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DYNAMIC INCOMPATIBILITY, BUNDLING AND INNOVATION IN SYSTEMS MARKETS

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This paper analyzes R&D incentives in systems markets where two or more complementary components must be used in combination to serve consumers. I consider the situation where innovation in one component may result in incompatibility with other components. Bundling components turns out to improve R&D incentives regardless of whether components are subject to dynamic compatibility or incompatibility. Bundling, however, improves R&D incentives more in the case of dynamic incompatibility than in the case of dynamic compatibility. These results provide economic justifications of bundling in systems markets when strong complementarity between components makes them subject to the dynamic incompatibility.

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Many high-tech industries, including the computer and the communications industries, are characterized by "systems markets", where two or more complementary components must be used in combination to serve consumers. And some or all components are subject to significant technological progress as the result of suppliers' investments in R&D. The analysis of R&D incentives in systems markets is important since strong complementarity across components in systems markets render the previous analytical framework, in which the effects of R&D were confined to an individual market, less applicable. Furthermore, since many high-tech industries can be characterized as systems markets, the understanding of R&D incentives and identification of possible distortions in these markets will be of significant importance for a sensible formulation of

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industrial policies.

Compatibility is one of key factors affecting R&D incentives in these systems markets with rapid technological progress.[1] This is because compatibility makes the combination of components feasible and, thus, firms should consider whether this compatibility could be maintained after the innovation when they engage in their R&D activities. In this paper, I consider the situation where innovation in one component may result in incompatibility with other components without proper efforts of standardization. When strong complementarity between components exists, it is likely that innovation in one component requires innovations in other components in a system for maintaining compatibility among them and thereby innovating the system. In the computer and the communications industries, we can observe many examples in which innovation in one component results in incompatibility with other components.[2] I would like to refer to "dynamic incompatibility" when the innovation in one component brings about the incompatibility with other components and, thus, innovations in other components are required for the innovation of the system. On the other hand, "dynamic compatibility" implies that the compatibility between components is maintained despite the innovation in one component. In the case of dynamic compatibility, even innovation in one component can improve the system.

Another important factor influencing the R&D incentives in these systems markets is bundling or integration across components. The fact that components must be combined for meaningful consumption does not necessarily imply that those components should be produced in combination. But in many cases, some or all of components are combined in the production by a firm or a group of firms in strategic alliance who have capability of producing those components. Numerous theories have been proposed to explain the motives for the bundling practice and to find ensuing anti-trust and welfare implications.[3] And they are mainly occupied with the consequences of bundling for price competition. In this paper, however, the focus will be on the effects of bundling on the R&D incentives.[4] In the recent antitrust case of Microsoft, for instance, most

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[1] Analyses of R&D incentives in the framework of compatibility decisions can be found in Monroe(1993), De Bijl and Goyal(1995), Choi(1996) and Matutes and Regibeau(1996) among others. Matutes and Regibeau(1996) provides a survey on this issue.

[2] Microsoft's 'Windows 98' no longer supports application software programmed in 16 bit. Digital CDMA service is incompatible with analog CDMA handsets. Intel's 'Pentium III' can not be combined with 72 pin memory chips. And so on.

[3] Bundling is viewed as a means of price discrimination by Stigler(1963), Adams and Yellen(1976) and Schmalensee(1984) among others. The anti-competitive role of bundling is exemplified by the so called leverage theory but it was dismissed by a number of authors from the University of Chicago school such as Bowman(1957), Posner(1976), Bork(1978). Whinston (1990), however, revives the leverage theory in modern economic language with the consideration of strategic incentives for bundling.

[4] Choi(1998) analyzes the effects of bundling on R&D incentives. Although it has a general specification of R&D, it deals with two independent products and thus compatibility between

discussion is concerned with the future impact of bundling on the pace of innovation. The reason is that in the long run the overriding factor distinguishing systems markets from other markets will be firms' different R&D incentives shaped by complementarity between components. In particular, I will investigate how this bundling strategy affects R&D incentives when components are subject to dynamic compatibility and incompatibility, respectively.

The plan of the paper is as follows. Basic specifications of the model are presented in Section I. In section II, I compare R&D incentives under bundling and unbundling when components are subject to dynamic compatibility. The same kind of comparison is made in Section III but components are subject to dynamic incompatibility in this section. In Section IV, I compare results from the previous two sections. Section V sums up the results of the paper and gives some policy implications.

