that results of basic research will suddenly change from public goods to private goods and that the anticommons problem will emerge in the product innovation where basic research and development of new products are complementary.[7] This paper investigates effects of the transition of National University to University Corporation on social welfare and expected profits for firms engaged in product developments. Our conclusion is that expected profits and social welfare will decrease in the transition under the current situation. A decline in incentive to develop new products is so large that incentive for universities to do basic research must increase so much to dominate in total effects. This condition is not satisfied under the current situation, as discussed in the last section.

[3]In what follows, when I refer to National University, it includes government research institutes and some universities funded by municipal governments.

[4]See Kneller (2003) for tedious procedures for patents and other cooperative research activity with private companies.

[5]Donations to individual researchers of National University are exceptionally allowed in the regulation.

[6]We use this shorter name rather than the formal name, the Ministry of Education, Sports and Science.

[7]The reader might wonder why U.S. universities, which have been in a similar situation to University Corporation, have not brought about the anticommons problem. Jensen & Thursby (2001), based on a vast survey, point out that it is necessary to modify work of basic research in order for it to take a form of easy commercialization and that the modification is an obstacle to smooth transfer of basic research results. However, this argument does not apply to the recent case of new drugs based on knowledge of DNA sequences, where smooth transfer of basic research results eventually takes place. Furthermore, Jensen & Thursby (2001) seem to discuss *any* invention developed in university and are opaque about whether the invention is of basic research and whether there is technological complementarity between the invention and commercialization.

The model we present in this paper is similar to models of Aoki & Nagaoka (2002, 2003)). They concern how conditions of patentability such as utility standard affect incentive to innovate and social welfare. Their two-stage patent race models with free entry at each stage, trade secrecy, and fixed cost assume that firms can engage in patent races at both stages of basic research and commercialization development. On the other hand, our two-stage patent race model assumes that universities specialize in basic research and firms in commercialization (development) of new products, in which case we do not have to consider trade secrecy because it is better (or safer) to obtain patent of discovery rather than to keep it secret. We also assume a fixed number of firms and universities at each stage. Otherwise we will have zero (or reservation level) expected profit for all the parties involved, which seems implausible even if we take into account risk premium of R&D investment. Our model simplifies cost structure to the minimum: research intensity is regarded as expenditure on research so that there is no cost difference among the parties. We will discuss how robust our results are even in the case of different costs in the section of some extensions.

A new aspect of our model is to compare expected profits and social welfare under different systems, in one of which some parties (National University) do not seek profit. There are some researches on how differently non-profit organizations behave from profit-seeking organizations (James & Rose-Ackerman (1986), Rose-Ackerman (1996)). However, it is difficult to avoid a criticism that what is assumed as the objective function of non-profit organization in fact determines differences of behavior between non-profit and profit-seeking organizations. So we take a primitive treatment of behavior of National University: we assume intensity of (expenditure on) basic research at each of National University exogenously given. In spite of the primitive treatment, we can make some interesting comparisons, as we will show in the proceeding sections.

Strictly speaking, the anticommons problem presumes independent setting of patent fees rather than bargaining among patent holders. In our model, however, we assume that patent holders bargain for share of maximized revenue from a new product. This assumption not only simplifies our model but also mitigates effects of the anticommons at the development stage. Therefore our results would be strengthened if patent holders set patent fees independently as in the original anticommons problem.

With our model we show that (1) interim expected profits of firms evaluated at the beginning of the commercialization stage become less than half, that (2) ex ante expected profits of firms evaluated at the beginning of the basic research stage decrease if the ratio of total expenditures on basic research between before and after University Corporation is less than the ratio of interim expected profits between before and after University Corporation (which is less than one half), and that (3) for social welfare to increase, total expenditure on basic research must increase in the case where consumer surplus is high relative to total revenue from patents and there is a small number of firms competing in the development stage.

The structure of the paper is as follows. We develop a simple two-stage patent race model and compare expected profits under both university systems in the next section. In section 3, we construct iso-welfare contours and make a comparison of welfare under both university systems. All the proofs are in the Appendix. We discuss possible extensions of the simple model to capture more realistic circumstances in section 4. In the last section, we briefly discuss implications for the transition to University Corporation.

2 A Simple Two-Stage Patent Race Model

Let us consider a simple two-stage patent race model where upstream and downstream technologies of product innovation are complementary to each other. We assume that only universities specialize in basic research at the research stage and only private firms in commercialization at the development stage.[8] Both basic research and commercialization of product innovation are assumed patentable with infinite length. After basic research is finished, commercialization starts. There is no time lag between research finding and patent approval. There are m firms in the development stage and n universities in the research stage ($m \geq 1$ and $n \geq 1$). We assume in this section that a (cross) license contract is not allowed between a university and a firm, among firms and among universities.

We assume the Poisson discovery process for basic research and commercialization, respectively. We regard research intensity in the Poisson discovery process as research expenditure for simplicity.[9] Firms and universities are assumed to have symmetric constant marginal R&D costs with no fixed cost.

It is necessary and worthwhile to explain how this paper formulates behavior of university. In the case of University Corporation, we could treat University Corporation as if it maximized its "profit (revenue minus cost)" of its research activity. Since University Corporation will face budget cuts and have to earn their own "profits" or "incomes" to cross subsidize pure basic research such as philosophy and astronomy as well as overhead functions such as library, "profit" maximization is acceptable as behavior standard of University Corporation.

In the case of National University, there seems no consensus (no argument so far) on how economists should formulate the objective function of national university.[10] Even if we assume that national university behaves as if it maximized a particular objective function such as probability of research success subject to budget and other constraints, equilibrium variables of national university will not be far from those arbitrarily given, as long as the particular objective function is not convincing. Therefore we have no choice but to exogenously give particular values to variables

[8] To avoid complications, by abuse of name, I sometimes use "universities" rather than "university corporations" even when I refer to the case of university corporations.

[9] As we will see, as long as R&D costs are symmetric, it does not matter to distinguish research intensity from research expenditure.

[10] There are some analytical models of non-profit organization with explicit objective functions. See Estelle James & Susan Rose-Ackerman (1986) and Susan Rose-Ackerman (1996). However, they do not analyze (state-run) university explicitly as non-profit organization.

of national university in our model. Despite of the obstacle, we can make some comparisons of profits and social welfare, as we will see later.

Since our model is of two-stage, we will first analyze patent races in the development stage. Then we will examine the research stage given the equilibrium in the development stage. Finally in this section we will compare profits under University Corporation with those under National University.

2.1 The Development-Stage Patent Race

Let V be the total revenue evaluated at the time of successful commercialization of the product innovation in question. Under National University, a firm can receive all the total revenue, V, if it succeeds in commercialization, since universities publish and avail at free their research results without claiming patent rights. Thus the patent race in the development stage (after some university has succeeded in the basic research) under National University has the same structure as that of the typical patent race model.

