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Inter-Technology versus Intra-Technology Competition in Network Markets

by
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Abstract: The model analyzes the competition between two firms when their incompatible technologies exhibit network effects in that high expected sales increase the willingness to pay for the corresponding good. An incumbent firm faces the strategic choice of whether to share its superior technology (via free licensing) with a follower or to keep its technology for itself. The first option of sponsoring intra-technology competition increases the incumbent firm's network and thus consumers' willingness to pay. On the other hand, the latter option involves inter-technology competition. Depending on the relative cost advantage of the incumbent firm, the entry of the rival technology may be blockaded, both technologies can coexist in an incompatible duopoly or the incumbent firm may deter the entry of its rival. The model investigates the incumbent firm's choice of whether to sponsor intra-technology competition or to insist on inter-technology competition.

1. Introduction

A fundamental question of strategy for a firm facing horizontal competition in a network market is whether to share its technology with other firms and to compete within a joint network or to keep its technology for itself.[1] With just two firms, this strategic choice involves three combinations of strategies (Besen and Farell, 1994). In the first, both firms prefer inter-technology competition to determine the industry standard. In the second case, which corresponds to the Battle of the Sexes, both firms want to compete within a joint network but they

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[1]Alternatively, firms could ensure (at least partial) compatibility by using converters. In this case, they might adopt different technologies without losing the network advantage of a joint technology. For this alternative, see Farrell and Saloner (1992).

cannot agree on the standard: "Each sponsor wants the other to join its network but would be willing to join the other's if the alternative is incompatibility" (Besen and Farrell, 1994, p. 125). Finally, in the last case, one sponsor may prefer to maintain its technology while the competitor may wish to join the rival's network.

It is an empirical question whether firms actually invite potential rivals to license their technology and to compete within a joint network. In the early 1980s, Intel licensed its microprocessor designs to AMD. Later on, Intel reversed this decision and broke off its agreement with AMD (see, for example, Shapiro and Varian, 1999, p. 125). Another well-known example for both inter-technology and intra-technology competition is the VHS/Betamax contest to determine the standard for video cassette recorders. Despite an early lead and a superior quality, the Sony Betamax system was finally driven out of the market by the VHS system from Japan Victor Corporation (JVC). The ultimate victory of VHS can be attributed to JVC's strategy of licensing its technology to other manufacturers (see, for example, Grindley, 1995, pp. 75-130).

In this model, we follow Economides (1996) who assumes that high expected sales increase the willingness to pay for the network good.[2] He shows that it can be beneficial for the exclusive holder of a network technology to invite competitors into its network. The reason for this "seeming paradox" (Economides, 1996, p. 31) is that the holder of the technology cannot credibly commit to a network size which exceeds its relatively low profit-maximizing monopoly output. Consumers' expectations have to be fulfilled at the equilibrium level. The invitation of other firms is a self-binding device for the innovator because the rational consumers anticipate that the market's total output rises with the number of competitors.

Whereas the model by Economides is confined to intra-technology competition, this paper also deals with inter-technology competition. We focus on two firms A and B, each is the exclusive holder of a technology. The modeling of inter-technology competition is based on a system of two linear demand functions. Total demand can be increased by network effects, i.e. the market size is not fixed such as in models of the Hotelling-type. Two asymmetries occur: First, firm A is assumed to be the quantity leader. Secondly, the technologies may have different marginal costs. The incumbent firm A faces the problem whether to share its superior technology (via free licensing) with the potential competitor B or to keep its technology for itself. Like in the model by Economides, the invitation of competitor B into product market A increases the network size and thus consumers' willingness to pay.

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[2]See Holler, Knieps and Niskanen (1997) for an overview of various models with network effects.

If the incumbent keeps its technology for itself, three different equilibria may occur. Depending on the relative cost advantage of technology *A*, the entry of technology *B* can be blockaded,[3] both technologies may coexist in an incompatible and heterogeneous duopoly or the incumbent can deter the entry of technology *B*. We will show that the incumbent can realize a higher profit in the case of entry deterrence than in the situation where the competitor's entry is blockaded.[4] Conversely, the textbook result (see, for example, Pfähler and Wiese, 1998, p. 116) is that the incumbent's entry deterrence strategy is less profitable. By supplying the deterrence output, the incumbent not only prevents the competitor's entry, it also credibly commits to a quantity which exceeds the profit-maximizing monopoly output. As a consequence, consumers have an increased willingness to pay. Furthermore, it is shown that the deterrence profit can rise with decreasing marginal costs of the competing technology. The reason for this perverse effect is that the positive network effect of expanding the quantity may exceed the deterrence costs.

There already exist models dealing with network effects and entry deterrence. Generally, these models examine how an incumbent exploits the network effect in order to prevent the entry of a competing technology. For example, Church and Gandal (1996) assume that the incumbent can commit earlier to an installed base of complementary goods than its competitor. By over-investing in the installed base, the incumbent strengthens the indirect network effects for its technology so that the market entry of the competing system is prevented. In an earlier model, Farrell and Saloner (1986) demonstrate that the incumbent can prevent the entry of a competing network technology by using predatory pricing.

In this paper, it will be demonstrated that entry deterrence can only be a fulfilled expectations equilibrium if the incumbent's cost advantage is not too strong. In the case of a strong cost advantage, the entry of the competing technology is blockaded and the incumbent cannot credibly commit to a network size that exceeds its profit-maximizing monopoly quantity. On the other hand, if one technology only has a weak cost advantage, both technologies coexist in an incompatible and heterogeneous duopoly.

The requirement, that expectations have to be fulfilled in the equilibrium, makes it necessary to determine the equilibrium in a two-step approach: In the

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[3]In section 3, we will omit the assumption that technology *A* is superior. As a consequence, the entry of *A* can be blockaded if technology *B* has a considerable cost advantage.

[4]In this paper, the usual terminology is used which distinguishes between "deterred" and "blockaded" entry. Blockaded entry occurs when the incumbent just chooses the profit-maximizing strategy and, given this decision, it is not worthwhile for the competitor to enter the market. Entry deterrence refers to situations where the incumbent has to modify its strategy in order to prevent entry because the competitor is not as weak in terms of costs or quality as in the former case.

first step, we will compute the profit-maximizing quantities that fulfill expectations for a given path. The second step deals with the fact that firms could leave the path. Stability conditions will be derived for each path and it will be shown that these conditions ensure the uniqueness of the fulfilled expectations equilibrium.

The structure of the paper is as follows: Section 2 presents the model assumptions. Section 3 is confined to inter-technology competition. Section 4 extends the analysis to the incumbent's strategic problem whether to share its technology with the competitor or to keep its technology for itself. In order to focus on the comparison of entry deterrence with the invitation strategy, we will assume that technology *A* has a moderate cost advantage. It will be demonstrated that entry deterrence can be more profitable for the incumbent than inviting entry. Concluding remarks follow in section 5.