I. MODEL

I consider a systems market in which two complementary components, A and B, should be used on a 1-to-1 basis. Consumers, whose total measure is normalized to 1, are assumed to be identical and have at most one unit of demand for the system valued at V. This reservation value is high enough relative to the unit production cost of the system so that the price of the system represents a transfer from consumers to producers and will have no effect on total consumption. In this case, the ranking of social surplus depends only on the unit production cost of the system.

There are two independent firms in each component market. Each firm decides its R&D investment and production independently. Each component as well as a combined system is assumed to be homogenous. Firms engage in price competition in the product market. c_i^J, $i=1,2$, $J=A, B$ is the unit production cost for firm i in component J market and is given as a constant. e_i^J, $i=1,2$, $J=A,B$ is the level of R&D investment in component J by firm i. $R(e_i^J)\equiv R_i^J$ is the cost function for the R&D investment of firm i in component J market and is given as

$$R_i^J=\frac{1}{2}(e_i^J)^2. \tag{1}$$

X_i^J, $i=1,2$, $J=A,B$ is a random variable which represents the post-R&D unit production cost for firm i in component J. The unit production cost does not change if R&D result turns out to be a failure whereas the unit production cost

products is not an issue. Farrel and Katz(1999) focus on the effect of bundling by a firm monopolizing one component market on the R&D incentives of other firms producing other components.

becomes zero if R&D brings about innovation. Let $p(c_i^J, e_i^J) \equiv p_i^J$ be the probability for the unsuccessful R&D of firm i in component J market and it takes the following simple form.

$$p_i^J \equiv c_i^J - e_i^J, \quad 1 \leq e_i^J \leq c_i^J \leq 1 \tag{2}$$[5]

Then, the random variable X_i^J has the following distribution.

$$X_i^J = \begin{cases} c_i^J, \text{ with } p(c_i^J, e_i^J) = c_i^J - e_i^J \\ 0, \text{ with } 1 - p(c_i^J, e_i^J) \end{cases} \tag{3}$$

The expected cost is given by $E(X_i^J) = c_i^J \cdot (c_i^J - e_i^J)$ and this has the following properties. First, as the current unit cost decreases, the expected cost saving with a unit of R&D investment decreases. That is, $\frac{\partial}{\partial c_i^J}\left(\frac{\partial E}{\partial e_i^J}\right) = -1 < 0$. This implies "diminishing returns to R&D". In addition to this, the size of the expected cost decreases as the current unit cost decreases. That is, $\frac{\partial E}{\partial c_i^J} = 2c_i^J - e_i^J > 0$. This implies "experience effect".

In the case of dynamic compatibility, the successful innovation does not alter the compatibility between components. In this case, X_i^J, $i = 1, 2$, $J = A, B$ represents the unit cost realized in the system. In the case of dynamic incompatibility, the compatibility between components is maintained only if we have innovations in both components. The sole innovation in one component results in the incompatibility between components and, thus, this innovation is of no use until the innovation in the other component occurs. In this case, X_i^J, $i = 1, 2$, $J = A, B$ can not be the realized unit cost in the system. Instead, the following Y_i^J, $i = 1, 2$, $J = A, B$ represents the realized unit cost of component J by firm i in the system when components are subject to dynamic incompatibility.

$$Y_i^J = \begin{cases} c_i^J, \text{ with } \bar{p}_i^J(p_i^{J^*} p_{i^*}^{J^*}) + p_i^J \\ 0, \text{ with } \bar{p}_i^J(1 - p_i^{J^*} p_{i^*}^{J^*}) \end{cases}, \quad i, i^* = 1, 2, \; J, J^* = A, B, \; i \neq i^*, \; J \neq J^* \tag{4}$$

where $\bar{p} \equiv 1 - p$. That is, for example, the innovation in component A by firm 1(with probability $\bar{p}_1^A$) can be adopted into the system only with the innovation in component B by either of two firms producing component B(with probability $1 - \bar{p}_1^B \bar{p}_2^B$).

[5] In this assumption, c_i^J is considered as reflecting current technology level of firm i in component J market. Therefore, this function implies that R&D result is more likely to be unsuccessful when the current level of technology is lower, or c_i^J, is higher.

II. DYNAMIC COMPATIBILITY

For the sake of simplicity, let's assume that unit production costs of four independent firms are all the same. That is, we assume $c_1^A = c_2^A = c_1^B = c_2^B = c$. This assumption also enables us to focus on the pure effect of bundling on R&D incentives without concern about the efficiency in the allocation of R&D resources, which should be considered with asymmetric costs between components. Under this simplifying assumption, R&D incentives are compared under unbundling and bundling when components are subject to dynamic compatibility. In each case, firms decide their R&D efforts and then engage in price competition in the product market.