Firm j maximizes the following expected profit with respect to its own research expenditure, y_{bj}, given other firms' research expenditures.

$$\frac{y_{bj}}{Y_b + r} V - y_{bj}$$

where $Y_b \equiv \sum_{j'=1}^{m} y_{bj'}$ and r is the interest rate. Suberscript, b, indicates "before" universities becoming Independent Administrative Entity (University Corporation). The first-order condition is given as follows. For $j = 1, 2, \cdots, m$,

$$V(\sum_{j' \neq j}^{m} y_{bj'} + r) = (\sum_{j'=1}^{m} y_{bj'} + r)^2.$$

Equilibrium is symmetric ($y_{bj} = y_b$ for $j = 1, 2, \cdots, m$) and characterized by the following equation of total expenditure, Y_b.

$$V\{(m-1)Y_b + mr\} = m(Y_b + r)^2, \tag{1}$$

$$Y_b = my_b. \tag{2}$$

Under University Corporation, both firm and university, having succeeded in R&D and obtained patents respectively, can eventually exercise exclusive rights to realization of revenue from the product innovation in question because of complementarity between basic research and commercialization development. The firm and university are in a position of bilateral monopoly after commercialization is finished and patented. Since expenditure on R&D becomes sunk cost at that time, the firm and university divide total revenue, V, equally between them. The amount of revenue a firm expects to receive if it succeeds is $V/2$. Given this difference, patent race is conducted in a similar fashion.

Firm j maximizes the following expected profit with respect to its own research expenditure, y_{aj}, given other firms' research expenditures.

$$\frac{y_{aj}}{Y_a + r}(V/2) - y_{aj}$$

where $Y_a \equiv \sum_{j'=1}^{m} y_{aj'}$. Suberscript, a, indicates "after" universities becoming Independent Administrative Entity (University Corporation). The first-order condition is given as follows. For $j = 1, 2, \cdots, m$,

$$(V/2)(\sum_{j' \neq j}^{m} y_{aj'} + r) = (\sum_{j'=1}^{m} y_{aj'} + r)^2.$$

Equilibrium is symmetric ($y_{aj} = y_a$ for $j = 1, 2, \cdots, m$) and characterized by the following equation of total expenditure, Y_a.

$$(V/2)\{(m-1)Y_a + mr\} = m(Y_a + r)^2, \tag{3}$$

$$Y_a = my_a. \tag{4}$$

2.2 The Research-Stage Patent Race

In the case of National University, we assume that expenditure on basic research at each university, x_{bi} for $i = 1, 2, \cdots, n$, is exogenously given. That is, $x_{bi} = \bar{x}_{bi}$ for $i = 1, 2, \cdots, n$ and total expenditure is denoted by $\bar{X}_b \equiv \sum_{i=1}^{n} \bar{x}_{bi}$.

In the case of University Corporation, each university maximizes its "profit" with respect to its expenditure on basic research, taking into account equilibrium of the patent race by firms in the commercialization stage. The expected revenue each university will receive at the time when it first succeeds is $V_u \equiv \frac{Y_a}{Y_a + r}(V/2)$. Given research expenditures by other universities, university i maximizes the following "profit" with respect to its expenditure on basic research, x_{ai}.

$$\frac{x_{ai}}{X_a + r}(V_u) - x_{ai}$$

where $X_a \equiv \sum_{i=1}^{n} x_{ai}$. The first-order condition is given as follows. For $i = 1, 2, \cdots, n$,

$$(V_u)(\sum_{i' \neq i}^{n} x_{ai'} + r) = (\sum_{i'=1}^{n} x_{ai'} + r)^2.$$

Equilibrium is symmetric ($x_{ai} = x_a$ for $i = 1, 2, \cdots, n$) and characterized by the following equation of total expenditure, X_a.

$$(V_u)\{(n-1)X_a + nr\} = n(X_a + r)^2, \tag{5}$$

$$X_a = nx_a. \tag{6}$$

2.3 Comparison of Expected Profits

Let us examine changes in profits of firms from National University to University Corporation. There are two kinds of expected profit to be examined in our model, depending on the time at which profits are evaluated. The first type is expected profit evaluated at the beginning of the development stage where some university has succeeded in basic research and its result has become available to firms. This type of profit may be called "interim" expected profit, based on prior information that basic research is successfully achieved. The second type is expected profit evaluated at the beginning of the research stage where universities start their research. This type of profit may be called "ex ante" expected profit, based on no information revealed. We will examine how these two types of expected profit change when National University moves to University Corporation.

We denote equilibrium interim expected profit of firm j under National University by π_b. (We drop a subscript j because of symmetry.) Similarly, we equilibrium interim expected profit of firm j under University Corporation by π_a.

$$\pi_b \equiv \frac{y_b^*(V)}{Y_b^*(V) + r} V - y_b^*(V) = P(V),$$

$$\pi_a \equiv \frac{y_a^*(V/2)}{Y_a^*(V/2) + r} (V/2) - y_a^*(V/2) = P(V/2).$$

where asterisk (*) indicates equilibrium variables. Both interim expected profits are represented by the form of indirect profit function $P(V)$ and $P(V/2)$ respectively.

In what follows, we make an assumption that V is greater than a certain positive level, to guarantee positive equilibrium total expenditure for any case.[11]

Assumption 1

$$V > 2r(\frac{Y_a^* + r}{Y_a^*}).$$

[11] Assumption 1 implies that expected revenue of R&D for "industry" as a whole is greater than twice the interest rate. This condition seems plausible.

By analyzing indirect profit functions we have the following proposition.

Proposition 1

$$\pi_a = P(V/2) < \{\frac{(1/2) - (r/V)}{1 - (r/V)}\}\pi_b = \{\frac{(1/2) - (r/V)}{1 - (r/V)}\}P(V).$$

Corollary 1

$$\pi_a = P(V/2) < \frac{1}{2}\pi_b = \frac{1}{2}P(V).$$

Proposition 1 and Corollary 1 show how much the anti-commons effect reduces interim expected profits of firms engaged in commercialization development. Interim expected profits become less than half as a result of the transition to University Corporation. Under University Corporation, if a firm succeeds in commercialization, it gets one-half of the total revenue that it would get under National University. This reduction of expected revenue holds for any level of research expenditure. It will suffice to reduce research expenditure to one-half in order to keep expected profit one-half, if the expected revenue does not depend on research expenditure. However, the reduced revenue lowers commercialization investments by firms, which delays success of commercialization on average. This further reduces expected revenue for firms. This causes expected profit to decrease more than proportionally. Mathematically this logic is reflected in convexity of profit function, $P(T)$, in the proof.

It is a little harder to examine ex ante expected profits. Ex ante expected profits are defined as interim expected profits multiplied by total probability of success in basic research. In the case of National University, ex ante expected profit, Π_b, is

$$\Pi_b \equiv \pi_b\{\frac{\bar{X}_b}{\bar{X}_b + r}\} = P(V)\{\frac{\bar{X}_b}{\bar{X}_b + r}\}.$$

Similarly, in the case of University Corporation, ex ante expected profit, Π_a, is

$$\Pi_a \equiv \pi_a\{\frac{X_a}{X_a + r}\} = P(V/2)\{\frac{X_a}{X_a + r}\}.$$

where X_a satisfies Equation (5).

Let v be the ratio of interim expected profit under University Corporation to that under National University. We define by μ the ratio of total expenditure on basic research under University Corporation to that under National University such that ex ante expected profits under both university systems are equal to each other. Then we have the following proposition.

Proposition 2

Let $v \equiv \pi_a/\pi_b = P(V/2)/P(V)$.

(1) In the case where $v/(1-v) \leq \bar{X}_b/r$, $\Pi_b > \Pi_a$.

(2) In the case where $v/(1-v) > \bar{X}_b/r$, $\Pi_b > \Pi_a$ if and only if

$X_a < \mu\bar{X}_b$, where $\mu \equiv 1/\{v-(1-v)(\bar{X}_b/r)\} = (1/v) + \{(1-v)/v\}(X_a/r)$.