2. Model structure

Suppose that there are two incompatible network technologies $i = A, B$ exclusively held by two firms. The demand for the network goods A and B is given by the following system of linear inverse demand functions:

$$p_i = \alpha_i - \beta_i y_i - \gamma y_j + n y_i^e, \quad i, j = A, B, \quad i \neq j. \tag{1}$$

The parameter γ denotes the degree of substitutability.[5] For simplicity, suppose that $\beta_A = \beta_B = 1$ holds. Moreover, let us assume $0 < \gamma < 1$, thus the markets for *A* and *B* are interdependent. Network effects for good *i* depend on the level of expected sales y_i^e and on the network effect parameter $0 \leq n \leq 1$.[6] Thus, network effects push the demand curves (for given expectations) up without changing their slopes.[7] For each unit sold, the network benefit is the same. For simplicity, suppose that the technologies have constant marginal costs with $0 \leq c_i < \alpha_i$. Hence, at least one firm will supply a positive quantity.

The model has three stages. In the first stage, consumers form expectations by backward induction, i.e. they anticipate the equilibrium levels of sales. In the

[5]This linear demand system - except the network effect - goes back to Spence (1976), Dixit (1979), and Singh and Vives (1984).

[6]For a discussion of the functional form of network effects, see Swann (2002).

[7]See Wiese (1997) who distinguishes between the "demand curves for a given level of sales expectations" and the "fulfilled expectations demand curve" which is defined by equating expected sales with actual demand.

second stage, firm *A* (which is assumed to be the quantity leader) selects the profit-maximizing quantity of *A*. Firm *B* responds in the third stage with the profit-maximizing quantity of *B*. Four equilibrium paths may occur:

1. Both technologies can coexist in a heterogeneous and incompatible duopoly, i.e. firm *B* responds with $y^e_{B,I}* > 0$ to the leader quantity $y^e_{A,I}* > 0$.
2. The market entry of firm *B* can be blockaded if firm *A* has a strong cost advantage. Then, firm *A* is able to select the profit-maximizing quantity $y^e_{A,M}* > 0$ without paying attention to firm *B*.
3. In the case of a strong cost advantage of technology *B*, the market entry of technology *A* may be blockaded so that follower *B* selects the profit-maximizing quantity $y^e_{B,M}* > 0$ in the third period.
4. If firm *A* has a moderate cost advantage, it can exploit its first mover advantage in order to deter the entry of the competing technology.[8] The deterrence quantity $y^e_{A,D}* > 0$ is derived from firm *B*'s reaction function. It corresponds to the quantity of good *A* which makes firm *B* respond with an output equal to zero.

Figure 1 summarizes the timing structure and the possible equilibrium paths which must fulfill consumers' expectations.

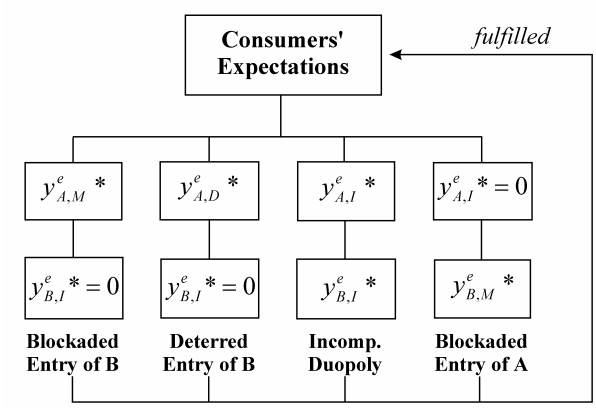

Figure 1. Model structure and possible equilibrium paths

[8]We do not distinguish between "quantity" and "capacity" in this model. However, Dixit (1980) demonstrates in a two-stage game that the incumbent cannot deter entry by investing in a large capacity, i.e. the deterrence strategy would not be subgame-perfect.

3. Fulfilled expectations equilibrium

The fulfilled expectations equilibrium is computed in a two-step approach. In the first step, the profit-maximizing quantities are derived for a given path, i.e. the quantities must be equal to the path expectations. For example, consider the case where firm *A* has a monopoly and the entry of technology *B* is blockaded. As usual, we apply the backward-induction principle. Starting in the second stage, the profit-maximizing monopoly output is computed as a function of the expected network size. Finally, in the first stage the expectations are endogenized: At the equilibrium level, actual quantities have to be equal to the expected ones.

The second step deals with the fact that firms could leave the path, given the path expectations. Consider the example of firm *A*'s monopoly with blockaded entry of *B*. In the third stage, firm *B* selects the optimal quantity of good *B*, given the path expectations and firm *A*'s optimal quantity. If it were beneficial for firm *B* to supply a positive quantity of good *B*, i.e. to leave the path, the path would not be consistent any longer and consumers would anticipate firm *B* to deviate. Thus, rational expectations exclude this path. For the other paths, we can define similar stability conditions.

3.1 Profit-maximizing quantities with fulfilled path expectations

This section deals with the first step of computing a fulfilled expectations equilibrium. For a given path, we will derive the profit-maximizing quantities which are equal to the expected ones.

3.1.1 Monopoly with blockaded entry of the competitor

Assume that firm *i* has a considerable cost advantage so that the entry of technology *j* is blockaded. The profit function of monopolist *i* is given by

$$\Pi_{i,M} = y_{i,M}\left(\alpha_i - y_{i,M} + n\, y_i^e - c_i\right). \tag{2}$$

Maximizing the profit function with respect to $y_{i,M}$ results in the monopoly quantity for given expectations:

$$y_{i,M}{}^*(y_i^e) = \frac{\alpha_i - c_i + n\, y_i^e}{2}. \tag{3}$$

The maximum monopoly profit for given expectations is equal to

(4) $$\Pi_{i,M}*\left(y_i^e\right) = \frac{\left(\alpha_i - c_i + ny_i^e\right)^2}{4}.$$

The expected quantity y_i^e must be set equal to the actual quantity $y_{i,M}*$. This defines the level of fulfilled expectations as the solution of

(5) $$y_{i,M}^e* = y_{i,M}*(y_{i,M}^e*) \Leftrightarrow y_{i,M}^e* = \frac{\alpha_i - c_i}{2-n},$$

where $y_{i,M}*(y_i^e)$ was substituted from Equation (3). The maximum monopoly profit with fulfilled expectations is then given by

(6) $$\Pi_{i,M}^e* = \frac{(\alpha_i - c_i)^2}{(n-2)^2}.$$

3.1.2 Incompatible duopoly

In the second stage, firm *A* selects $y_{A,I}$ as the quantity of good *A*. Firm *B* responds in the third stage with quantity $y_{B,I}$ of product *B*.
The profit functions of the duopolists are given by