1. Unbundling

In this case of unbundling and dynamic compatibility, since the application of the innovation in one component to the system does not depend on the innovation in the other component, each component market can be independently dealt with. For instance, profit maximization problem for firm 1 in component A market is given as

$$\max_{e_1^A} \overline{cp}_1^A \, p_2^A - R_1^A, \tag{5}$$

(5) implies that firm 1 in component A gets revenue only if it succeeds in innovation and the competitor(firm 2 in component A) fails at the same time. The first order condition for (5) is given as

$$cp_2^A - e_1^A = 0. \tag{6}$$

The second order condition is satisfied as $-1 < 0$. From the symmetry of initial production costs, the equilibrium levels of R&D investment of four independent firms are implicitly given as follows.

$$e^{CU} = cp^{CU}, \tag{7}$$

where $p^{CU} = c - e^{CU}$ and e^{CU} is the equilibrium level of R&D investment when components are subject to dynamic compatibility and they are independently produced.

2. Bundling

Suppose that firm 1 and firm 2 in each component market produce two components in combination by merger or strategic alliance. In this case, firms will engage in price competition with the bundled products. In this case, the unit production cost of merged firm 1 is given as

$$X_1 \equiv X_1^A + X_1^B = \begin{cases} 2c, \text{ with } p_1^A p_1^B \\ c, \text{ with } p_1^A \bar{p}_1^B + \bar{p}_1^A p_1^B. \\ 0, \text{ with } \bar{p}_1^A \bar{p}_1^B \end{cases} \tag{8}$$

The maximization problem facing this firm is given by

$$\max_{e_1^A,\, e_1^B} 2c\,\bar{p}_1^A \bar{p}_1^B p_2^A p_2^B + c[\bar{p}_1^A \bar{p}_1^B (\bar{p}_2^A p_2^B + \bar{p}_2^B p_2^A) + (\bar{p}_1^A p_1^B + \bar{p}_1^B p_1^A) p_2^A p_2^B] \\ - R_1^A - R_1^B \tag{9}$$

This implies that firm 1 will get the revenue only when it becomes to have cost advantage over its competitor in the bundled product. The first order conditions for (9) are as follows.

$$2c\bar{p}_1^B p_2^A p_2^B + c[\bar{p}_1^B(\bar{p}_2^A p_2^B + \bar{p}_2^B p_2^A) + (p_1^B - \bar{p}_1^B) p_2^A p_2^B] - e_1^A = 0 \tag{10}$$

$$2c\bar{p}_1^A p_2^A p_2^B + c[\bar{p}_1^A(\bar{p}_2^A p_2^B + \bar{p}_2^B p_2^A) + (p_1^A - \bar{p}_1^A) p_2^A p_2^B] - e_1^B = 0 \tag{11}$$

Assume that the second order conditions are satisfied. From the symmetry, the equilibrium levels of R&D investment of two merged firms are implicitly given as

$$e^{CB} = cp^{CB}(p^{CB} + 2(\bar{p}^{CB})^2), \tag{12}$$

where $p^{CB} = c - e^{CB}$ and e^{CB} is the equilibrium level of R&D investment when components are subject to dynamic compatibility and they are bundled in production.

Ⅲ. DYNAMIC INCOMPATIBILITY

In this section, under the same simplifying assumption of symmetric costs as in the previous section, R&D incentives are compared under unbundling and bundling when components are subject to dynamic incompatibility.

1. Unbundling

Now, even if firm 1 in component A market succeeds in the innovation, unless either of two firms in component B market succeeds in the innovation, the innovation by firm 1 in component A market will be of no use due to the dynamic incompatibility. That is, the unit production cost of component A in the system remains the same level as the pre-R&D level. From (4), firm 1's unit production cost of component A applied to the system will be given as

$$Y_1^A = \begin{cases} c, \text{ with } \bar{p}_1^A(p_1^B p_2^B) + p_1^A \\ 0, \text{ with } \bar{p}_1^A(1 - p_1^B p_2^B) \end{cases}. \tag{13}$$