Corollary 2

In the case where $v/(1-v) > \bar{X}_b/r$, $\Pi_b > \Pi_a$ if $X_a \leq (1/v)\bar{X}_b$.

Part (1) of Proposition 1 shows that when total expenditure on basic research under National University is larger than the threshold level ($rv/(1-v) \leq \bar{X}_b$), ex ante expected profit under National University is higher than that under University Corporation without any further conditions. In this case, total expenditure on basic research under National University has reached such a level that basic research is sufficiently encouraged. Thus there is no room for increasing total basic research expenditure and thus probability of success at the basic research stage in order to offset the decline in interim expected profits. In this case, we can say that ex ante expected profits will decrease by transition from National University to University Corporation.

However, this case is not plausible, since the condition for this case implies that "the adjusted probability" that at least one university succeeds in basic research is more than one-half under National University, since $1 < v/(1-v) \leq \bar{X}_b/r$ means that $\bar{X}_b/(\bar{X}_b + r) > 1/2$.

Part (2) of Proposition 2 and Corollary 2 characterize the remaining case. By μ we denote the critical ratio of total expenditure on basic research under University Corporation to that under National University at which ex ante expected profits under both systems are equal to each other. When total expenditure on basic research under National University is smaller than the threshold level, it requires a large increase in total research expenditure at the basic research stage to cancel out the decline of interim expected profits in the transition from National University to University Corporation. Since $v < 1/2$ from Corollary 1, it follows from Corollary 2 that total research expenditure at the basic research stage under University Corporation must be more than twice as large as that under National University in order to keep unchanged ex ante expected profits of firms engaged in commercialization. This result reflects the fact that we need a large increase in total basic research expenditure to compensate for the reduction of interim expected profits.[12]

2.4 Simulation of the Critical Ratio

It is worthwhile to examine exact values of μ for some plausible parameters by simulation. We need to know exactly how large total expenditure on basic research under University Corporation must be compared with that under National University when we make a policy recommendation. We choose the equation $\mu = (1/v) + \{(1-v)/v\}(X_a/r)$ for simulation since we want to limit parameterized variables to the original parameters. We first solve two endogenous variables v and X_a with respect to parameters V, m, n, and r.

Lemma 1

(1) $X_a = (1/2n)[-\{2nr - (n-1)V_u\} + \sqrt{4rnV_u + (n-1)^2 V_u^2}]$

where

$V_u = (V/2)[(1/2m)\{-(2rm - (m-1)(V/2))$

$+\sqrt{2rmV + (m-1)^2(V^2/4)}\}\{((m-1)V/4m) + (1/2m)\sqrt{2rmV + (m-1)^2(V^2/4)}\}^{-1}]$.

(2) $v = (1/2)(p_a/p_b)^2$

where

$$p_a = y_a/(my_a + r), \quad p_b = y_b/(my_b + r),$$

where

$$y_a = (1/2m^2)\{-(2mr - (V/2)(m-1)) + \sqrt{2mrV + (m-1)^2V^2/4}\},$$

$$y_b = (1/2m^2)\{-(2mr - V(m-1)) + \sqrt{4mrV + (m-1)^2V^2}\}.$$

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[12]Mathematically speaking, the reduced form of interim profit is convex in its argument (V or $V/2$), while the "adjusted probability" of success at the basic research stage is a concave function of total research expenditure ($\bar{X}_b$ or X_a). Since ex ante expected profit is the product of the interim expected profit and the "adjusted probability" of success in basic research, total research expenditure in basic research must increase more than the inverse of the reduction ratio of total revenue (V) in order to make ex ante expected profit unchanged.

The following results of comparative statics will reduce the number of the cases we have to examine.

Lemma 2

(1) $\partial X_a/\partial V > 0, \quad \partial X_a/\partial n > 0, \quad \partial X_a/\partial m > 0, \quad$ for $m \geq 2 \;\; \partial v/\partial m < 0,$

(2) $\partial \mu/\partial n > 0, \quad$ for $m \geq 2 \;\; \partial \mu/\partial m > 0,$

(3) $\lim_{V\to\infty} X_a = \infty, \quad \lim_{V\to\infty} \mu = \infty.$

Part (1) of lemma 2 means that (a) the larger the total revenue from product innovation, the larger the equilibrium total expenditure on basic research, that (b) the larger number of university (firm), the more intensive R&D competition and the larger the equilibrium total expenditure on basic research, and that (c) the larger the number of firm, the more intensive R&D competition (except for monopoly) amplifies the negative effect on interim expected profits. Part (2) is derived from Part (1). The larger the number of university, the larger the equilibrium total expenditure on basic research and the larger the critical value. The larger the number of firm, the larger the equilibrium total expenditure on basic research (except for monopoly) and the larger the critical value. Part (3) is about limit values. As the total revenue from product innovation becomes infinity, the equilibrium total expenditure on basic research approaches infinity. As a result, the critical value goes to infinity.

It follows from Lemma 2 that we can concentrate our simulation on the cases where $n = 1$ and $m = 1, 2$, since we are interested in the possible minimum value of the critical ratio, μ. Lemma 2 also shows that we do not have to examine the critical ratio for large values of V. We set r at $0.1, 0.2, 0.3$ taking account of risk premium of R & D innovations. We simulate the critical ratio μ over the range from $V = 2r$ to $V = 10$.[13] [14]

The simulation results are shown in Figure 1. (Figure 1 is omitted in this version.) In all the cases, the minimum value of the critical ratio is around 4. This means that total expenditure on basic research under University Corporation must be *at least* more than four times as high as that under National University in order to keep ex ante expected profits of firms increasing after the transition. From these simulation results, we can say that we will have to increase total expenditure on basic research more than several times in the transition from National University to

[13] Assumption 1 restricts V to higher values than a certain endogenous level, which is strictly larger than $2r$. The broader range of V does not increase the minimum value of μ we look for.

[14] Since μ is decreasing in v, $\mu > 2 + (X_a/r)$. If $n = 1, m = 1$ and $V = 32r$, then $X_a = (2\sqrt{3} - 1)r \simeq 2.46r$. Taking into account $\partial X_a/\partial V > 0$ and $V = 32r = 9.6$ for $r = 0.3$, movement of the above lower bound of μ is dominated by movement of X_a for $V > 10$.

University Corporation to compensate firms engaged in commercialization developments for the reduction of their interim expected profits due to the "anti-commons" effect.

3 Social Welfare

It is natural to ask effects of the transition from National University to University Corporation on social welfare (as long as we are concerned with product innovation). In this section, we will introduce iso-welfare contours to analyze welfare changes associated with the transition.

3.1 Iso-Welfare Contours

Let us define social welfare as the sum of expected consumer surplus and producer surplus accruing from the product innovation. We do not include any value from academic achievements in university research, though expenditure on basic research is regarded as (opportunity) cost whether universities earn revenue from their basic research or not. The social welfare thus defined, S, is generally expressed in terms of the "adjusted probability" of success at both stages, total revenue, V, and consumer surplus from the new product, C, as follows.

$$S(X,Y) \equiv \{X/(X+r)\}[\{Y/(Y+r)\}(C+V)-Y]-X,$$

where X is total expenditure on basic research, Y is total expenditure on development, and r is interest rate.[15]

From the above equation of social welfare, we can calculate the slope of iso-welfare contours.

$$\partial Y/\partial X$$

$$= -[\{r/(X+r)^2\}\{(Y/(Y+r))(C+V)-Y\}-1]/[\{X/(X+r)\}\{(r/(Y+r)^2)(C+V)-1\}].$$

Let

$$\hat{Y} \equiv argmax_{\ Y}\ \{Y/(Y+r)\}(C+V)-Y$$

and

$$\hat{X}(Y) \equiv argmax_{\ X}\ \{X/(X+r)\}[\{Y/(Y+r)\}(C+V)-Y]-X.$$

When we define $\hat{X}(Y)$, we assume that

$$\{Y/(Y+r)\}(C+V)-Y>0.$$

[15]Here we drop subscripts, a and b, because functional forms of social welfare are the same for both systems of university.