(7) $$\Pi_i = y_i(\alpha_i - y_i - \gamma\, y_j + n\, y_i^e - c_i).$$

Maximizing the follower's profit function with respect to $y_{B,I}$ results in the follower's optimal quantity for given expectations y_B^e and for the given leader quantity $y_{A,I}$:

(8) $$y_{B,I}*(y_B^e, y_{A,I}) = \frac{\alpha_B - c_B - \gamma\, y_{A,I} + n\, y_B^e}{2}.$$

Substituting Equation (8) in the profit function of firm *A* and maximizing with respect to $y_{A,I}$ yields the optimal leader quantity for given expectations y_A^e and y_B^e:

(9) $$y_{A,I}*(y_A^e, y_B^e) = \frac{2(\alpha_A - c_A) - \gamma(\alpha_B - c_B) - n(\gamma\, y_B^e - 2\, y_A^e)}{2(2-\gamma^2)}.$$

Substituting Equation (9) back in Equation (8) yields the follower's best reply

$$(10) \qquad y_{B,I}*(y_A^e, y_B^e) = \frac{(4-\gamma^2)(\alpha_B - c_B) - 2\gamma(\alpha_A - c_A) - n(\gamma^2 y_B^e - 4y_B^e + 2\gamma y_A^e)}{4(2-\gamma^2)}.$$

After having derived the optimal quantities of A and B as functions of the expected network sizes, the expectations have to be endogenized in the first stage. We make use of Equations (9) and (10) to define the fixed point conditions $y_{i,I}^e* = y_{i,I}*(y_{i,I}^e*, y_{j,I}^e*), \quad i,j = A,B, \quad i \neq j$. Solving these conditions for $y_{A,I}^e*$ and $y_{B,I}^e*$ results in the optimal quantities of A and B which fulfill expectations:

$$(11) \qquad y_{A,I}^e* = \frac{2\gamma(\alpha_B - c_B) - (4-2n)(\alpha_A - c_A)}{(4-n)\gamma^2 - 2(n^2 - 4n + 4)},$$

$$(12) \qquad y_{B,I}^e* = \frac{2\gamma(\alpha_A - c_A) + (\gamma^2 - 4 + 2n)(\alpha_B - c_B)}{(4-n)\gamma^2 - 2(n^2 - 4n + 4)}.$$

The maximum profits of firm A and B are given by:

$$(13) \qquad \Pi_{A,I}^e* = \frac{2(2-\gamma^2)\left[\gamma(\alpha_B - c_B) - (2-n)(\alpha_A - c_A)\right]^2}{\left[2(n^2 - 4n + 4) - \gamma^2(4-n)\right]^2},$$

$$(14) \qquad \Pi_{B,I}^e* = \frac{\left[2\gamma(\alpha_A - c_A) + (\gamma^2 + 2n - 4)(\alpha_B - c_B)\right]^2}{\left[2(n^2 - 4n + 4) - \gamma^2(4-n)\right]^2}.$$

Figure 2 shows the profit-maximizing quantities (as dashed lines) and the maximum profits with fulfilled expectations. Quantities and profits are functions of alternative marginal costs c_B. The lower and the upper bounds of the incompatible duopoly are denoted by $c_{B,1}$ and $c_{B,2}$, respectively. At the equilibrium level, the quantities have to be positive, i.e. $y_{A,I}^e* > 0$ and $y_{B,I}^e* > 0$ must hold.

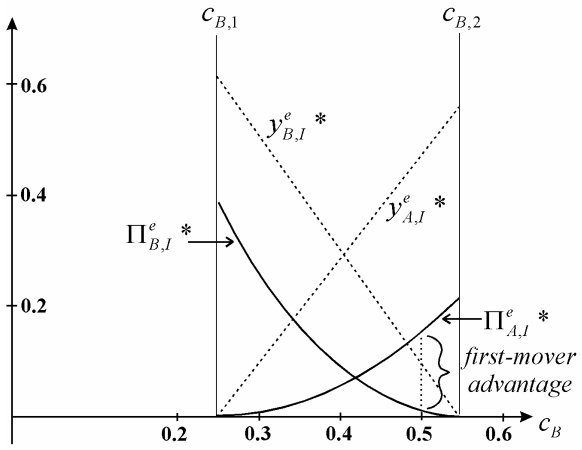

Figure 2. Profit-maximizing quantities and maximum profits with fulfilled expectations for $\alpha_A = \alpha_B = 1,\ n = \gamma = 0.8$ and $C_A = 0.5$

After rearranging Equations (11) and (12), we see that an incompatible duopoly with fulfilled expectations exists if

$$(15) \qquad c_{B,1} = \alpha_B - \frac{(2-n)(\alpha_A - c_A)}{\gamma} < c_B < c_{B,2} = \alpha_B - \frac{2\gamma(\alpha_A - c_A)}{4-2n-\gamma^2}.$$

In Figure 2, the quantities and profits of firm A rise with c_B. On the other hand, the quantities and profits of firm B decrease with c_B. Generally, quantities and profits show normal reactions to cost variations if

$$\frac{\partial y^e_{i,I}*}{\partial c_j} = \frac{2\gamma}{2(n^2-4n+4)-(4-n)\gamma^2} > 0 \text{ with } i,j = A,B,\ i \neq j,$$

$$\frac{\partial y^e_{B,I}*}{\partial c_B} = \frac{\gamma^2+2n-4}{2(n^2-4n+4)-(4-n)\gamma^2} < 0 \text{ and}$$

$$\frac{\partial y^e_{A,I}*}{\partial c_A} = \frac{2n-4}{2(n^2-4n+4)-(4-n)\gamma^2} < 0 \text{ holds.}$$

Since $2\gamma > 0$, $\gamma^2 + 2n - 4 < 0$ and $2n - 4 < 0$, the denominators must be positive. Making use of this condition, we have

$$(16) \quad \frac{\partial y_{i,I}^{e}*}{\partial c_j} > 0 \text{ and } \frac{\partial y_{i,I}^{e}*}{\partial c_i} < 0 \quad \Leftrightarrow \quad n < n_{ID} = 2 - \frac{\gamma^2 + \gamma\sqrt{\gamma^2 + 16}}{4}.$$

In the following analysis, we will assume that $n < n_{ID}$ holds. With increasing network parameter n and rising degree of substitutability γ, the existence area $\left[c_{B,1}, c_{B,2}\right]$ shrinks and the functions $y_{A,I}^{e}*$ and $y_{B,I}^{e}*$ become steeper. The case of $c_{B,1} = c_{B,2}$ corresponds to the situation of $n = n_{ID}$: The incompatible duopoly does not exist any longer and $y_{A,I}^{e}*$ and $y_{B,I}^{e}*$ are vertical lines.

Proposition 1. The incompatible duopoly occurs as a fulfilled expectations equilibrium if $c_{B,1} < c_B < c_{B,2}$ holds.

