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The impact of compatibility on incentives to innovate and consumer benefits in a network industry

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Abstract

Compatibility and connectivity are essential elements in a network economy. Using the degree of network compatibility as a measure of market competitiveness, we consider the impact of compatibility on profit incentives to innovate in a network goods industry. That is, an increase in the degree of network compatibility possibly reduces market competitive pressure. In addition, we investigate the impact on consumer benefits (i.e., marginal consumer surplus) caused by the innovation. We demonstrate that as the degree of compatibility increases, the profit incentives to innovate first decrease, then increase (i.e., a *U*-shaped function of compatibility); but, conversely, the consumer benefits first increase, then decrease (i.e., an inverted *U*-shaped function of compatibility).

Keywords: innovation; network compatibility; a fulfilled expectation; cost-reducing R&D; Cournot duopoly

JEL Classification: D43, L13, L15, O31

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1. Introduction

Since the last decade of the 20th century, with the progression of networking and digital technologies, remarkable growth has been observed in the information and communication technology (ICT) industries, including telecommunications, Internet businesses, and social networking services. In addition, enterprises (e.g., Amazon Web Services) using the Internet of Things through networking are providing various ICT-related goods and online services, both real and virtual, to many customers, not only individual consumers but also manufacturing firms. Thus, it is apparent that research and development (R&D) in networking and information technology has become highly significant in our modern digital society.

When focusing on networking technology, compatibility (and connectivity) between goods and services as well as between networks is very important in the current network economy in which people spend increasing amounts of time and money on Internet services (e.g., e-commerce, mobile games, and search engine sites). In reality, there are various degrees of compatibility (ranging from incompatible to perfectly compatible) and of network effects among network industries. In this environment, competition in network industries is undertaken at various levels and involves a mix of strategic investments, such as process and product R&D and price and quantity competition.

Thirty years ago, Economides and White (1994) wrote their paper discussing the economic and legal (i.e., antitrust policy) implications of compatibility and the networks. In particular, they indicate that compatibility is equivalent to the more general concept of complementarity. From the perspective of complementarity and vertical relationships (e.g., merger and integration), they conclude that compatibility and the network arrangements bring benefits (and efficiencies) to firms; however, compatibility may lead to anti-competitive consequences in some cases.

Recently, relating to Economides and White (1994), Heywood et al. (2022, p. 355) discuss compatibility as follows: "the extent to which one firm's R&D may allow it to lower costs and capture customers can be limited by the lack of compatibility. In addition, it is recognized that the extent of compatibility can influence the introduction of new technology." Furthermore, Heywood et al. (2022, p. 356) comment that "reflecting this interconnection, firm compatibility decisions by network firms raise public policy issues regarding both anti-competitive behavior and reduced technological progress."

Our main research question is how such compatibility affects incentives to undertake R&D activities designed to reduce costs. That is, does an increase in compatibility improve or reduce the incentives to innovate? If an increase in the degree of compatibility reduces the incentives, is compatibility standardization policy anti-competitive? Furthermore, how does an increase in the degree of compatibility affect consumer welfare by the innovation?

There is a lot of related literature in line with Arrow (1962), Yi (1999) and Belleflamme and Vergari (2011) that is very closely related to ours. Yi (1999) assumes the number of firms to be a measure of market competition and conducts a Cournot oligopoly model with a homogeneous product market. He shows that an infinitesimal increase in the number of firms reduces the single innovating firm's incentives. Furthermore, Belleflamme and Vergari (2011) use a horizontally differentiated oligopoly model and assume the degree of product differentiation to be an inverse measure of competition. That is, if the degree of product differentiation is sufficiently large (small), the products are substitutes (differentiated). They define the incentive to innovate as an increase in the marginal profit from reducing the marginal cost, i.e., profit incentive. They demonstrate that the profit incentive first decreases, then increases as the degree of product differentiation decreases, in other words, the degree of product substitutability increases. This result holds in the cases of Cournot quantity and Bertrand price competition.

Our approach follows the frame of Belleflamme and Vergari (2011), in which they assume that there is only one innovator, which cannot be imitated by rival firms. This assumption implies that there is no competitive threat from any rival firm's innovation, in other words, no strategic relationships between firms' R&D investments competition. Assuming a homogenous product with network externalities and compatibility between the products, we will show the same result for the profit incentive as Belleflamme and Vergari (2011).

Furthermore, the studies of Buccella et al. (2023) and Shrivastav (2021), which are different from our approach, assume a standard quadratic utility function with network externalities and consider R&D investments competition between firms. Based on a horizontally differentiated duopoly model with network externalities, Shrivastav (2021) demonstrates the ranking of R&D investments in the cases of Bertrand and Cournot duopolistic competition. Furthermore, Shrivastav (2021, Appendix B) shows the effects of compatibility on R&D investment levels. That is, he points out that the following results hold in both Bertrand and Cournot competition:

Result (i): If R&D investment levels are strategic complements, as compatibility increases, R&D investment levels increase.