This condition seems to hold for relevant values of Y since

$$\{Y_b/(Y_b+r)\}(C+V)-Y_b > \{Y_b/(Y_b+r)\}V-Y_b = m\{(y_b/(Y_b+r))V-y_b\}.$$

The right-hand side is positive because inside of the parentheses is equilibrium interim expected profit of individual (and symmetric) firms. Similarly for the case of University Corporation.

Note that $\hat{Y}$ and $\hat{X}(Y)$ satisfy

$$(r/(\hat{Y}+r)^2)(C+V)-1=0$$

and

$$\{r/(\hat{X}+r)^2\}\{(Y/(Y+r))(C+V)-Y\}-1=0,$$

respectively. From concavity of the maximand, note also that

$$\{(r/(Y+r)^2)(C+V)-1\} > (<) \;\; 0 \;\; \text{if} \;\; Y < (>) \;\; \hat{Y},$$

$$\{r/(X+r)^2\}\{(Y/(Y+r))(C+V)-Y\}-1 > (<) \;\; 0 \;\; \text{if} \;\; X > (<) \;\; \hat{X}(Y).$$

It is easy to see that $\hat{X}(Y)$ is increasing in Y if $Y < \hat{Y}$ and decreasing in Y if $Y > \hat{Y}$ by calculating the slope of $\hat{X}(Y)$. For later convenience of drawing iso-welfare contours, we also show the slope of the inverse function:

$$\partial Y/\partial \hat{X} = 2[\{Y/(Y+r)\}(C+V)-Y]/[\{r/(Y+r)^2\}(C+V)-1].$$

Having clarified these properties, we can draw iso-welfare contours in the space of total expenditure at the basic research stage, X, and total expenditure at the commercialization development stage, Y. Figure 2 shows a typical iso-welfare contour. The space is segmented into four areas by $Y=\hat{Y}$ and $X=\hat{X}(Y)$. The iso-welfare contour has a positive slope in the North-West and South-East areas where the numerator and the denominator of the slope equation have the same sign, a negative slope in the North-East and South-West areas where the numerator and the denominator of the slope equation have different signs. It follows from the definition of $\hat{Y}$ and $\hat{X}(Y)$ that social welfare is maximized at $(\hat{X}(\hat{Y}),\, \hat{Y})$, which may be called social optimal pair of research expenditures. The closer a contour is to the social optimal pair, the higher its associated social welfare is.[16]

[16]The easier construction of iso-welfare contours is as follows. The pair $(\hat{X}(\hat{Y}),\hat{Y})$ is the social optimum. As Y deviates from $\hat{Y}$, expected social welfare on condition that basic research has succeeded declines and optimal total expenditure on basic research, $\hat{X}(Y)$, also decline. This explains the shape of $\hat{X}(Y)$. Iso-welfare contours cut across vertically at $\hat{Y}$ and horizontally at $\hat{X}(Y)$. Together with convexity of contours, we have circle-type contours.

3.2 Comparison of Welfare

Now that we have developed iso-welfare contours in the space of total expenditures at both stages, we will examine social welfare changes in the transition from National University to University Corporation. It is rather tedious and without clear results to examine all possibilities (all positions of expenditure pairs) since total expenditure on basic research under National University is treated as given as a parameter in our model. Thus we limit the analysis to the segmented areas below the $Y = \hat{Y}$ line, which is likely to correspond to the cases of product innovation such as biomedical R & D, as we will see later.

Before we move on to the analysis, we make sure relative magnitudes of $\hat{Y}$, Y_b, and Y_a.

Lemma 3

(1) $Y_b > Y_a$.

(2) $\hat{Y} > Y_b$ if $m = 1$.

(3) Suppose that $C < \{(V/r) - 1\}V$. Then there exists $m^*(2 \leq m^* < \infty)$ such that $\hat{Y} \leq Y_b$ for all $m \geq m^*$, while that $\hat{Y} > Y_b$ for all $m < m^*$.

(4) $\hat{Y} > Y_b$ if $C \geq \{(V/r) - 1\}\{(m-1)/m\}V$.

Lemma 3 shows that total expenditure on commercialization development under University Corporation is always smaller than that under National University. This is a consequence of the "anti-commons" effect that reduces the revenue a successful firm can appropriate. Lemma 3 also shows that total expenditures on commercialization development never exceed the social optimal level, $\hat{Y}$, if consumer surplus is large relative to the total revenue from the product innovation (the larger the consumer surplus, the larger the $\hat{Y}$) and the number of firms at the development stage is small (which mitigates intensive patent race and lower total expenditure on R&D). These conditions seem to be satisfied in the case of biomedical innovation. Demand for new and effective drug is inelastic so that consumer surplus is large relative to monopoly profit from the drug.[17] There are a limited number of pharmaceutical companies worldwide that can develop new drugs based on new discovery of biotechnology. It is safe to focus on the cases where both expenditure levels at the development stage are less than the social optimum as long as we are interested in the typical case such as biomedical innovation that attracts attention.

With iso-welfare contours and relative magnitudes of expenditures on commer-

[17] It is not difficult to show that the ratio of consumer surplus to monopoly profit converges to infinity as demand elasticity approaches unity under the assumptions of constant elasticity of demand and constant marginal cost.

cialization developments, we can show the range of total expenditure on basic research under University Corporation in order to increase social welfare in the transition. Let X_b^* and X_b^{**} be X_b such that $S(X_b, Y_b) = S(X_a, Y_a)$ and $X_b^* < X_b^{**}$. These total expenditures on basic research, given equilibrium total expenditure on commercialization, guarantee the same level of social welfare as that under University Corporation. It is easy to prove the following proposition and corollary from Figure 2.

Proposition 3

$S(X_a, Y_a) > S(\bar{X}_b, Y_b)$ if and only if $\bar{X}_b \notin [X_b^*, X_b^{**}]$.

Corollary 3

Suppose that $\hat{Y} \geq Y_b$. Then $S(X_a, Y_a) > S(\bar{X}_b, Y_b)$ if and only if either $\bar{X}_b \leq X_b^* < X_a$ or $X_a < X_b^{**} \leq \bar{X}_b$.

Corollary 3 implies that social welfare will increase in the transition if total expenditure on basic research under National University is either too small ($\bar{X}_b < X_b^*$) or too large ($\bar{X}_b > X_b^{**}$). In the former case, total expenditure on basic research must increase in order to raise social welfare in the transition from National University to University Corporation. Anti-commons effect reduces equilibrium total expenditure on commercialization development so much that we need more expenditure on basic research to compensate for the decline of welfare. This mechanism is reinforced in the case of a small number of firms in the development stage, where patent race does not accelerate total expenditure so much. The effect of anti-commons on social welfare is amplified when consumer surplus is large compared with total revenue from innovation.