3.1.3 Entry deterrence

In the second stage, quantity leader *A* can supply an excessive quantity of good *A* in order to prevent the entry of technology *B* in the following stage. The optimal response of firm *B*, given by Equation (8), must be set equal to zero. Substituting rational expectations $y_B^e = 0$ and solving for y_A results in the deterrence output which fulfills expectations:

$$(17) \qquad y_{B,I}^{e}* = \frac{\alpha_B - c_B - \gamma\, y_{A,D}}{2} \overset{!}{=} 0 \quad \Leftrightarrow \quad y_{A,D}^{e}* = \frac{\alpha_B - c_B}{\gamma}.$$

Substitution of $y_{A,D}^{e}*$ and $y_B = 0$ in the profit function of firm *A*, given by Equation (7), yields the deterrence profit with fulfilled expectations:

$$(18) \qquad \Pi_{A,D}^{e}* = \frac{(\alpha_B - c_B)\left[\gamma(\alpha_A - c_A) - (1-n)(b - c_B)\right]}{\gamma^2}.$$

Figure 3 depicts deterrence quantities and profits as functions of alternative marginal costs c_B. In the interval $x' \le c_B \le 1$, firm *A*'s deterrence profit, $\Pi_{A,D}^{e}*$, rises with decreasing marginal costs, c_B, of its rival. To identify the reason for this perverse cost effect, it is necessary to scrutinize firm *A*'s profit function. The deterrence profit is composed of the deterrence revenue, $r_{A,D}^{e}*$, and total costs $c_A\, y_{A,D}^{e}*$. As shown in Figure 3, firm *A* has to supply a larger deterrence quantity, $y_{A,D}^{e}*$, with decreasing c_B. The larger network size results

in an increased willingness to pay for good A.[9] The deterrence revenue is hyperbolic, it is maximal at x and goes back to zero because the positive network effect of the quantity expansion is finally offset by a negative price effect.

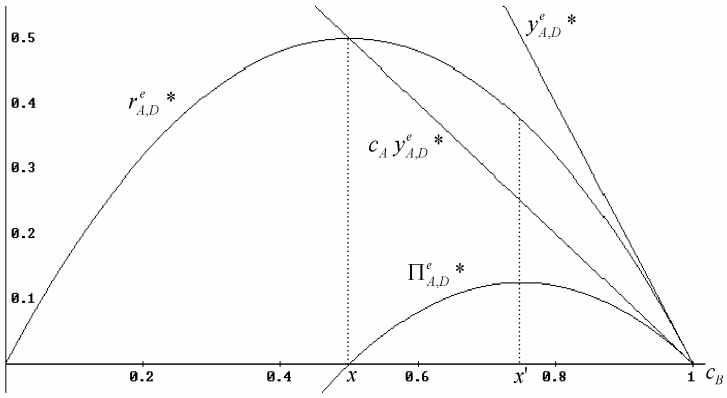

Figure 3. Entry deterrence output and profit for $\alpha_A = \alpha_B = 1$, $n = \gamma = c_A = 0.5$

The deterrence profit is positive if

(19) $$\Pi^e_{A,D}{*} > 0 \;\Leftrightarrow\; \alpha_B - \frac{\gamma(\alpha_A - c_A)}{1-n} < c_B < \alpha_B \text{ holds.}$$

Figure 4 illustrates how the deterrence profit reacts to variations of the degree of substitutability. If the degree of substitutability, γ, is low, firm A needs a larger quantity in order to prevent the entry of technology B. Thus, starting with $c_B = 1$, the maximum deterrence profit $\Pi^e_{A,D}{*}(c_B^{\max})$ and the zero point are reached faster.

[9]The entry deterrence strategy is not necessarily a credible commitment. Later on, we will derive the conditions for credibility.

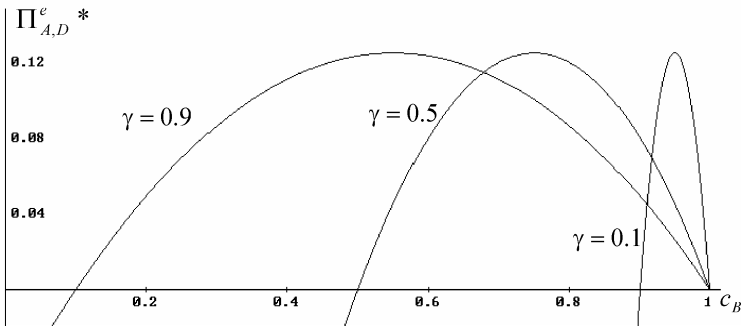

Figure 4. Impact of γ on the deterrence profit for $\alpha_A = \alpha_B = 1$, $n = c_A = 0.5$

Figure 4 also demonstrates that the maximum deterrence profit is independent of the degree of substitutability:

$$(20) \quad c_B^{\max} = \frac{2(1-n)\alpha_B - \gamma(\alpha_A - c_A)}{2(1-n)} \;;\; \Pi^e_{A,D}{}^*(c_B^{\max}) = \frac{(\alpha_A - c_A)^2}{4(1-n)}$$

The impact of the network parameter n on the deterrence profit is unambiguous, i.e. the deterrence profit always rises in n:

$$(21) \qquad \frac{d\,\Pi^e_{A,D}{}^*}{d\,n} = \frac{(\alpha_B - c_B)^2}{\gamma^2} > 0\,.$$

Figure 5 depicts this result. If n approaches its upper limit $n = 1$, the deterrence profit is illustrated by a straight line.

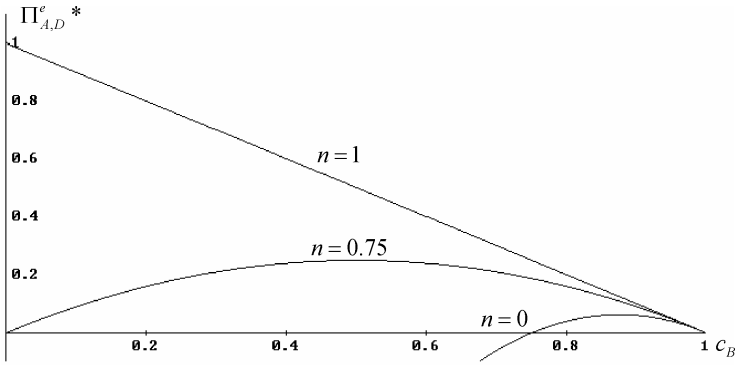

Figure 5. Impact of *n* on the deterrence profit for $\alpha_A = \alpha_B = 1$, $\gamma = c_A = 0.5$

3.2 Consistency of equilibrium paths

So far, we have derived the profit-maximizing quantities which fulfill expectations on a given path. For example, in the case of blockaded entry, it was assumed that it is not beneficial for the weaker firm to enter the market. The second step of the equilibrium analysis deals with the fact that firms may deviate from the path.