Result (ii): If R&D investment levels are strategic substitutes, as compatibility increases, R&D investment levels first decrease, and then increase.

As shown below, Result (ii) is like ours; however, we show that (ii) holds if the degree of network externalities is relatively large. In addition, we will demonstrate that an increase in the degree of compatibility monotonically decreases incentives to innovate if the degree of network externalities is relatively small.

Buccella et al. (2023) assume a homogeneous product with network externalities and technological spillover effects. They compare the investments, quantities, and profits in the equilibrium in the case of full compatibility with those in the case of incompatibility. In particular, if there are no technological spillover effects, we can show that the investment level in the case of incompatibility is larger than in the case of full compatibility.

As for the novelty of this paper, first, in addition to an infinitesimal analysis, we investigate the impact on the incentives in the case of discrete innovation and confirm our results. Second, we examine the impact of compatibility on consumer surplus. The problem is not explicitly examined in the related literature. In particular, we demonstrate the conditions under which an increase in the degree of compatibility affects the marginal benefits of consumers. That is, an increase in the degree of compatibility monotonically increases marginal consumer surplus, if the degree of network externalities is relatively small. Furthermore, if the degree of network externalities is relatively large, the marginal consumer surplus first increases, then decreases. This result is opposite to that in the analysis of the innovating firm's incentives.

2. The Model

2.1 Setup

We assume the following linear inverse demand function:[1]

$$p_i = a - q_i - q_j + n\left(q_i^e + \phi q_j^e\right), \quad i, j = 1, 2, \quad i \neq j, \tag{1}$$

where a implies the intrinsic size of a network product market, $n \in [0,1)$ denotes network externalities, and $\phi \in [0,1]$ denotes the degree of compatibility (or the quality of connectivity).[2] If $\phi = 1\,(0)$, the products are perfectly compatible (incompatible). In particular, the homogeneous product associated with network externalities has two conflicting features, that is, perfect substitutability and complementarity. $q_i^e\left(q_j^e\right)$ is an expected output

[1] See the online appendix of Buccella, et al. (2023).

[2] We assume a two-way network system, where compatibility (connectivity) between the products is expressed as $\phi_i = \phi_j = \phi$.

of *firm i* (*j*) and $q_i^e + \phi q_j^e$ expresses the expected network size for *firm i*. Thus, $N_i \equiv n\left(q_i^e + \phi q_j^e\right)$ is the expected network effect for *firm i*.

Assuming a constant marginal cost of production, i.e., c_i, the profit function of *firm i* is expressed as $\pi_i = \left(p_i - c_i\right)q_i$, where $a > c_i \geq 0$, $i = 0,1$. We assume that *firm 0* is the only firm with the capability to invest in R&D to reduce the marginal cost. This assumption implies how much a firm is willing to pay for acquiring the innovation and being its single user (see Belleflamme and Vergari, p. 12, 2011). Furthermore, regarding consumers' expectations of network sizes, we assume passive (rational) expectations and adopt the concept of a fulfilled expectations equilibrium (Katz and Shapiro, 1985).[3]

2.2 Compatibility and incentives to innovate in an infinitesimal analysis

The first-order condition (FOC) for profit maximization by *firm i* is given by $\dfrac{\partial \pi_i}{\partial q_i} = p_i - c_i - q_i = 0$, $i = 0,1$. Using Equation (1), at the fulfilled expectations Cournot equilibrium, i.e., $q_i^e = q_i$, we derive the following output of *firm i*:

$$q_i\left[c_i, c_j; \phi\right] = \frac{(2-n)\left(a - c_i\right) - \Gamma\left(a - c_j\right)}{D}, \quad i, j = 0,1, \quad i \neq j, \tag{2}$$

where $\Gamma \equiv 1 - n\phi > 0$, and $D \equiv \left\{1 - n(1-\phi)\right\}\left\{3 - n(1+\phi)\right\} > 0$. Hereinafter, we call the network effect multiplied by the degree of compatibility, i.e., $n\phi\left(<1\right)$, network compatibility. Parameter Γ implies the measure of competitiveness. That is, if $\phi = 0\ (1)$, then $\Gamma = 1\ \left(1 - n\right)$. The products are incompatible (perfectly compatible), in other words, the homogeneous product associated with network externalities is perfectly (partly) substitutable.

[3] In the case of responsive (active) expectations, we have the same results as in our model.