With this, the probability that firm 1's unit production cost of component A in the system becomes 0 and firm 2's unit production cost of component A in the system remains unchanged is given as

$$\begin{aligned} &P(Y_1^A = 0,\ Y_2^A = c) = P(Y_1^A = 0) \cdot P(Y_2^A = c \mid Y_1^A = 0) \\ &= \bar{p}_1^A [1 - p_1^B p_2^B] \cdot p_2^A. \end{aligned} \tag{14}$$

Therefore, the maximization problem facing firm 1 in component A market is given as

$$\max_{e_1^A} c\bar{p}_1^A[1 - p_1^B p_2^B] \cdot p_2^A - R_1^A. \tag{15}$$

From the first order condition for this, we get the following.

$$c[1 - p_1^B p_2^B] \cdot p_2^A - c_1^A = 0 \tag{16}$$

The second order condition is also satisfied as $-1<0$. From the symmetry, the equilibrium levels of R&D investment of four firms are implicitly given as follows.

$$e^{IU} = cp^{IU}(1 - (p^{IU})^2), \tag{17}$$

where $p^{IU} = c - e^{IU}$ and e^{IU} is the equilibrium level of R&D investment when components are subject to dynamic incompatibility and they are independently produced.

2. Bundling

In this section, cost reduction from the innovation is realized in the system only when innovations occur at the same time in both of components in a bundled product. Let Y_1 be the post-R&D unit production cost of merged firm 1. Then it is given as

$$Y_1 = \begin{cases} 2c, \text{ with } 1 - \bar{p}_1^A \bar{p}_1^B \\ 0, \text{ with } \bar{p}_1^A \bar{p}_1^B \end{cases} \tag{18}$$

With this, the maximization problem facing this firm is given as follows.

$$\max_{e_1^A, e_1^B} 2c\bar{p}_1^A \bar{p}_1^B(1-\bar{p}_2^A \bar{p}_2^B) - R_1^A - R_1^B \tag{19}$$

The first order conditions for (19) are given as

$$2c\bar{p}_1^B(1-\bar{p}_2^A \bar{p}_2^B) - e_1^A = 0, \tag{20}$$

$$2c\bar{p}_1^A(1-\bar{p}_2^A \bar{p}_2^B) - e_1^B = 0. \tag{21}$$

Assume also that the second order conditions are satisfied. From the symmetry, the equilibrium levels of two merged firms are implicitly given as follows.

$$e^{IB} = cp^{IB}(2\bar{p}^{IB} + 2(\bar{p}^{IB})^2) \tag{22}$$

where $p^{IB} = c - e^{IB}$ and e^{IB} is the equilibrium level of R&D investment when components are subject to dynamic incompatibility and they are bundled in production. Note that, in the symmetric equilibrium, the second order condition for (19) requires the following inequality to be fulfilled.

$$1-[2c(1-(\bar{p}^{IB})^2)]^2 > 0 \tag{23}$$

Ⅳ. COMPARISON

Let's compare R&D incentives under bundling and unbundling when components are subject to dynamic compatibility and incompatibility, respectively. The following proposition sums up the result.

Proposition 1.
$\forall 0<c<1,\ 0<e^{IU}<e^{CU}<e^{CB}<e^{IB}$ · $e^{IU}=e^{CU}=e^{CB}=e^{IB}=0$ if $c=0$.
When $c=1,\ 0<e^{IU}<e^{CU}=e^{CB}<e^{IB}$.

Proof. See appendix

This proposition has several implications. First of all, since $e^{CU} \leq e^{CB}$ and $e^{IU} \leq e^{IB}$, bundling components always gives firms better incentives for R&D and, thus, makes them invest more in each component.[6] Intuitively, bundling components raises R&D incentives because it integrates two component markets and, thus, has the same effect of expansion of the market size for each firm.[7]

[6] Choi(1998) also reaches the same result in the context of bundling of two independent products.

Even though this result implies that we have better expected social surplus with bundling, this should be interpreted with some caution to our simplifying assumptions.

Secondly, since $e^{CB}-e^{CU}\leq e^{IB}-e^{IU}$, we can conclude that bundling improves R&D incentives more in the case of dynamic incompatibility than in the case of dynamic compatibility. Intuitively, in the case of dynamic incompatibility, innovation in one component requires innovation in the other component in a system to make the value of the innovation to be realized in the system. In case firms produce components independently, then successful R&D can be of no use until firms in the other component market succeed in R&D. Therefore, the R&D incentives of independent firms will be mitigated due to this coordination problem. On the contrary, in case firms bundle their components through merger or strategic alliance, this failure of coordination will not happen and they have strong incentives for simultaneous innovations.