3.2.1 Blockaded entry of technology B

Suppose that the entry of technology *B* is blockaded. The possible equilibrium path with fulfilled expectations is given by:

First stage: Consumers form the expectations $y_A^e = y_{A,M}^e *$ and $y_B^e = 0$.

Second stage: Firm *A* selects the monopoly quantity $y_{A,M}^e *$.

Third stage: Firm *B* does not enter the market, i.e. $y_{B,I}^e * = 0$.

Starting with the third stage, we examine whether it is beneficial for firm *B* to choose $y_{B,I}^e * = 0$. Substituting path expectations $y_B^e = 0$ and the leader quantity $y_A = y_{A,M}^e *$ in firm *B*'s best reply, given by Equation (8), yields:

$$\text{(22)} \qquad \overline{y}_B \;=\; y_B(y_B^e = 0,\; y_A = y_{A,M}^e *) \;=\; \frac{(2-n)(\alpha_B - c_B) - \gamma(\alpha_A - c_A)}{2(2-n)}.$$

$$\text{(23)} \qquad \overline{y}_B \le 0 \;\Leftrightarrow\; c_B \ge c_{B,3} \;=\; \alpha_B - \frac{\gamma(\alpha_A - c_A)}{2-n}.$$

Proposition 2. The market entry of technology *B* is blockaded if $c_B \ge c_{B,3}$ holds.

Note that the upper bound of the incompatible duopoly, $c_{B,2}$, is always smaller than the lower bound, $c_{B,3}$, of technology B's blockaded entry:

$$c_{B,2} \;=\; \alpha_B - \frac{2\gamma(\alpha_A - c_A)}{4 - 2n - \gamma^2} \;<\; c_{B,3} \;=\; \alpha_B - \frac{\gamma(\alpha_A - c_A)}{2-n}$$

Rearranging the inequation yields

$$\frac{2\gamma(\alpha_A - c_A)}{4-2n} < \frac{2\gamma(\alpha_A - c_A)}{4-2n-\gamma^2},$$

which is always fulfilled. Hence, the blockaded entry of technology *B* excludes the incompatible duopoly.

3.2.2 Blockaded entry of technology A

The next step is to analyze under which circumstances the entry of technology *A* is blockaded. The possible equilibrium path is given by:

First stage: Consumers form the expectations $y_A^e = 0$ and $y_B^e = y_{B,M}^e{}^*$.

Second stage: Firm *A* does not enter the market, i.e. $y_A{}^* = 0$.

Third stage: Firm *B* supplies the monopoly quantity $y_{B,M}^e{}^*$.

In order to examine whether it is beneficial for firm *A* to choose $y_A{}^* = 0$, we have to derive firm *B*'s optimal reply to the leader quantity for given path expectations $y_B^e = y_{B,M}^e{}^*$:

(24) $$y_B(y_A) = \frac{2(\alpha_B - c_B) - (2-n)\gamma\, y_A}{2(2-n)}.$$

Substituting Equation (24) and $y_A^e = 0$ in firm *A*'s profit function and maximizing with respect to y_A results in firm *A*'s optimal quantity in the case where firm *A* supplies a positive quantity - i.e. it leaves the path - in the second stage:

(25) $$\bar{y}_A = \frac{\gamma(\alpha_B - c_B) - (2-n)(\alpha_A - c_A)}{(2-n)(\gamma^2 - 2)}.$$

(26) $$\bar{y}_A \le 0 \;\Leftrightarrow\; c_B \le c_{B,1} = \alpha_B - \frac{(2-n)(\alpha_A - c_A)}{\gamma}.$$

Proposition 3. The market entry of technology *A* is blockaded if $c_B \le c_{B,1}$ is given.

Note that the upper bound of technology *A*'s blockaded entry is equal to the lower bound of the incompatible duopoly. Hence, the incompatible duopoly

cannot occur as a fulfilled expectations equilibrium if the entry of technology *A* is blockaded.

3.2.3 Entry deterrence

Firm *A* can exploit its first-mover advantage in order to prevent the entry of technology *B*. But the deterrence path is only consistent if it is worthwhile for firm *A* to select the deterrence output $y^e_{A,D}*$ in the second stage, given the path expectations. The possible equilibrium path is given by:

First stage: Consumers form the expectations $y^e_A = y^e_{A,D}*$ and $y^e_B = 0$.

Second stage: Firm *A* supplies the deterrence quantity $y^e_{A,D}*$.

Third stage: Firm *B* does not enter the market, i.e. $y_B = 0$.

Suppose that firm *A* selects a lower quantity $y_A < y^e_{A,D}*$ in the second stage. In this case, it is beneficial for firm *B* to enter the market in the third stage. Its best reply for given expectations $y^e_B = 0$ is equal to:

(27) $$y_B*(y_A) = \frac{\alpha_B - c_B - \gamma\, y_A}{2} > 0 .$$

Substituting $y_B*(y_A)$ and $y^e_A = y^e_{A,D}*$ in firm *A*'s profit function yields:

(28) $$\Pi_{A,I}(y_A) = \frac{y_A(2\gamma\,\alpha_A + 2n\,\alpha_B - \gamma^2\,\alpha_B) - 2\gamma\,c_A + \gamma^2\,c_B - 2n\,c_B}{2\gamma} - \frac{(y_A)^2(2-\gamma^2)}{2} .$$

Maximizing Equation (28) with respect to y_A and substituting the deterrence quantity $y^e_{A,D}*$ results in:

(29) $$\frac{d\,\Pi_{A,I}}{d\,y_A} = \frac{2\gamma(\alpha_A - c_A) + (\gamma^2 + 2n - 4)(\alpha_B - c_B)}{2\gamma} .$$

Entry deterrence is not consistent if it is worthwhile for the leader to reduce its quantity y_A and to accept firm *B*'s market entry. In this case, the first derivative of firm *A*'s profit function must be negative:

(30) $$\frac{d\,\Pi_{A,I}}{d\,y_A} < 0 \;\Leftrightarrow\; c_B < c_{B,2}\,.$$

Note that $c_{B,2}$ is the upper bound of the incompatible duopoly. Given the deterrence output $y^e_{A,D}*$ and the deterrence expectations $y^e_A = y^e_{A,D}*$ and $y^e_B = 0$, firm *A* could increase its profit by reducing its output. Thus, entry deterrence is not consistent in this case. Rational consumers would anticipate the deviation from the deterrence path for values lower than $c_{B,2}$. However, if $c_B > c_{B,2}$ holds, firm *A* would always lower its profit by reducing the output. This is a necessary, but not sufficient, condition for the consistency of entry deterrence.