Thus, the degree of competitiveness becomes high (low). As mentioned above, if $\phi = 1$, although the property of the product is homogenous, the products are complementary through the perfect network compatibility. This implies that the market competitiveness between the firms reduces as the degree of compatibility increases, i.e., $\phi \to 1$.

Using Equation (2), the effects of an infinitesimal cost reduction by *firm 0*, i.e., $-dc_0 (> 0)$, on the output of the firms are given by:

$$-\frac{dq_0}{dc_0} = \frac{2-n}{D} > 0, \tag{3.1}$$

$$-\frac{dq_1}{dc_0} = -\frac{\Gamma}{D} < 0. \tag{3.2}$$

For the following analysis, we call Equation (3.1) the cost-reducing effect. Equation (3.2) implies that there are strategic substitutes between the firms. Furthermore, as the degree of network compatibility increases, the magnitude of a decrease in the rival firm's output reduces.

The impact of an increase in the degree of compatibility on the output is given by:

$$\frac{dq_i}{d\phi} = \frac{n\left[\left\{(2-n)^2 + \Gamma^2\right\}(a-c_j) - 2(2-n)\Gamma(a-c_i)\right]}{D^2}, \quad i, j = 0,1, \quad i \neq j, \tag{4}$$

In Equation (4), we assume symmetric marginal costs at the initial situation. As the degree of compatibility increases, the output increases (see (A.2) in Appendix 1). That is, taking into account Equation (3.2), an increase in the degree of compatibility expands market sizes, and thus output; however, it reduces market competitiveness.

We now examine the impact of compatibility on the incentive to innovate, that is, the effect of an increase in the degree of compatibility on the marginal profit caused by the cost reduction. Using the FOC, the equilibrium profit of firm i is expressed as $\pi_i = \left(p_i - c_i\right)q_i = \left(q_i\left[c_i, c_j; \phi\right]\right)^2$, $i, j = 0,1,$ $i \neq j$. The marginal profit of an infinitesimal cost reduction to *firm 0* is given by:

$$-\frac{d\pi_0}{dc_0} = -\frac{d(p_0 - c_0)}{dc_0} q_0 + (p_0 - c_0)\left(-\frac{dq_0}{dc_0}\right)$$
$$= 2(p_0 - c_0)\left(-\frac{dq_0}{dc_0}\right) = 2q_0\left(-\frac{dq_0}{dc_0}\right), \tag{5}$$

where $p_0 - c_0 = q_0$, and thus, $-\frac{d(p_0 - c_0)}{dc_0} = -\frac{dq_0}{dc_0}$. Using Equation (3.1), Equation (5) is rewritten as:

$$-\frac{d\pi_0}{dc_0} = \frac{2(2-n)}{D} q_0\left[c_0, c_1; \phi\right] = 2(2-n) X_0\left[c_0, c_1; \phi\right](>0), \tag{6}$$

where $X_0\left[c_0, c_1; \phi\right] \equiv \frac{(2-n)(a-c_0) - \Gamma(a-c_1)}{D^2}$. Hereinafter, we define $X_0\left[c_0, c_1; \phi\right]$ as the benefit (marginal profit) function of an infinitesimal cost reduction for *firm 0*.

First, we investigate the effect of an increase in the degree of compatibility on the benefit. Based on Equation (6), we obtain the following:

$$\frac{dX_0}{d\phi} = \frac{n\left\langle\left\{(2-n)^2 + 3\Gamma^2\right\}(a-c_1) - 4(2-n)\Gamma(a-c_0)\right\rangle}{D^3}. \tag{7}$$

Assuming that the firms' marginal costs are equal at the initial situation, i.e., $c_0 = c_1 = c(>0)$, and based on Equation (7), we derive the following relationship:

$$\left.\frac{dX_0}{d\phi}\right|_{c_0=c_1=c} = \frac{nA\{1-n(1-\phi)\}\{3n\phi-(1+n)\}}{D^3} > (<) 0 \Leftrightarrow \phi > (<) \hat{\phi}[n] \equiv \frac{1+n}{3n}, \tag{8}$$

where $A \equiv a - c > 0$.[4] With respect to the economic implications of the effect of an increase in the degree of compatibility on the benefit function as shown in Equations (7) and (8), see

[4] $\lim_{n\to+0}\hat{\phi}[n] = \infty$, $\lim_{n\to1}\hat{\phi}[n] = \frac{2}{3}$, and $\hat{\phi}\left[n = \frac{1}{2}\right] = 1$.

Appendix 1.