In the latter case where total expenditure on basic research under National University is too large, expenditure on basic research is larger than the social optimum given equilibrium total expenditure on commercialization, $\hat{X}(Y_b)$. Transition to University Corporation in this case reduces incentive to innovate for both firms and universities and thus (equilibrium) total expenditure on basic research. This change trims waste of basic research expenditure, though ex ante expected profits of firms decline (due to Proposition 2).

Theoretically there are two possible cases discussed above. To my knowledge, however, no one has proposed that success in basic research should be less probable, or that the "adjusted probability" or equivalently total expenditure on basic research should be smaller. It is safe to say that the current level of basic research expenditure under National University is *not* in the East area of Figure 2. With this qualification, we can say that total expenditure on basic research must increase in order to improve social welfare in the transition from National University to University Corporation.

We will discuss implications of these results for the transition to University Corporation in Section 5.

4 Some Extensions

We have considered so far a simple case of two-stage patent race with complementarity between upstream and downstream technologies. In what follows in this section, we will examine how more realistic assumptions might affect our results in the previous section.

4.1 Asymmetric Costs of R&D

We have so far assumed that expenditure on R&D is equal to research intensity. This assumption also implies no cost difference in R&D among firms and universities. A natural extension is to assume that expenditure on R&D is proportional to R&D intensity, say $c_j(y_j) = c_j y_j$ for firm j and $c_i(x_i) = c_i x_i$ for university i, where y_j and x_i are now interpreted as intensity of R&D, while c_j and c_i are constants. Since equilibrium profits (both interim and ex ante) are continuous in cost parameters, slight perturbation of these parameters from $c_j = 1$ for all j and $c_i = 1$ for all i induces only slight changes in equilibrium profits. The same is true for (equilibrium) total intensity of R&D, which is approximately equal to total expenditure. Thus our results are not non-generic.[18]

When cost differences among firms are not negligible, it is easy to see that the lower cost, the higher intensity and the larger interim expected profit for a firm. We may expect that interim expected profits become less than half by the transition to University Corporation under different costs.[19] When costs are different among universities (with no cost difference among firms), our results on ex ante expected profits hold by replacing "total expenditure" with "total intensity". Equilibrium condition for basic research intensity under University Corporation is rewritten as follows. For all i,

$$V_u(\sum_{i' \neq i}^{n} x_{ai'} + r) = c_i(\sum_{i'=1}^{n} x_{ai'} + r)^2.$$

Summing the above equation over all i, we get

$$V_u\{(n-1)X_a + nr\} = (X_a + r)^2(\sum_{i=1}^{n} c_i),$$

[18] It holds for more general cost functions that our results are generic.

[19] We have to quickly add a qualification that neither firm nor university exits from patent races. This qualification imposes restriction on the diversity of cost difference we have to consider.

where X_a is total intensity of basic research, $X_a = \sum_{i=1}^{n} x_{ai}$. If we normalize arithmetic average of marginal cost as unity, $\sum_{i=1}^{n} c_i/n = 1$, the above equation turns out the same as Equation (5). Since we assume x_{bi} as given, total intensity under National University, X_b, is also given. Proposition 2 and Corollary 2 hold in terms of "total intensity" instead of "total expenditure".

However, we can rewrite these results in terms of total expenditure. Let E_b and E_a be total expenditures on basic research under National University and University Corporation, respectively. By definition, we have $\bar{E}_b = \sum_{i=1}^{n} c_i x_{bi}, E_a = \sum_{i=1}^{n} c_i x_{ai}, \bar{E}_b \leq c_H X_b, E_a \geq c_L X_a$, where c_H and c_L are the highest and lowest marginal costs, respectively.[20] Proposition 2 and Corollary 2 should be read as "$\Pi_b > \Pi_a$ if $E_a < \mu(c_L/c_H)\bar{E}_b$ and "$\Pi_b > \Pi_a$ if $E_a < (1/v)(c_L/c_H)\bar{E}_b$, respectively. Since our simulation shows that the minimum value of μ is around 4, for moderate cost differences such as $c_L/c_H = 1/2$ we can say that we need more expenditure on basic research under University Corporation than under National University in order to increase ex ante profits.

Our analysis on welfare (Proposition 3) also should be interpreted in terms of "total intensity".

4.2 Budget Constraints under University Corporation

We have assumed that University Corporation behaves as if it maximized its own "profit (revenue minus cost)". Though each university corporation is to have some discretion to earn its own incomes through patent fees and other businesses, the Ministry of Education is to disburse most of expenses as subsidy. Furthermore no measure to finance long-run risky projects is available to University Corporation. This suggests that University Corporation will be still subject to its own budget constraint and never achieve its optimal level of research intensity as an inner solution. Even in this case, our results hold except for those based on simulations, as shown below.

Since research expenditures are strategic substitutes in our model, every university faces the same constraint due to symmetry.[21] In that case, total expenditure on basic research should be interpreted as given. All propositions and corollaries are still valid, though the results based on simulations are not. This is because we eventually treat X_a parametrically in all propositions and corollaries other than in simulations.

[20] What is given under National University is allocation of expenditure to each university. Research intensity at each university is determined by allotted expenditure and marginal cost.

[21] Even under asymmetric costs, strategic substitutes imply that if one university has a corner solution due to budget constraint, other universities are likely to have their corner solutions.

4.3 Ex ante Agreements

We have assumed no ex ante agreements between a university and a firm. It is well known that ex ante agreements are sometimes crucial to incentive for innovation.[22] In this subsection we will examine how ex ante agreements affect interim and ex ante expected profits.[23]

Since we focus on product innovations, it is always better for a patent holder firm to exclusively use the patent and earn monopoly profit.[24] In other words, there is no incentive for a patent holder to license its invention to other firms or universities. Thus it is safe to limit the analysis to the cases where ex ante agreement is concluded between a firm and a university. There are two possible cases of ex ante agreements between a firm and a university. One is an ex ante agreement after a university has succeeded in basic research of the new product in question. The other is an ex ante agreement before no university has started basic research.

When a successful university with patent of its basic research offers firms an ex ante agreement, the university is eventually a monopoly to these firms.[25] It can realize not only the first-best outcome (for the university and a contracting firm) but also extracting all profits accruing from the new product by making an offer of "take a contingent contract or leave it" to all competing firms[26] and concluding the contract with one (the lowest cost) firm exclusively. Thus the firm will get zero expected profit at the beginning of the development stage, while other firms have zero profit at all. The transition to University Corporation together with an ex ante agreement at the beginning of the development stage will deprive firms of profit opportunity from product innovation.[27]

The analysis in the previous paragraph assumes that contractual agreements are enforceable whatever happens in the future. This assumption seems implausible. Suppose that a third party succeeded in commercialization for the first place and obtained its patent. Then the university with basic research patent will have to lose huge profit as long as it keeps the contractual agreement that it never allows other firms to use its patent of basic research. The university has strong incentive to breach the agreement and share patent revenue from a new product with the third party. Consequently after a university succeeds in basic research, all other firms will actually engage in a patent race in commercialization. Subgame perfect

[22] Following Green & Scotchmer (1995), by "ex ante" I mean before investment cost is sunk either at the research or development stage.

[23] We will not examine cooperative joint R&D activity through ex ante agreements. We will not consider social welfare either. This is because, in analyzing social welfare, we need explicit divisions of profit between firms and universities, which is difficult to get in a general setting.