The next step is to analyze under which circumstances firm *A* would deviate from the deterrence path by increasing its output. Suppose that firm *A* chooses $y_A > y^e_{A,D}*$ in the second stage. In this case, firm *B* would not enter the market in the third stage. Firm *A*'s monopoly profit for given expectations $y^e_A = y^e_{A,D}*$ and $y^e_B = 0$ and for the actual quantity $y_B = 0$ is equal to

(31) $$\Pi_{A,M}\,(y_A) \;=\; \frac{y_A\left[\gamma(\alpha_A - c_A) + n(\alpha_B - c_B)\right]}{\gamma} - (y_A)^2\,.$$

Maximizing Equation (31) with respect to y_A and substituting the deterrence quantity $y_A = y^e_{A,D}*$ results in:

(32) $$\frac{d\,\Pi_{A,M}}{d\,y_A} \;=\; \alpha_A - c_A - \frac{(2-n)(\alpha_B - c_B)}{\gamma}\,.$$

Suppose that the first derivative of firm A's profit function is positive:

(33) $$\frac{d\,\Pi_{A,M}}{d\,y_A} > 0 \;\Leftrightarrow\; c_B > c_{B,3}\,.$$

In this case, firm *A* would select a quantity which exceeds the deterrence output. Hence, the first-stage expectations $y^e_A = y^e_{A,D}*$ are not consistent with firm *A*'s behavior in the second stage. Thus, if technology *B*'s entry is blockaded, $y^e_A = y^e_{A,M}*$ is the only equilibrium with fulfilled expectations.

Proposition 4. Entry deterrence is a fulfilled expectations equilibrium if and only if $c_{B,2} < c_B < c_{B,3}$ holds, i.e. the incompatible duopoly and the monopoly with blockaded entry of the competing technology are not feasible.

Proposition 5. Let $c'_{B,3}$ be infinitesimally smaller than $c_{B,3}$. If the network effect is positive, $n > 0$, we have: $\Pi^e_{A,D}*(c'_{B,3}) > \Pi^e_{A,D}*(c_{B,3}) = \Pi^e_{A,M}*$. For a sufficiently strong network effect $n > n_{ED}$, $\Pi^e_{A,D}*$ exceeds $\Pi^e_{A,M}*$ throughout the relevant interval $c_{B,2} < c_B < c_{B,3}$.

Proof.

We have that $\Pi^e_{A,D}*(c_{B,3}) = \Pi^e_{A,M}*$ is always fulfilled.

The first derivative of $\Pi^e_{A,D}*$ is negative at $c_{B,3}$:

$$\frac{\partial\, \Pi^e_{A,D}*(c_{B,3})}{\partial c_B} = -\frac{n(\alpha_A - c_A)}{\gamma(2-n)} < 0\,. \tag{34}$$

The limit n_{ED} follows from $\Pi^e_{A,D}*(c_{B,2}) > \Pi^e_{A,M}*$:

$$n > n_{ED} = 1 - \frac{\sqrt{2}\sqrt{(2-\gamma^2)}}{2}\,. \tag{35}$$

Since $\Pi^e_{A,D}*(c_B)$ is concave with

$$\frac{\partial^2\, \Pi^e_{A,D}*}{\partial c_B{}^2} = -\frac{2(1-n)}{\gamma^2} < 0$$

and continuous, $\Pi^e_{A,D}*(c_B) > \Pi^e_{A,M}*$ throughout the interval $c_{B,2} < c_B < c_{B,3}$.

QED

3.3 Numerical example

Figure 6 depicts the different fulfilled expectations equilibria for a numerical example. The deterrence profit, $\Pi^e_{A,D}*$, rises with decreasing marginal costs of technology *B* because the incumbent firm can credibly commit to a larger network. Since the network effects are sufficiently strong, the deterrence profit is always higher than firm *A*'s monopoly profit with blockaded entry of technology *B*.

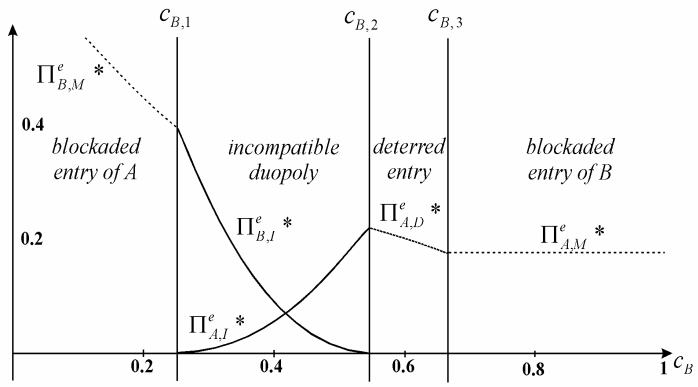

Figure 6. Fulfilled expectations equilibria for $\alpha_A = \alpha_B = 1$, $n = \gamma = 0.8$ and $c_A = 0.5$

Figure 7 shows the equilibrium areas, where the marginal costs of both technologies are variable. Note that Figure 6 is a cross-section of Figure 7 at $c_A = 0.5$. The figure illustrates that the deterrence strategy is only feasible if firm *A* has a moderate cost advantage.

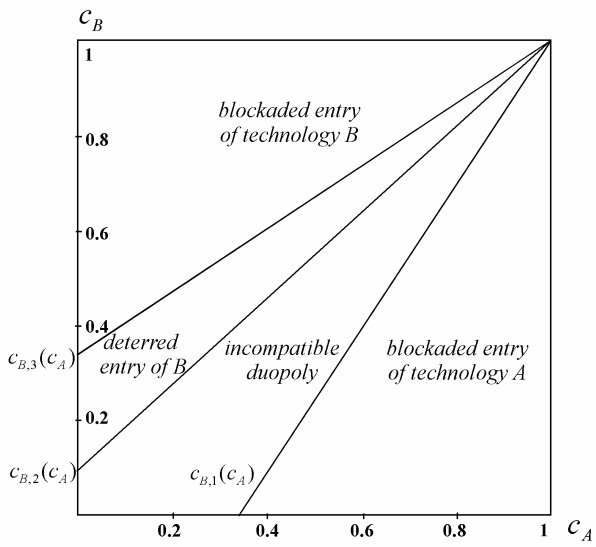

Figure 7. Two-dimensional representation of fulfilled expectations equilibria for $\alpha_A = \alpha_B = 1$, $n = \gamma = 0.8$

4. Entry deterrence vs. intra-technology competition

In this section, we will analyze the incumbent's strategic choice of whether to share its technology with the rival or to keep its technology for itself. Let us restrict the analysis to the deterrence region $c_{B,2} < c_B < c_{B,3}$. Recall that technology *A* is superior to *B* in this area. In order to exclude multiple equilibria, it is also assumed that standardization on the superior technology *A* (by deterrence or invitation) is focal.[10] The timing structure is as follows: In the first stage, firm *A* decides whether to invite its competitor into network *A* or not. This decision affects consumers' expectations in the second stage. After having invited its competitor, firm *A* selects its leader quantity in the third stage. Finally, firm *B* chooses the optimal follower quantity of good *A* in the fourth stage. It is assumed that firm *B* can either join network *A* or enter the market with its own technology *B* but not use both strategies at the same time. Moreover, suppose that both firms have the same marginal costs c_A if they produce good *A*.