Second, we have

$$X_0\left[\phi\right] \equiv \frac{A}{\{1-n(1-\phi)\}\{3-n(1+\phi)\}^2}. \tag{9}$$

Based on Equation (8), if $\frac{1}{2} > n,$ it holds that $\hat{\phi}\left[n\right] > 1.$ Thus, we have $\left.\frac{dX_0}{d\phi}\right|_{c_0=c_1=c} < 0.$

Conversely, if $\frac{1}{2} < n,$ the benefit is a *U*-shaped function of compatibility and the value of $X_0\left[\phi\right]$ reaches its minimum value at $\hat{\phi}\left[n\right].$

Furthermore, using Equation (9), it holds that $X_0\left[\phi=0\right] > X_0\left[\phi=1\right].$ In particular, the benefit under the incompatible (i.e., a firm-specific) network system is larger than that under the perfectly compatible (i.e., a single-industry-wide) one. This implies that compatibility standardization between individual firms' network systems may reduce incentives to cost-reducing R&D investments. If assuming an investment cost function, which is usually assumed in the literature of R&D investments competition, we can derive the same result as that of Buccella et al. (2023).

We summarize the results derived above as the following Proposition 1.

Proposition 1

(i) If $\frac{1}{2} > n,$ *an increase in the degree of compatibility reduces the benefit and thus decreases incentives to innovate.*

(ii) If $1 > n > \frac{1}{2},$ *the effect of an increase in the degree of compatibility on the benefit*

(marginal profit) is as follows: $\left.\frac{dX_0}{d\phi}\right|_{c_0=c_1=c} > (<) 0 \Leftrightarrow \phi > (<) \hat{\phi}[n]$. *Thus, the larger (the smaller) the degree of network compatibility, the higher (lower) the incentives to innovate.*

Let us consider the economic implications of Proposition 1. How an increase in the degree of compatibility affects incentives to innovate depends on the properties of the network products, such as the degree of product substitutability and network compatibility. In particular, if the homogenous product is a perfect substitute, its degree is always that of network compatibility. In particular, in Proposition 1 (i), where the network effect is smaller than a half, an increase in the degree of compatibility affects incentives to innovate negatively. This is because the direct positive output-expansion effect is smaller than the indirect negative cost-reduction effect.

However, in Proposition 1 (ii), where the network effect is larger than a half, an increase in the degree of compatibility reduces the magnitude of the negative indirect cost-reduction effect whereas it increases that of the positive output-expansion effect. Thus, as network compatibility increases, the benefit function (marginal profit) first decreases, then increases. This result is the same as that of Belleflamme and Vergari (Proposition 1, 2011) and of Shrivastav (p. 159, p. 162, 2021).

Remark. A discrete innovation

We examine the effect of an increase in the degree of compatibility on the benefit in the case of a discrete (but, not drastic) innovation and reconfirm Proposition 1.

We assume that $c_1 = c_{0(before)} = \overline{c}$ before the innovation and that $c_{0(after)} = \underline{c}\left(< \overline{c}\right)$ after the innovation by *firm 0*. Using the definition of the profit in the equilibrium before and after the innovation, we derive the following increase in *firm 0*'s profit.

$$\Delta\pi_0 \equiv \pi_{0(after)} - \pi_{0(before)} = \left(q_0\left[c_{0(after)} = \underline{c}, c_1 = \overline{c}; \phi\right]\right)^2 - \left(q_0\left[c_{0(before)} = c_1 = \overline{c}; \phi\right]\right)^2$$

$$= \left\langle q_0\left[\underline{c}, \overline{c}; \phi\right] - q_0\left[\overline{c}; \phi\right]\right\rangle \left\langle q_0\left[\underline{c}, \overline{c}; \phi\right] + q_0\left[\overline{c}; \phi\right]\right\rangle.$$

Based on Equation (2), the above equation is revised as:

$$\Delta\pi_0 = \left\langle \frac{(2-n)(\overline{c}-\underline{c})}{D} \right\rangle \left\langle \frac{2\{1-n(1-\phi)\}(a-\overline{c}) + (2-n)(\overline{c}-\underline{c})}{D} \right\rangle. \tag{10}$$

Thus, the effect of an increase in the degree of compatibility on the discrete benefit is given by:

$$\frac{d\Delta\pi_0}{d\phi} = G\left\langle (a-\overline{c})D - 2\Gamma\left[2\{1-n(1-\phi)\}(a-\overline{c}) + (2-n)(\overline{c}-\underline{c})\right]\right\rangle, \tag{11}$$

where $G \equiv \dfrac{2n(2-n)(\overline{c}-\underline{c})}{D^3} > 0.$ Based on Equation (11), we obtain the following relationship:

$$\begin{aligned} &\frac{d\Delta\pi_0}{d\phi} > (<)0 \\ &\Leftrightarrow \overline{A}\{1-n(1-\phi)\}\{3n\phi-(1+n)\} - 2(1-n\phi)(2-n)(\overline{c}-\underline{c}) > (<)0, \end{aligned} \tag{12}$$

where $\overline{A} \equiv a - \overline{c} > 0.$[5] In view of Equation (12), and using Equation (8), we directly obtain the following results.