[24] We exclude from the analysis an equivalent case where a patent holder firm lets another firm to exclusively use the patent and earns monopoly profit as (two-part tariff) patent fee.

[25] When there is only one firm capable developing a new product, bilateral monopoly emerges and the analysis is the same as one in the preceding sections.

[26] In other words, by auctioning a right to use exclusively patent of basic research with contingent fees based on when a contracting firm succeeds in commercialization.

[27] In this case we have a clear conclusion on social welfare. Since a successful university can control an innovation process of the development stage, the model is eventually reduced to the one-stage patent race. Welfare analysis is also the same as that on the one-stage patent race.

equilibrium outcome is likely to be realized in spite of ex ante agreement.[28] Thus ex ante agreements do not seem to appear in the case of product innovation with supplementary technologies.

When ex ante agreements are allowed before no university has started basic research, any division of profit between firms and universities can take place, depending on balance of bargaining power among parties, as long as contractual agreements are enforceable.[29] This is because reservation profits (or threat-point profits) for all parties are zero. This result might be general, but as we discussed in the previous paragraph, ex ante agreements do not seem to appear even in this case.

All in all, possibility of ex ante agreements does not affect our analysis in the preceding sections.

4.4 Multiple Patent Holders and Multiple Applications of Basic Research

When there is more than one patent holder of basic research, interim expected profits decline further and more total expenditure on basic research is necessary to compensate for the reduction of interim expected profits and keep ex ante profits non-decreasing.[30] Multiple patent holders reinforce the effect of transition to University Corporation on welfare, requiring more total expenditure on basic research in order to increase welfare in the transition. This is exactly a nightmare called "patent thicket" (Shapiro (2001)).

When basic research is applied to many different developments of new products, anti-commons effect is mitigated on ex ante expected profits and social welfare. Since University Corporations expect to receive patent revenue of basic research from more than one commercialization based on an application of the basic research, equilibrium intensity of (or expenditure on) basic research is higher than in the case of only one commercialization. If there is enough number of expected applications of basic research to new products relative to the number of expected patent holders of basic research used for these new products, total intensity of (or expenditure on) the basic research under University Corporation will be high enough to compensate

[28] When revenue from a new product is small, in addition to the subgame perfect equilibrium analyzed in the previous sections, there is another subgame perfect equilibrium in which a contracting firm with the university with basic research patent chooses the monopoly level of research intensity while other firms choose zero research intensity. Economic logic behind this case is as follows. Since the revenue from a product innovation is small, patent race is *not* profitable for firms if more than one firm is involved, but profitable for monopoly. Furthermore the ex ante agreement can signal to other firms the commitment the contracting firm made. Therefore other firms will be eventually in a position of followers and give up patent race.

[29] This is true if there is more than one party in both stages. If there is only one party in one of the two stages, market force gives the party in a monopoly position all the surplus.

[30] As the number of patent holders increases, the parties are likely to set their patent fees independently rather than bargain for division of maximized revenue from the new product. In this case, as Buchanan & Yoon (2000) and Shapiro (2001) show, the revenue each party could get is smaller than under bargaining, which exacerbates anti-commons effects.

for the reduced level of development activity.[31]

Although the number of possible applications of basic research may be determined technologically, the number of expected patent holders of basic research is determined by strategic behavior of University Corporations. Many research companies compete in finding a fraction of DNA sequences and registering it as patent in the U.S. and Europe. So will University Corporations in Japan. It is safe to say that we face a danger that expected profits and social welfare will decline in the transition to University Corporation unless a massive increase in total expenditure on basic research is accompanied.

5 Concluding Remarks

We have shown how expected profits and social welfare from new products would decrease in the transition from National University to University Corporation unless total expenditure on (intensity of) basic research increased under the latter system. This conclusion results from the fact that multiple patent holders reduce more incentive for firms to innovate by sharing revenue from innovation than increase incentive for University Corporations to innovate.

Let us conclude by discussing implications for the transition to University Corporation. Given the fact that basic research is patentable, the transition to University Corporation will deteriorate not only profit opportunity of firms developing new products but also social welfare under the current situation briefed below. In other words, we surely expect that total intensity of basic research will not increase enough under University Corporation so as to offset the anti-commons effect on the development stage. In order to apply our propositions, we will first make sure the current situation on cost differences of research intensity among universities, plausibility of budget constraints and changes in total research intensity.

We do not know exactly how different costs of basic research are among universities. However, diversity of costs is limited by the participation constraint: university corporations with negative expected "profits" due to high costs exits from patent races. Thus it is safe to assume that cost differences are moderate. University Corporations will be subject to budget constraint because they cannot finance long-run risky projects and it will take universities a long time to accumulate internal retention. The National Budget Plan for 2004 fiscal year indicates that total subsidy to University Corporation will be reduced by one percent every year. Although a new research fund ("Center of Excellence Program") concentrates on several "promising" universities, its amount is much smaller than the one percent reduction of total subsidy.[32] This implies that total intensity of basic research will not likely increase

[31]This is true unless "patent thicket" makes firms give up developments of new products and government encourages basic research because of its externality under National University.

[32]According to Homepage of the Ministry of Education (www.mext.go.jp), the total amount of "Center of Excellence Program" in 2003 is 15.8 billion yen, while 1 % of total subsidy to University

enough to offset the anti-commons effect on the commercialization stage.

Having discussed that the current situation satisfies the conditions for our conclusion, we can say that University Corporation is worse than National University for the firms engaged in developing new products and society as a whole *even if we limit our attention to purely economic benefits.* I think that it is at least worthwhile to reconsider the system of University Corporation from the viewpoint of the anti-commons effect on R&D.

Corporation in the 2004 budget plan is 144.7 billion yen.

Appendix

Proof of Proposition 1

Let $P(T) \equiv \frac{z(T)}{Z(T)+r}T - z(T)$ where $z(T)$ and $Z(T)$ satisfy

$$T\{(m-1)Z(T) + mr\} = m(Z(T)+r)^2, \tag{7}$$

$$Z(T) = mz(T). \tag{8}$$

Then $P(V) = \pi_b$ and $P(V/2) = \pi_a$. Since $Z(r) = z(r) = 0$, $P(r) = 0$. We will show that $P(T)$ is increasing and convex in T.

$$P^{'}(T) = \frac{z}{mz+r} + \{Tr/(mz+r)^2 - 1\}(\partial z/\partial T). \tag{9}$$

Substituting (8) into (7), totally differentiating (7) with respect to z and T, we have

$$\partial z/\partial T = \frac{(m-1)z + r}{2m(mz+r) - T(m-1)}.$$

Substituting (7) into the right-hand side of the above equation to eliminate T and rearranging, we get

$$\partial z/\partial T = \{(m-1)z + r\}^2[(mz+r)\{m(m-1)z + (m+1)r\}]^{-1} > 0.$$

Substituting the above into (9) and eliminating T by using (7), and rearranging, we have

$$P^{'}(T) = [(mz+r)\{m(m-1)z + (m+1)r\}]^{-1}z\{(m-1)z + 2r\} > 0.$$

Differentiating the above equation with respect to T and rearranging, we get

$$P^{''}(T) = [(mz+r)\{m(m-1)z + (m+1)r\}]^{-2}2\{(m-1)z + r\}(m+1)r^2(\partial z/\partial T).$$

Since $\partial z/\partial T > 0$, $P^{''}(T) > 0$. Thus $P(T)$ is increasing and convex in T.