V. POLICY IMPLICATIONS AND CONCLUDING REMARKS

Most of high-tech markets including the computer and the communications industries can be characterized by systems markets and the effect of bundling components on R&D incentives in these markets is a crucial issue as is demonstrated in the recent legal debates on the Microsoft case. This issue, however, can be analyzed properly with the consideration of dynamic compatibility among components. If we take the strong complementarity between components into account, innovation in one component can result in incompatibility with other components. We have analyzed how the bundling components affects R&D incentives when components are subject to dynamic compatibility and incompatibility, respectively. Bundling is proved to give firms better incentives for R&D regardless of whether component are subject to dynamic compatibility or not. Bundling, however, improves R&D incentives more in the case of dynamic incompatibility than in the case of dynamic compatibility.

These results provide economic justifications for bundling in systems markets where technological innovation in a system product requires simultaneous innovations in components constituting it. For example, in the computer industry, close alliance between Intel and Microsoft in bundling their products is not severely challenged because CPU chip and OS software have so strong complementarity that innovation in one component requires innovation in the other component. This aspect of bundling in systems markets should be taken into account when

[7] When bundling is interpreted as an (static) incompatibility decision of firms in alliance, Matutes and Reibeau's (1996) conjecture about R&D incentive in the framework of compatibility decision can be viewed as similar to our result. They conjecture that the firms' incentives to invest in R&D would be greater when their components are incompatible with those of their rivals because they would capture the whole benefit of their own cost saving.

government needs to judge on the welfare effects of the bundling.

While this paper focuses on comparing R&D incentives in many different situations, it does not provide complete solutions to the model. In particular, since this paper does not address on the rational choice between bundling and unbundling by firms, it can not be answered in the model whether or not private incentives coincide with social incentives. This limitation can be overcome by incorporating the choice of bundling into the game played by firms. This should be pursued in the future.

Appendix

The proof will consist of three parts as follows.

1. Proof of $e^{IU} \le e^{CU}$ (equality holds iff $c=0$)

From (7) and (17), we have the following.

$$\begin{aligned} e^{CU}-e^{IU} &= c\,[c-e^{CU}-(c-e^{IU})(1-(c-e^{IU})^2)] \\ &= c\,(e^{IU}-e^{CU})+c\,(c-e^{IU})^3 \text{ or} \end{aligned}$$

$$(e^{CU}-e^{IU})=\frac{c}{1+c}(c-e^{IU})^3 \ge 0 \tag{A1}$$

And the equality holds if and only if $c=0$ because $c=e^{IU}$ and $c>0$ is a contradiction from(17). Therefore, we have $e^{CU} \ge e^{IU}$ (Equality holds iff $c=0$)

2. Proof of $e^{CU} \le e^{CB}$ (equality holds iff $c=0$ or $c=1$)

First note that in case $c=0$, $e^{CB}=e^{IB}=0$, constitute solutions to (7) and (12). In case $c \neq 0$, it is straightforward to show $e^{CB}>0$, $e^{IB}>0$ from (7) and (12), and we have the following.

$$\frac{e^{CU}}{e^{CB}}=\frac{p^{CU}}{p^{CB}(p^{CB}+2(\bar{p}^{CB})^2)} \tag{A2}$$

Suppose that $e^{CU}=e^{CB}$ for some $0<c\le 1$. Then $p^{CU}=p^{CB}\equiv p$ and we have the following from (A2)

$$\frac{e^{CU}}{e^{CB}}=\frac{1}{(p+2\bar{p}^2)}=1 \tag{A3}$$

From (A3), we have $p=1$ or $p=\frac{1}{2}$. But with $p=1$, we have a contradiction from (7) or (12). And when $p=\frac{1}{2}$, $c=1$ and $e^{CB}=e^{IB}=\frac{1}{2}$ constitute solutions

to (7) and (12).
Suppose that $e^{CU} > e^{CB}$ for some $0 < c \leq 1$. Then $p^{CU} < p^{CB}$ and we have the following.

$$1 < \frac{e^{CU}}{e^{CB}} = \frac{p^{CU}}{p^{CB}(p^{CB} + 2(\bar{p}^{CB})^2)} \leq \frac{1}{(p^{CU} + 2(\bar{p}^{CU})^2)} \tag{A4}$$

The last inequality comes from the following.