Result 1: If $\phi \le \hat{\phi}[n]$, it holds that $\dfrac{d\Delta\pi_0}{d\phi} < 0.$

Result 2: If $\phi > \hat{\phi}[n]$, the following relationship holds:

$$\frac{d\Delta\pi_0}{d\phi} > (<)0 \Leftrightarrow \frac{\overline{A}\{1-n(1-\phi)\}\{3n\phi-(1+n)\}}{2(1-n\phi)(2-n)} > (<)\overline{c}-\underline{c}.$$

[5] Regarding Equation (12), if $\overline{c}-\underline{c} \to 0$, we have Equation (8).

Result 1 corresponds to Proposition 1 (i), where the negative cost-reduction effect outweighs the positive output-expansion effect because of smaller network compatibility, i.e., $n\phi \le n\hat{\phi}\left[n\right]$. Thus, because an increase in the degree of compatibility decreases the discrete benefit, the impact of network compatibility on the incentives to innovate is negative.

Result 2, where the network compatibility is larger, i.e., $n\phi > n\hat{\phi}\left[n\right]$, implies that the impact depends on the degree of cost differences between before and after the innovation. In particular, if the degree of cost differences is sufficiently small, i.e., $\overline{c} - \underline{c} \,\square\, 0$, an increase in the degree of compatibility increases the discrete benefit. This corresponds to Proposition 1 (ii) in the infinitesimal analysis. However, even with larger network compatibility, if the degree of cost differences is sufficiently large, an increase in the degree of compatibility decreases the discrete benefit. This is because the benefits of innovating *firm 0* are spilled over rival *firm 1* by larger network compatibility. This does not hold in the infinitesimal analysis.

2.3 The effect on consumer benefits

We consider the impact of compatibility on consumer benefits (marginal consumer surplus) by cost reduction. Using the utility function of Buccella, et al. (the online appendix, 2023) and Equation (1), consumer surplus at the equilibrium is given by $CS = \frac{1}{2}\left\{\left(1-n\right)\left[(q_0)^2 + (q_1)^2\right] + 2\Gamma q_0 q_1\right\}$. Thus, we obtain the following effect of an infinitesimal cost reduction by *firm 0* on consumer surplus:

$$-\frac{dCS}{dc_0} = \left\{\left[\left(1-n\right)q_0 + \Gamma q_1\right]\left(-\frac{dq_0}{dc_0}\right) + \left[\left(1-n\right)q_1 + \Gamma q_0\right]\left(-\frac{dq_1}{dc_0}\right)\right\}. \tag{13}$$

Given Equation (13), using Equation (1) at the fulfilled expectations equilibrium, we derive $\left(1-n\right)q_i + \Gamma q_j = a - p_i\left(>0\right)$, $i, j = 0,1, \quad i \ne j$. This implies an increment in consumer surplus per a unit of output. Assuming symmetric marginal costs at the initial situation, it holds that $q_0 = q_1 = \dfrac{A}{3 - n(1+\phi)}$. Equation (13) can be rewritten as $-\left.\dfrac{dCS}{dc_0}\right|_{c_0=c_1=c} = \dfrac{\{2-n(1+\phi)\}A}{\{3-n(1+\phi)\}^2}\left(\equiv Z_0[\phi]\right) > 0,$ where $-\dfrac{dCS}{dc_0}$ is the marginal consumer surplus caused by the cost reduction. Hereinafter, we call it as consumer benefits.

Given Equation (13), we derive the following relationship:

$$\left.\frac{dZ_0}{d\phi}\right|_{c_0=c_1=c} = \frac{nA(1-n-n\phi)}{\{3-n(1+\phi)\}^3} > (<) 0 \Leftrightarrow \frac{1-n}{n} \equiv \tilde{\phi}[n] > (<) \phi. \quad (14)$$

We summarize the results derived above as Proposition 2.

Proposition 2

(i) If $\dfrac{1}{2} > n,$ *an increase in the degree of compatibility increases consumer benefits, i.e..* $\left.\dfrac{dZ_0}{d\phi}\right|_{c_0=c_1=c} > 0.$

(ii) If $1 > n > \dfrac{1}{2},$ *the effect of an increase in the degree of compatibility on consumer benefits (marginal consumer surplus) is as follows:* $\left.\dfrac{dZ_0}{d\phi}\right|_{c_0=c_1=c} > (<) 0 \Leftrightarrow \tilde{\phi}[n] > (<) \phi.$

Unless the degree of compatibility is sufficiently large, an increase in the degree of compatibility improves consumer benefits. Conversely, if the degree of network externalities is sufficiently large, e.g., under a single-industry-wide network system $(\phi = 1),$ consumer benefits become smaller because of the cost-reducing innovation.