From convexity of $P(T)$ and $P(r) = 0$, we have

$$\frac{P(V/2)}{P(V)} < \frac{(V/2) - r}{V - r}.$$

The left-hand side is equal to $\frac{\pi_a}{\pi_b}$, while the right-hand side is equal to $\frac{(1/2)-(r/V)}{1-(r/V)}$. Q.E.D.

Proof of Corollary 1

$\frac{(1/2)-(r/V)}{1-(r/V)}$ is decreasing in (r/V) and converges to $1/2$ as (r/V) approaches zero. Then Corollary 1 follows from Proposition 1. Q.E.D.

Proof of Proposition 2

$\Pi_b > \Pi_a \Leftrightarrow \frac{\bar{X}_b}{\bar{X}_b+r}/\frac{X_a}{X_a+r} > v$. Let $\mu \equiv X_a/\bar{X}_b$ such that $\frac{\bar{X}_b}{\bar{X}_b+r}/\frac{X_a}{X_a+r} = v$. Then $\Pi_b > \Pi_a \Leftrightarrow X_a < \mu\bar{X}_b$. Substituting $\mu \equiv X_a/\bar{X}_b$ to eliminate X_a and solving for μ, we get

$$\mu = 1/\{v - (1-v)(\bar{X}_b/r)\}.$$

The denominator must be positive since both X_a and $\bar{X}_b$ are positive. Thus Statement (2) in Proposition 2 holds if $v-(1-v)(\bar{X}_b/r) > 0$. Otherwise $\pi_b\{\frac{\bar{X}_b}{\bar{X}_b+r}\} \geq \pi_a$. This means $\Pi_b > \Pi_a$. This proves Statement (1) in Proposition 2.

If we eliminate $\bar{X}_b$ in solving for μ, we get

$$\mu = (1/v) + \{(1-v)/v\}(X_a/r).$$

Q.E.D.

Proof of Corollary 2

We have $\mu > (1/v)$. Thus Corollary 2 follows from Proposition 2. Q.E.D.

Proof of Lemma 1

Part (1): Expanding Equation (5) with respect to X_a, we have

$$nX_a^2 + (2nr - V_u(n-1))X_a + nr^2 - nrV_u = 0.$$

Since $V_u = (Y_a^*/(Y_a^* + r))(V/2)$ in equilibrium, $V_u > r$ by Assumption 1. Thus the above quadratic equation has a unique positive solution, which is explicitly solved as follows.

$$X_a = (1/2n)[-\{2nr - (n-1)V_u\} + \sqrt{4rnV_u + (n-1)^2V_u^2}]$$

Similarly we can solve Equation (3) for Y_a.

$$Y_a = (1/2m)[-\{2mr - (m-1)(V/2)\} + \sqrt{2rmV + (m-1)^2(V^2/4)}]$$

Substituting into V_u and rearranging terms, we get

$V_u = (V/2)[(1/2m)\{-(2rm - (m-1)(V/2))$

$$+\sqrt{2rmV+(m-1)^2(V^2/4)}\}\{((m-1)V/4m)+(1/2m)\sqrt{2rmV+(m-1)^2(V^2/4)}\}^{-1}].$$

Part (2): Substitute Equations (1) and (3) into interim expected profits respectively, we get

$$\pi_b = P(V) = Vy_b^2/(my_b+r)^2 = V(p_b)^2,$$

$$\pi_a = P(V/2) = (V/2)y_a^2/(my_a+r)^2 = (V/2)(p_a)^2.$$

Thus $v = (1/2)(p_a/p_b)^2$. Expanding Equation (1) with respect to Y_b, we have the following quadratic equation.

$$mY_b^2 + (2mr - V(m-1))Y_b + mr^2 - mrV = 0.$$

From Assumption 1, we have a unique positive solution of the above equation:

$$Y_b = (1/2m)\{-(2mr - V(m-1)) + \sqrt{4mrV + (m-1)^2V^2}\}.$$

From Equation (2), we get

$$y_b = (1/2m^2)\{-(2mr - V(m-1)) + \sqrt{4mrV + (m-1)^2V^2}\}.$$

Similarly, from Equations (3) and (4) we can have

$$y_a = (1/2m^2)\{-(2mr - (V/2)(m-1)) + \sqrt{2mrV + (m-1)^2V^2/4}\}.$$

Q.E.D.

<u>Proof of Lemma 2</u>

Part (1): $\partial X_a/\partial V = (\partial X_a/\partial V_u)(\partial V_u/\partial V) > 0$ since, using Part (1) of Lemma 1,

$$\partial X_a/\partial V_u = (1/2n)[(n-1) + \{4rnV_u + (n-1)^2V_u^2\}^{-1/2}\{4rn + 2(n-1)^2V_u\}] > 0,$$

$$\partial V_u/\partial V = (1/2)\{my_a/(my_a+r)\} + (V/2)\{mr/(my_a+r)^2\}(\partial y_a/\partial V) > 0,$$

because, using Part (2) of Lemma 1,

$$\partial y_a/\partial V = (1/2m^2)[(m-1)/2 + \{2rmV + (m-1)^2V^2/4\}^{-1/2}\{2rm + (m-1)^2V/2\}] > 0.$$

Directly differentiating, we have

$$\partial X_a/\partial n = (1/2n)[V_u/n + \{4rnV_u + (n-1)^2V_u^2\}^{-1/2}V_u^2(n-1)\{2-(n-1)/n\}] > 0.$$

$$\partial X_a/\partial m = (\partial X_a/\partial V_u)(\partial V_u/\partial m) > 0,$$

since $\partial V_u/\partial m = (V/2)\{r/(Y_a+r)^2\}(\partial Y_a/\partial m) > 0$ where $\partial Y_a/\partial m > 0$ analogous to $\partial X_a/\partial n > 0$.

$\partial v/\partial m = (p_a/p_b)\{(-p_a/p_b^2)(\partial p_b/\partial m) + (1/p_b)(\partial p_a/\partial m)\}$

$= (p_a/p_b)^2\{(-1/p_b)(\partial p_b/\partial m) + (1/p_a)(\partial p_a/\partial m)\}$

We calculate each term in the curly bracket as follows.

$$(1/p_b)(\partial p_b/\partial m) = (r/(y_b(my_b + r)))(\partial y_b/\partial m),$$

$$(1/p_a)(\partial p_a/\partial m) = (r/(y_a(my_a + r)))(\partial y_a/\partial m).$$

Using Equations (1) and (3) and eliminating V, we have

$$\partial y_b/\partial m = y_b\{(2 - m)y_b - r\}/\{m(m - 1)y_b + r(m + 1)\},$$

$$\partial y_a/\partial m = y_a\{(2 - m)y_a - r\}/\{m(m - 1)y_a + r(m + 1)\}.$$

Substituting these results, we calculate the value of the curly bracket.

$(-1/p_b)(\partial p_b/\partial m) + (1/p_a)(\partial p_a/\partial m)$

$= A[-\{(2 - m)my_ay_b - r^2 + r((2 - m)y_b - my_a)\}\{(m - 1)my_a + r(m + 1)\}$

$+\{(2 - m)my_ay_b - r^2 + r((2 - m)y_a - my_b)\}\{(m - 1)my_b + r(m + 1)\}],$

where $A \equiv r/[(my_a+r)(my_b+r)\{(m-1)my_a+r(m+1)\}\{(m-1)my_b+r(m+1)\}]$.