The equilibrium analysis is similar to the preceding one. First, the profit-maximizing quantities that fulfill expectations on a given path are derived. Then, we will analyze under which circumstances the invitation strategy is self-enforcing, i.e. it must be beneficial for firm *B* to join voluntarily network *A* instead of selecting its own technology *B*. The last step of the equilibrium analysis deals with firm *A*'s first-stage decision, i.e. whether to invite its competitor to engage in intra-technology competition or not.

4.1 Profit-maximizing quantities with fulfilled expectations

Suppose that firm *A* has invited its competitor. In the case of intra-technology competition, the profit function of firm *A* is given by:

$$\Pi_{A,L} = y_{A,L}\left(\alpha_A - y_{A,L} - y_{A,F} + n\, y_A^e - c_A\right), \tag{36}$$

where the leader output is denoted by $y_{A,L}$ and the follower quantity by $y_{A,F}$. The profit function of firm *B* is equal to

$$\Pi_{A,F} = y_{A,F}\left(\alpha_A - y_{A,L} - y_{A,F} + n\, y_A^e - c_A\right). \tag{37}$$

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[10]Therefore, it is not necessary to analyze the invitation of firm *A* into network *B*. Suppose that both firms invite each other into their networks. This coordination game, which corresponds to the "Battle of the Sexes", has multiple expectations and equilibria respectively.

Optimal quantities for given expectations are equal to.

(38) $$y_{A,L}*(y_A^e) = \frac{\alpha_A - c_A + n\,y_A^e}{2},$$

(39) $$y_{A,F}*(y_A^e) = \frac{\alpha_A - c_A + n\,y_A^e}{4}.$$

Summing up yields the total output for given expectations:

(40) $$y_A*(y_A^e) = \frac{3(\alpha_A - c_A + n\,y_A^e)}{4}.$$

Maximum profits for given expectations are equal to:

(41) $$\Pi_{A,L}*(y_A^e) = \frac{(\alpha_A - c_A + n\,y_A^e)^2}{8},$$

(42) $$\Pi_{A,F}*(y_A^e) = \frac{(\alpha_A - c_A + n\,y_A^e)^2}{16}.$$

The fixed point condition is derived from Equation (40):

(43) $$y_A^e* = y_A*(y_A^e*) \;\Leftrightarrow\; y_A^e* = \frac{3(\alpha_A - c_A)}{4-3n}.$$

Optimal quantities and profits with fulfilled expectations are given by Equations (44)-(47):

(44) $$y_{A,L}^e* = \frac{2(\alpha_A - c_A)}{4-3n},$$

(45) $$y_{A,F}^e* = \frac{\alpha_A - c_A}{4-3n},$$

(46) $$\Pi_{A,L}^e* = \frac{2(\alpha_A - c_A)^2}{(3n-4)^2},$$

(47) $$\Pi^e_{A,F}* = \frac{(\alpha_A - c_A)^2}{(3n-4)^2}.$$

Note that the leader profit is twice as high as the follower profit. This result reflects the first mover advantage of the Stackelberg leader.

Figure 8 illustrates the impact of firm *B*'s entry on the expected network size of good *A*. Suppose that the entry of technology *B* is blockaded. In the monopoly case, A_1 represents the optimal quantity of good *A* which fulfills expectations. This quantity is given by the intersection point of $y*_{A,M}(y^e_A)$ with the 45°-line. By the entry of firm *B* into network *A*, the curve $y*_A(y^e_A)$ is shifted outward. The optimal quantity, which fulfills expectations, increases to A_2. The invitation is the only way to commit credibly to a network size which exceeds firm *A*'s profit-maximizing monopoly output. If firm *A* promised to produce the output A_2 by itself, it would not be credible because, as a monopolist, firm *A* has an incentive to reduce output for any given level of expectations exceeding A_1.

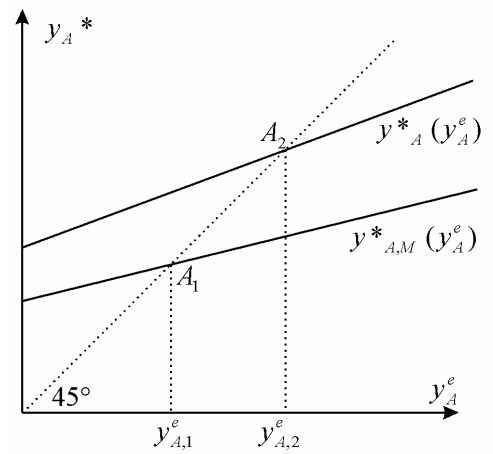

Figure 8. Impact of the invitation on the expected network size

At $y^e_A = 0$, the curve $y_A*(y^e_A)$ is above the 45°-line because of $\alpha_A > c_A$. If its slope is smaller than one, the function has an intersection with the 45°-line:

(48) $$\frac{d\,y_A*(y^e_A)}{d\,y^e_A} < 1 \;\Leftrightarrow\; n < \frac{4}{3},$$

which is always fulfilled because of the assumption $n < 1$. If firm A is a monopolist, the existence condition is relaxed. From Equation (3) follows that $n < 2$ must hold in this case.

4.2 Consistency of the invitation strategy

So far, we have derived the profit-maximizing quantities which fulfill expectations on a given path. Thus, in the case of intra-technology competition, it was assumed that it is worthwhile for firm B to join network A. Now, it must be taken into account that firm B could deviate from this path. The duopoly within market A is given by the following path:

First stage: Firm A invites its competitor into network A.

Second stage: Consumers form the expectations $y_A^e = y_{A,L}^e{}^* + y_{A,F}^e{}^*$ and $y_B^e = 0$.

Third stage: Firm A selects the leader quantity $y_{A,L}^e{}^*$ of good A.

Fourth stage: Firm B reacts with the follower quantity $y_{A,F}^e{}^*$ of good A.

Starting with the last stage, we analyze whether it is really beneficial for firm B to accept the invitation into network A. First, the profit-maximizing quantity of good B must be derived, given the leader output $y_{A,L}^e{}^*$ and the expectations $y_B^e = 0$. Substituting $y_{A,L}^e{}^*$ and $y_B^e = 0$ in firm B's best reply, given by Equation (8), yields:

$$(49) \qquad \hat{y}_B = y_B(y_B^e = 0,\ y_A = y_{A,L}^e{}^*) = \frac{(4-3n)(\alpha_B - c_B) - 2\gamma(\alpha_A - c_A)}{2(4-3n)}.$$

Firm B's maximum profit for deviating from the invitation path is given by:

$$(50) \qquad \hat{\Pi}_B = \begin{cases} \dfrac{\left[2\gamma(\alpha_A - c_A) - (4-3n)(\alpha_B - c_B)\right]^2}{4(3n-4)^2}, & \text{if } \hat{y}_B > 0 \\ 0, & \text{otherwise} \end{cases}$$

Firm B voluntarily joins network A if the follower profit within network A exceeds the deviation profit $\hat{\Pi}_B$:

$$(51) \qquad \Pi_{A,F}^e{}^* > \hat{\Pi}_B \Leftrightarrow c_B > \hat{c}_B = \alpha_B - \frac{2(\alpha_A - c_A)(1+\gamma)}{4-3n}$$

Proposition 6. Firm *B* accepts the invitation into network *A* if $c_B > \hat{c}_B$ holds. Otherwise, the invitation path cannot be a fulfilled expectations equilibrium because firm *B* would run its own technology *B*.