Regarding the implications of Proposition 2, Equation (13) can be revised as follows: $-\frac{dCS}{dc_0} = \left\{ (a - p_0)\left(-\frac{dq_0}{dc_0} \right) + (a - p_1)\left(-\frac{dq_1}{dc_0} \right) \right\}$. Thus, with the symmetric marginal costs in the initial situation, the equation is given by:

$$-\frac{dCS}{dc_0}\bigg|_{c_0=c_1=c} = (a - p_0)\left\{ \left(-\frac{dq_0}{dc_0} \right) + \left(-\frac{dq_1}{dc_0} \right) \right\}, \text{ where } p_0 = p_1.$$

In this case, we can divide the impacts of an increase in the degree of compatibility into the two parts: $\frac{d(a - p_0)}{d\phi} < 0$ and $\frac{d\left\{ \left(-\frac{dq_0}{dc_0} \right) + \left(-\frac{dq_1}{dc_0} \right) \right\}}{d\phi} > 0$. The former denotes the direct impact on marginal consumer surplus, which is negative because of an increase in the price. The latter denotes the indirect impact on the cost-reducing effects on the outputs. If the degree of network externalities themselves is sufficiently small, the latter over-weights the former, so that an increase in the degree of compatibility increases consumer benefits (Proposition 2 (i)). However, if the degree of network externalities is sufficiently large, as the degree of compatibility increases, the magnitude of the positive cost-reducing effects falls whereas that of the negative marginal consumer surplus effect increases by prices increasing. As a result, consumer benefits first increase, then decrease as the degree of compatibility increases (Proposition 2 (ii)).

Furthermore, consumer benefits in the cases of incompatibility (perfect compatibility) are given by $-\frac{dCS}{dc_0}\Big|_{\phi=0} = \frac{(2-n)A}{(3-n)^2} = Z_0[\phi = 0]$ $\left(-\frac{dCS}{dc_0}\Big|_{\phi=1} = \frac{(2-2n)A}{(3-2n)^2} = Z_0[\phi = 1] \right)$.

Thus, we derive the following relationship:

$$Z_0[\phi = 0] > (<) Z_0[\phi = 1] \Leftrightarrow n > (<) \frac{3-\sqrt{3}}{2}\left(> \frac{1}{2} \right). \tag{15}$$

2.4 Conflict of benefits between the innovating firm and consumers

Based on Propositions 1 (i) and 2 (i), it is clear that the innovating firm and consumers are rivals for the benefits if $n < \frac{1}{2}$. Furthermore, taking Propositions 1 (ii) and 2 (ii), the marginal profit is a U-shaped function of the degree of compatibility. On the other hand, the marginal consumer surplus is an inverse U-shaped function of the degree of compatibility. Does this result imply conflict of benefits between the innovating firm and consumers?

Using Equations (8) and (14), we can draw Figure 1 and summarize the results as the following Corollary.[6]

Corollary 1

There is rivalry of benefits between the innovating firm and consumers under the following conditions: (i) $n < \frac{1}{2}$, *and (ii) if either* $0 \le \phi < \tilde{\phi}[n]$ *or* $\hat{\phi}[n] < \phi \le 1$, *for* $\frac{1}{2} < n < 1$. *However, if* $\tilde{\phi}[n] < \phi < \hat{\phi}[n]$, *the benefits for the innovating firm and consumers decrease together as an increase in the degree of compatibility increases.*

3. Conclusion

In this paper, we investigate Cournot duopoly in a market for a homogenous product with network externalities. That is, the nature of the product itself is a perfect substitute, whereas the

[6] In Figure 1, it holds that $Z_0[\phi = 0] > Z_0[\phi = 1]$, given that $n > \frac{3-\sqrt{3}}{2}$. Otherwise, the opposite result arises.

products are complementary thorough compatibility between the firms. Thus, as the degree of compatibility increases the degree of competitiveness decreases.

First, we have considered how compatibility and connectivity between products and services affects the profit incentive of the single innovator (user of the license). We have demonstrated that the impact on the profit incentive is not monotonic, but rather is *U*-shaped in the degree of compatibility, given strong network externalities.[7] As the degree of compatibility increases, in other words, as the degree of competitiveness falls, the profit incentive first decreases, then increases because of market expansion through increasing network compatibility.

Furthermore, the magnitude of the profit incentive in the case of incompatibility is larger than in the case of perfect compatibility. This implies that the profit incentive is large when the degree of competitiveness is high.