Since $y_b > y_a$, the value of the curly bracket is negative if $m \geq 2$.

Part (2): Using the results of Part (1), we have

$$\partial \mu/\partial n = ((v - 1)/vr)(\partial X_a/\partial n) > 0,$$

$$\partial \mu/\partial m = (-1/v^2)(1 + (X_a/r))(\partial v/\partial m) + ((1 - v)/vr)(\partial X_a/\partial m) > 0 \quad \text{for } m \geq 2.$$

Part (3): From the direct expression of X_a, $\lim_{V\to\infty} X_a = \infty$. Since v is bounded ($0 < v < 1/2$), $\lim_{V\to\infty} \mu = \infty$ if $v \to 0$ as $V \to \infty$. Thus $\lim_{V\to\infty} \mu = \infty$. Q.E.D.

Proof of Lemma 3

Let

$$\Phi(Y) \equiv Y^2 + 2rY + r^2 - r(C+V),$$

$$\Phi_b(Y) \equiv Y^2 + \{2r - (m-1)V/m\}Y + r^2 - rV,$$

$$\Phi_a(Y) \equiv Y^2 + \{2r - (m-1)(V/2)/m\}Y + r^2 - r(V/2).$$

Note that $\Phi(\hat{Y}) = 0, \Phi_b(Y_b) = 0$, and $\Phi_a(Y_a) = 0$. Using these relations, we get

$$\Phi_a(Y_b) = (V/2)\{(m-1)Y_b + mr\} > 0 \quad \text{since} \quad Y_b > 0.$$

This implies that $Y_b > Y_a$. This completes part (1) of the Lemma. Similarly we have

$$\Phi_b(\hat{Y}) = rC - \{(m-1)/m\}V\hat{Y}.$$

Solving explicitly $\hat{Y} = \sqrt{r(C+V)} - r$ and substituting into the above expression, we define $F(C,V,m,r) \equiv (rC - \{(m-1)/m\}\{\sqrt{r(C+V)} - r\}$. Then $F(C,V,m,r) > 0$ if and only if $\hat{Y} > Y_b$.

Since $F(C,V,1,r) = rC > 0$, $\hat{Y} > Y_b$ if $m = 1$. This completes part (2) of the Lemma.

Since $\partial F/\partial m = -V(\sqrt{r(C+V)} - r)(1/m^2) < 0$, $F(C,V,1,r) = rC > 0$, and $F(C,V,\infty,r) = rC - V(\sqrt{r(C+V)} - r) = \sqrt{r(C+V)}(\sqrt{r(C+V)} - V)$, there is an m^* such that $F(C,V,m,r) > 0$ for all $m < m^*$ and $F(C,V,m,r) < 0$ for all $m \geq m^*$ if $C < \{(V/r) - 1\}V$. This completes part (3) of the Lemma.

We also have

$$F(k\{(m-1)/m\}V, V, m, r) = V\{(m-1)/m\}[rk - \{\sqrt{rV(1 + k(m-1)/m)} - r\}]$$

$$> V\{(m-1)/m\}[rk - \{\sqrt{rV(1+k)} - r\}]$$

$$= V\{(m-1)/m\}\sqrt{r(k+1)}(\sqrt{r(k+1)} - \sqrt{V}) \geq 0 \quad \text{if} \quad k \geq (V/r) - 1.$$

Thus $F(C,V,m,r) > 0$ if $C \geq \{(V/r) - 1\}\{(m-1)/m\}V$. This completes part (4) of the Lemma. Q.E.D.

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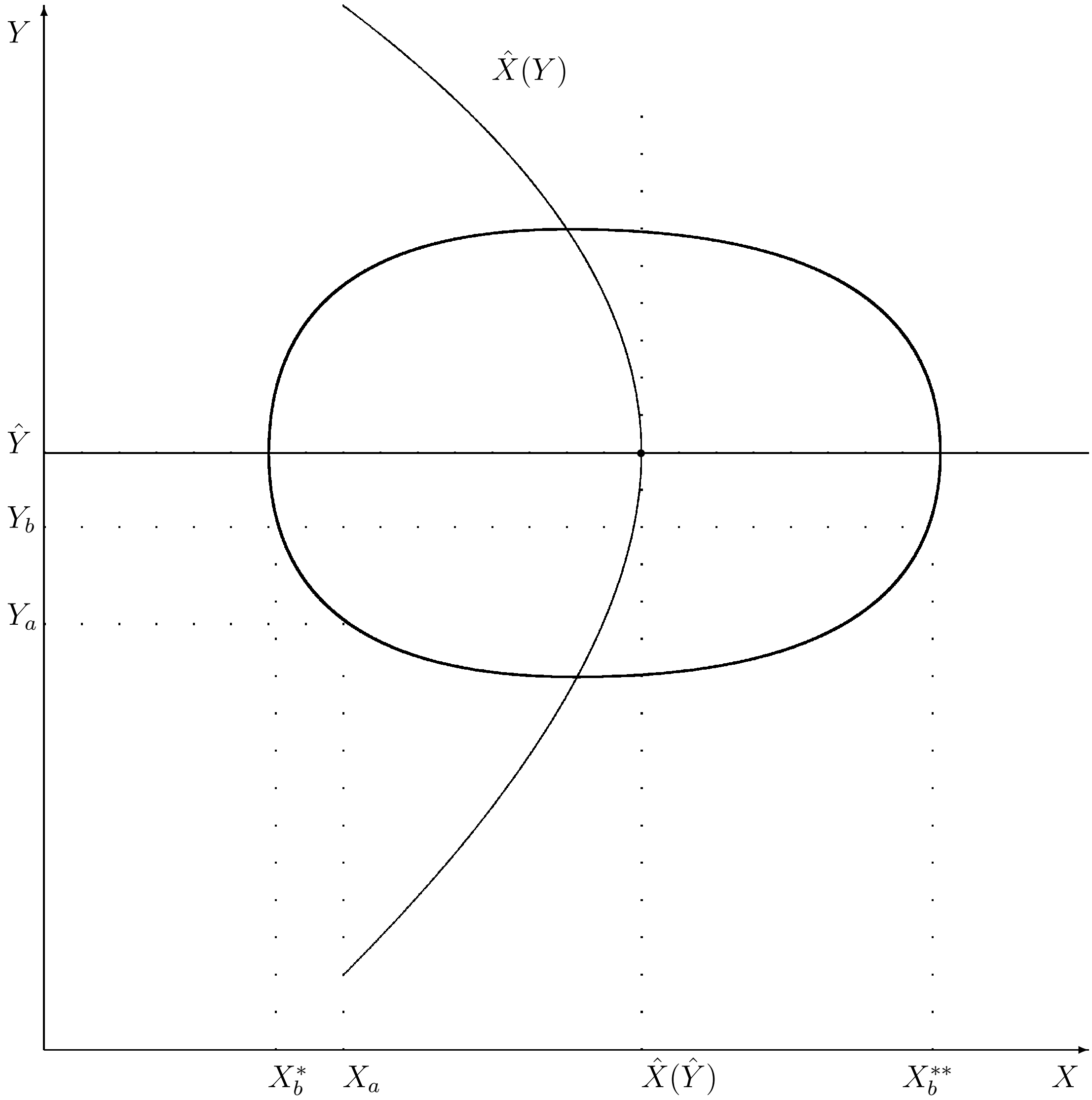

Figure 1: Iso-Welfare Contours