Figure 9 illustrates the consistency condition for the invitation path. For $c_B < \hat{c}_B$, firm *B*'s deviation profit $\hat{\Pi}_B$ exceeds its follower profit $\Pi^e_{A,F}*$ within market *A*. Thus, the invitation strategy is not feasible. If $c_B > \hat{c}_B$ is given, the invitation strategy is self-enforcing.

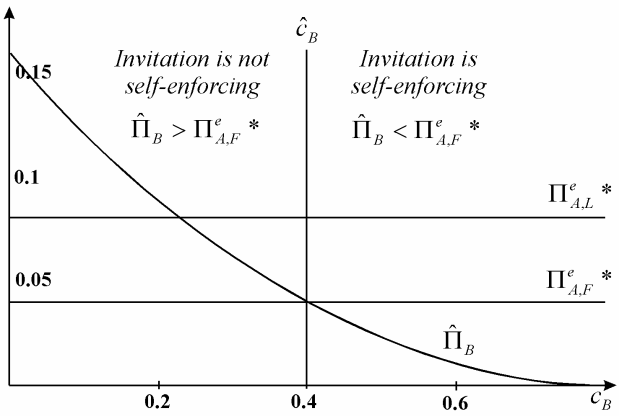

Figure 9. Consistency of the invitation strategy for $\alpha_A = \alpha_B = 1$, $n = \gamma = c_A = 0.5$

4.3 The invitation decision

It remains to be analyzed under which circumstances firm *A* will invite its competitor instead of selecting the deterrence output of good *A*. If the invitation strategy is feasible, firm *A* has to compare its invitation payoff with its deterrence payoff.

Proposition 7. Suppose that entry deterrence is feasible, i.e. $c_{B,2} < c_B < c_{B,3}$. Network *A* is closed and entry deterrence occurs as a fulfilled expectations equilibrium if $\Pi^e_{A,D}* > \Pi^e_{A,L}*$ holds. Conversely, if $\Pi^e_{A,D}* < \Pi^e_{A,L}*$ is given, the invitation of firm *B* is a fulfilled expectations equilibrium.[11]

[11]Since $\hat{c}_B < c_{B,2}$ always holds, the invitation into network *A* is self-enforcing throughout the deterrence interval $c_{B,2} < c_B < c_{B,3}$.

Figure 10 compares the deterrence profits with the profits in the case of intra-technology competition. If $\tilde{c}_B < c_B$ holds, firm A invites its competitor. For $c_{B,2} < c_B < \tilde{c}_B$, firm A selects the deterrence strategy. Thus, in this situation deterrence is a more successful commitment device than the invitation strategy.

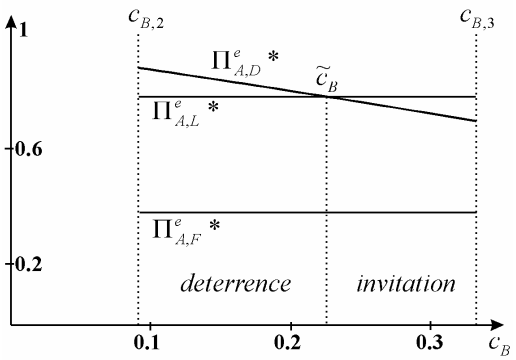

Figure 10. Invitation into network A vs. entry deterrence for $\alpha_A = \alpha_B = 1$, $n = \gamma = 0.8$ and $c_A = 0$

5. Concluding remarks

In this paper, we have modeled the problem of whether an incumbent firm has an incentive to share its technology with a rival firm or to keep its technology for itself. By sharing its technology, the incumbent credibly commits to a future network size which exceeds the profit-maximizing monopoly quantity. As a consequence, the incumbent reaps the benefits of the consumers' increased willingness to pay for the network good. What drives the model is the assumption that consumers form rational expectations about the network size before the firms are able to choose their output levels.[12] This timing structure (including the Stackelberg assumption) is the same as in the model by Econonomides (1996). Whereas Economides' model is confined to intra-technology competition, we have presented a framework dealing both with inter-technology and intra-technology competition.

[12]The model deals with rational expectations in that consumers' expectations involve all information available. Of course, in real market situations, there can be uncertainty (perhaps with respect to the pace of technological progress). See Farrell and Katz (1998) for an analysis covering other types of expectations, most notably "stubborn expectations".

We have analyzed the problem in two steps. The first step was restricted to inter-technology competition, i.e. the incumbent was assumed to keep the own technology for itself. We have seen that the fulfilled expectations equilibria depend on the relative marginal costs of both technologies. The entry of the follower may be blockaded if the incumbent firm has strong cost advantages. But if the follower has a considerable cost advantage, the incumbent's entry can be blockaded as well. On the other hand, in the case of weak cost differences, both technologies coexist in an incompatible and heterogeneous duopoly. Entry deterrence is feasible only if the incumbent has a moderate cost advantage. Each of the four possible fulfilled expectations equilibria has to meet consistency conditions which ensure the uniqueness of the equilibrium. The above results reflect the idea that markets are "tippy", i.e. the coexistence of incompatible products may be unstable if firms are dissimilar in terms of costs. Moreover, the region of the incompatible duopoly shrinks with strong network effects and with a rising degree of substitutability.

The central argument of the paper is that the incumbent may realize a higher profit in the case of entry deterrence than in the situation where the competitor's entry is blockaded. The deterrence quantity not only prevents the competitor's entry, it also increases the incumbent's network and thus consumers' willingness to pay. Furthermore, we have derived the perverse effect that the deterrence profit can rise with decreasing marginal costs of the follower because the incumbent has to supply a larger deterrence quantity with increasing strength of its rival.

In the second part of the model, we have analyzed the incumbent's choice of whether to share its technology or to insist on inter-technology competition. We have seen that the deterrence strategy can be more profitable for the incumbent (if the incumbent's cost advantage is not too strong) than the strategy of sharing its technology. Since the incumbent does not internalize the positive externalities of the invitation strategy, which exists in terms of the follower profit and in an increased consumers' surplus, one can expect the deterrence strategy to be welfare inferior. Consequently, a policy recommendation should be to oblige the incumbent firm to license its technology to the rival.

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