Second, we have denoted the incremental consumer surplus as the marginal benefit for consumers. The impact on marginal consumer benefit is also not monotonic, but rather is an inverse *U*-shaped function, which is opposite to the results of the impact on profit incentive. That is, as the degree of compatibility increases, the marginal consumer benefit first increases, then decreases. That is, first, because the degree of competitiveness is relatively large, the marginal consumer benefit increases. Then, an increase in the degree of compatibility mitigates market competitiveness, and thus, the magnitude of marginal consumer benefit decreases.

There are some remaining issues that we plan to consider in our future research. First, we should confirm our main results by extending our duopolistic model to an oligopolistic one. Second, we have dealt with the single innovator case. This implies there is no competitive threat from the rival firm. Thus, we should investigate the impact of compatibility and connectivity on the strategic (process and product) R&D competition. Third, we have analyzed the impact

[7] Under weak network externalities, the profit incentive is monotonically decreases as the degree of compatibility increases.

of compatibility assuming that compatibility is exogenously given. However, as Heywood et al. (2022) examine endogenous choice of compatibility, we should extend the model to introducing a stage involving an endogenous compatibility decision and examine the resulting impact on R&D activities. Finally, we have compared incentives under perfect compatibility with those under incompatibility. In this case, the perfect compatibility case weakens incentives to innovate compared with the incompatibility case. This result implies that standardization of network systems may reduce firms' innovative activities in network industries. However, we have not explicitly discussed the policy perspectives and implications of the model. We should examine optimal compatibility standardization and/or connectivity between various products and services in future research.

Appendix 1.

We discuss the economic implications of the effect of an increase in the degree of compatibility on the benefit function as shown in Equations (7) and (8). Based on Equation (6), it holds that $\dfrac{dX_0}{d\phi} = \dfrac{d\left(-\dfrac{d\pi_0}{dc_0}\right)}{2(2-n)d\phi}$. Using Equation (5), the effects on the benefit function are decomposed into two parts:

$$\frac{d\left(-\dfrac{d\pi_0}{dc_0}\right)}{2d\phi} = \left(\frac{dq_0}{d\phi}\right)\left(-\frac{dq_0}{dc_0}\right) + q_0 \frac{d\left(-\dfrac{dq_0}{dc_0}\right)}{d\phi}. \tag{A.1}$$

In the first term on the right-hand side of Equation (A.1), using Equation (4), we have

$$\left.\frac{dq_0}{d\phi}\right|_{c_0=c_1=c} = \frac{nA}{\{3-n(1+\phi)\}^2} > 0. \tag{A.2}$$

This equation implies that the effect of an increase in the degree of compatibility on output of innovating *firm 0* is positive because of direct network effects (hereinafter, we refer to this as an output-expansion effect). However, regarding the second term, the effect of an increase in the degree of compatibility on the cost-reduction effect is negative:

$$\left.\frac{d\left(-\dfrac{dq_0}{dc_0}\right)}{d\phi}\right|_{c_0=c_1=c} = -\frac{2n(2-n)\Gamma}{D^2} < 0. \tag{A.3}$$

An increase in the degree of compatibility reduces the magnitude of the cost-reduction effect. In this case, the higher the degree of compatibility, the lower the degree of $\Gamma(\Box\, 1-n)$. In this case, in view of Equation (3.2), although the cost reduction itself decreases the output of rival *firm 1*, an increase in the degree of compatibility eases the degree of the decrease in the output of *firm 1*. In turn, the decrease in the price of *firm 0* becomes large. This affects the marginal profit of *firm 0* negatively. Conversely, for example, $\Gamma \square 1$ if $\phi \to 0,$ the decrease in the price becomes small, such that the effect on the marginal profit of *firm 0* can be positive.

Equation (A.1) can be rewritten as:

$$\frac{d\left(-\frac{d\pi_0}{dc_0}\right)}{2d\phi} = \left(\frac{q_0}{\phi}\right)\left(-\frac{dq_0}{dc_0}\right)\left\langle \left(\frac{dq_0}{d\phi}\right)\left(\frac{\phi}{q_0}\right) + \frac{d\left(-\frac{dq_0}{dc_0}\right)}{d\phi}\frac{\phi}{\left(-\frac{dq_0}{dc_0}\right)} \right\rangle, \tag{A.4}$$

where $\left(\frac{dq_0}{d\phi}\right)\left(\frac{\phi}{q_0}\right)$ denotes the elasticity of the output-expansion effect in relation to the degree of compatibility and $\frac{d\left(-\frac{dq_0}{dc_0}\right)}{d\phi}\frac{\phi}{\left(-\frac{dq_0}{dc_0}\right)}$ denotes the elasticity of the cost-reduction effect in relation to the degree of compatibility. In particular, the term in parentheses in Equation (A.4) can be rewritten as:

$$\langle \bullet \rangle = \frac{n\phi}{3-n(1+\phi)} - \frac{2n\phi(1-n\phi)}{\{1-n(1-\phi)\}\{3-n(1+\phi)\}} = \frac{n\phi}{3-n(1+\phi)}\left\{1-\frac{2(1-n\phi)}{1-n(1-\phi)}\right\}.$$

The above equation indicates the relationship between the elasticities of the output-expansion and the cost-reduction effects. Therefore, using Equation (A.4), we derive Equations (8).