$$\frac{\partial p(p + 2\bar{p}^2)}{\partial e} = -2p + 4p\bar{p} - 2\bar{p} \leq -2p^2 + 4p\bar{p} - 2\bar{p}^2 = -2(p - \bar{p})^2 \leq 0 \tag{A5}$$

This means $p^{CU}(p^{CU} + 2(\bar{p}^{CU})^2) \leq p^{CB}(p^{CB} + 2(\bar{p}^{CB})^2)$ since $e^{CU} > e^{CB}$. From (A4), we have the following inequality.

$$\frac{1}{2} < p^{CU} < 1 \tag{A6}$$

From (7), (A6) implies that $c > 1$ and this is a contradiction. Therefore, we have $e^{CU} < e^{CB}$ for $0 < c < 1$.

3. Proof of $e^{CB} \leq e^{IB}$ (equality holds iff $c = 0$)

First note that in case $c = 0$, $e^{CB} = e^{IB} = 0$ constitute solutions to (12) and (22).

In case $c \neq 0$, it is straightforward to show $e^{CB} > 0$, $e^{IB} > 0$ from (12) and (22) and, thus, we have the following.

$$\frac{e^{CB}}{e^{IB}} = \frac{p^{CB}(p^{CB} + 2(\bar{p}^{CB})^2)}{p^{IB}(2\bar{p}^{IB} + 2(\bar{p}^{IB})^2)} \tag{A7}$$

Suppose that $e^{CB} = e^{IB}$ for some $0 < c \leq 1$. Then $p^{CB} = p^{IB} \equiv p$ and we have the following from (A7)

$$\frac{e^{CB}}{e^{IB}} = \frac{(p + 2\bar{p}^2)}{(2\bar{p} + 2\bar{p}^2)} = 1 \tag{A8}$$

From (A8), we have $p = \frac{2}{3}$. And from (12), we have

$$c - e^{CB} = p = c\,[1 - p(p + 2\bar{p}^2)] \text{ or } c = \frac{p}{1 - p(p + 2\bar{p}^2)} \tag{A9}$$

When $p=\frac{2}{3}$, (A9) shows that $c=\frac{54}{33}$, which is a contradiction. Thus, we prove $e^{CB} \neq e^{IB}$ for $\forall\, 0<c\leq 1$.
Suppose that $e^{CB}<e^{IB}$ for some $0<c\leq 1$. Then $p^{CB}<p^{IB}$ and we have the following from (A7)

$$1<\frac{e^{CB}}{e^{IB}}=\frac{p^{CB}(p^{CB}+2(\bar{p}^{CB})^2)}{p^{IB}(2\bar{p}^{IB}+2(\bar{p}^{IB})^2)}\leq\frac{\bar{p}^{IB}+2(\bar{p}^{IB})^2}{2\bar{p}^{IB}+2(\bar{p}^{IB})^2} \tag{A10}$$

The last inequality comes from (A5). For (A10) to be satisfied, $p^{IB}>\frac{2}{3}$ is required. We will show that $p^{IB}>\frac{2}{3}$ is a contradiction. From (22), we have the following.

$$p^{IB}=c-e^{IB}=c\,[1-p^{IB}(2\bar{p}^{IB}+2(\bar{p}^{IB})^2)] \text{ or}$$

$$c=\frac{p^{IB}}{1-p^{IB}(2\bar{p}^{IB}+2(\bar{p}^{IB})^2)} \tag{A11}$$

Note also that we have the constraint from (23).

$$2c(1-(\bar{p}^{IB})^2)<1 \text{ or } c<\frac{1}{2p^{IB}(2-p^{IB})} \tag{A12}$$

Suppose $p^{IB}>\frac{2}{3}$. From (A11), we have

$$c=\frac{p^{IB}}{1-p^{IB}(2\bar{p}^{IB}+2(\bar{p}^{IB})^2)}>\frac{\frac{2}{3}}{1-p^{IB}(2\bar{p}^{IB}+2(\bar{p}^{IB})^2)}>\frac{2}{3} \tag{A13}$$

From (A12) and $1\geq p^{IB}>\frac{2}{3}$, we have

$$c\leq\frac{1}{2p^{IB}(2-p^{IB})}\leq\frac{1}{\min\limits_{p^{IB}\in[\frac{2}{3},1]}2p^{IB}(2-p^{IB})}\leq\frac{9}{16}<\frac{2}{3}. \tag{A14}$$

From (A13) and (A14), we have a contradiction. Therefore, we have $e^{CB}<e^{IB}$ for $c\neq 0$. QED

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