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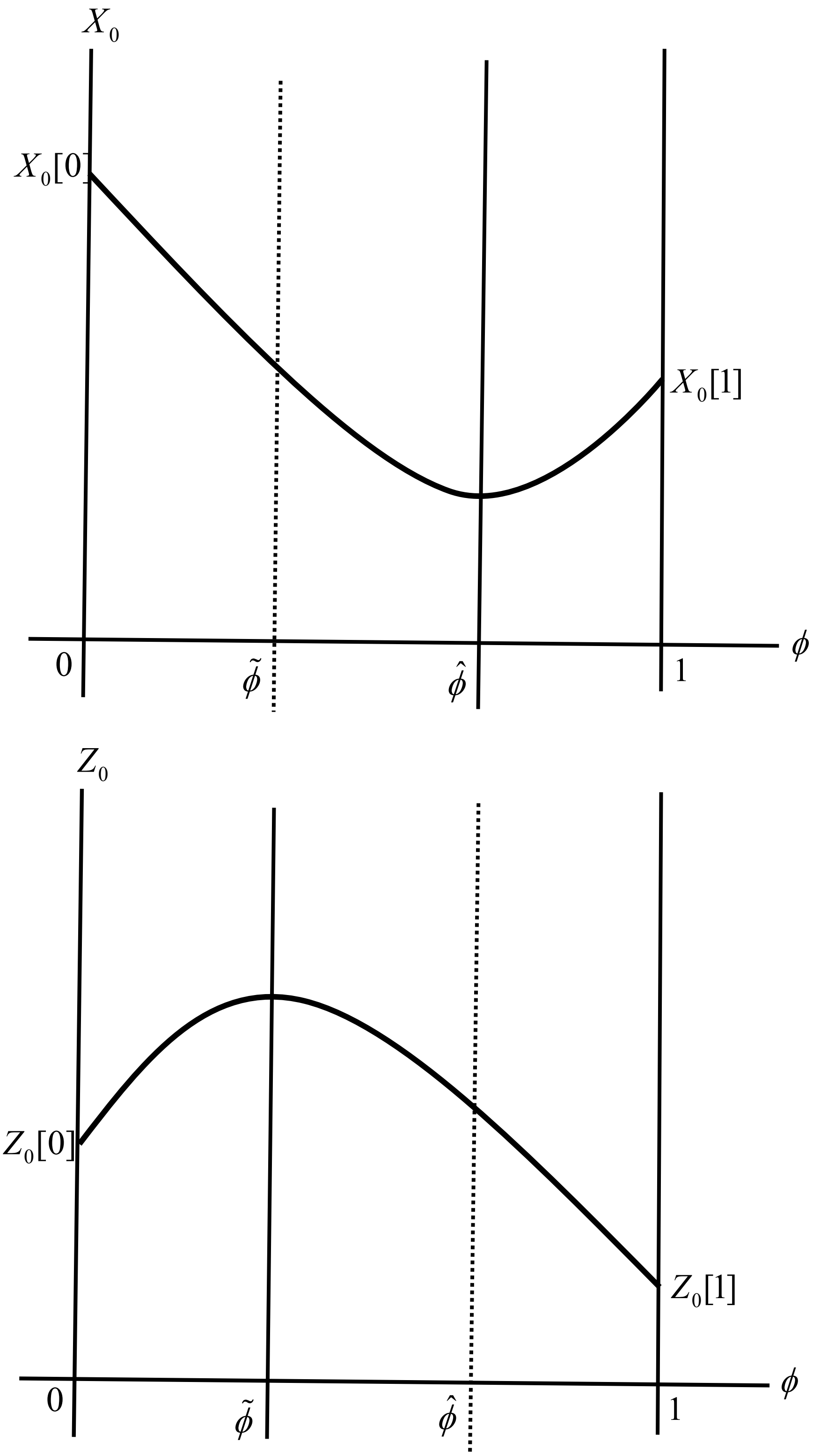
Figure 1



X_0
$X_0[0]$
$X_0[1]$
0
$\tilde{\phi}$
$\hat{\phi}$
1
ϕ
Z_0
$Z_0[0]$
$Z_0[1]$
0
$\tilde{\phi}$
$\hat{\phi}$
1
ϕ