DISCUSSION PAPER SERIES

Discussion paper No. 310

Welfare Effect of Network Compatibility Promotion under Strategic R&D Competition: The Role of Consumer Expectations in a Hotelling Model

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April 2026

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Welfare Effect of Network Compatibility Promotion under Strategic R&D Competition: The Role of Consumer Expectations in a Hotelling Model †

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Abstract
We conduct welfare analysis of an improvement in compatibility in a network goods market, where firms compete on price and research and development (R&D) activity. Using a Hotelling model, we explore the impact of compatibility on a firm's R&D activity and on producer surplus, consumer surplus, and social welfare. Focusing on the difference in the formation of consumer expectations for network sizes, i.e., rational and active expectations, we demonstrate the following. First, under rational (active) expectations, an improvement in compatibility reduces (does not affect) a firm's R&D activity, but increases (decreases) consumer surplus. However, except for perfect compatibility, although the level of R&D activity is greater under rational expectations than under active expectations, consumer surplus is smaller under rational expectations than under active expectations. Second, regardless of the difference in the formation of consumer expectations, an improvement in compatibility increases producer surplus and social welfare. In addition, producer surplus and social welfare are greater under rational expectations than under active expectations. Finally, we consider the implications of social optimality for perfect compatibility.

Keywords
Network externality, compatibility, strategic R&D competition, Hotelling linear market, fulfilled expectation equilibrium, rational expectation, active expectation

JEL Classifications
L13, L15, L31, L32, D43

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† A part of the first draft of this paper was presented at the Brown Bag Seminars organized by the Department of Economics at Simon Fraser University. Many participants provided useful comments, for which I would like to express my gratitude. I owe much to Nicolas Schmitt for his advice. Any errors or omissions are the sole responsibility of the author.
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1. Introduction

In the digital economy since the 21st. century, networks have not only spread to all economic activities but also to every aspect of our lives. For example, people are addicted to a cellphone, with which they rely on various applications such as social network services, electronic (e-)markets (e.g., e-commerce and e-payments), search engine sites, mobile games, and so on. Under such an environment, the functions of compatibility, connectivity, and interoperability between network goods and services are critically important for users, i.e., consumers and firms. Accordingly, more compatibility between network goods and services and between platforms are desirable for users.[1] Çavuş (2025) explores the effect of interoperability on innovation in the context of the Digital Markets Act (DMA) and European Union (EU) competition law. Although "vertical interoperability" favors incentives for small- and medium-sized enterprises, the impact of "horizontal interoperability" on innovation is uncertain.[2] In addition, if the requisite fees increase and/or the quality of network goods and services deteriorates, would compatibility really be preferable for users? For example, we often observe that digital markets tend to become monopolistic or more highly concentrated over time (e.g., merger and acquisition between digital companies), which leads to a winner-takes-all or a winner-takes-most situation, as has been the case for Google, Apple, Facebook, Amazon, and Microsoft. This undesirable characteristic of digital markets may limit the potential for

[1] For the analysis of compatibility promotion between platforms, see Spaeth and Niederhöfer (2022).

[2] Çavuş (2025) defines "horizontal interoperability" as the form of interconnection between users of network goods and services. Network compatibility in our model corresponds to the horizontal interoperability.

competition.

Economides and White (1994) argue that compatibility is equivalent to the more general concept of complementarity, and conclude that network arrangements typically bring benefits to firms, whereas compatibility may lead to anticompetitive consequences. Similarly, Heywood et al. (2022) contend that compatibility decisions by network firms raise public policy issues regarding both anticompetitive behavior and reduced technological progress. Relating to this point, Shy (2001) also argues that compatibility is anticompetitive.

The purpose of this paper is to demonstrate how an improvement in compatibility between network goods and services provided by firms affects consumers, firms, and thus, social welfare in a network market, where firms compete on prices and research and development (R&D) activities. In particular, we will examine the impact of compatibility promotion on consumer surplus in the short run given exogenous R&D activities, and in the long run, endogenously determined R&D activities. When conducting the analysis, we focus on the difference in the formation of consumer expectations for network sizes. We review the studies of the role of consumer expectations under price competition based on a Hotelling model, for example, Griva and Vettas (2011), Suleymanova and Wey (2012), and Hurkens and López (2014).

Griva and Vettas (2011) investigate price competition under a firm-specific network effect and demonstrate that the equilibrium outcomes depend on the role of consumers' expectations formation. They point out that competition becomes more intense when expectations are influenced by prices. This is because the demand function under expectations influenced by prices is more elastic than that under expectations not influenced by prices. Second, Suleymanova and Wey (2012) examine how the formation of consumer expectations affects duopolistic competition and market outcomes when firms provide incompatible products, based on a Hotelling model. Furthermore, Hurkens and López (2014) investigate the puzzle that profit decreases and consumer surplus increases when mobile termination charges increase and show that the puzzle is related to the formation of consumer expectations.

In this paper, following Katz and Shapiro (1985) and the previous studies, especially, Griva and Vettas (2011), we explore the following formation of consumer expectations, i.e., "rational" and "active" expectations.[3] Rational expectations follow the concept of a fulfilled expected equilibrium. That is, consumers can rationally form their expectations of network sizes in equilibrium. Accordingly, given expectations, consumers do not believe that advance announcements of network sizes by firms are credible, in other words, firms cannot commit to their announcements of network sizes (i.e., consumption externalities). By contrast, with active expectations, consumers believe that the announcements of actual sizes (i.e., the number of consumers or output) are equal to their expected sizes. This implies that the firms can commit to their actual outputs.[4]

Since seminal contributions by Farrell and Saloner (1985) and Katz and Shapiro (1985), many studies have examined strategic R&D competition in the presence of network externalities. We review the literature employing a Hotelling model, in which heterogenous consumers possessing individual preferences for network goods and

[3] Based on Griva and Vettas (2011), the equilibrium under rational (active) expectations corresponds to that with expectations not influenced (influenced) by prices. In addition, using the terminology of Suleymanova and Wey (2012), rational and active expectations correspond to "strong" and "weak" expectations, respectively, whereas in Hurkens and López (2014), they correspond to "passive" and "responsive" expectations, respectively.

[4] Following the definition of Shy (2001, Definition 2.4, p. 20), active expectations imply that consumers have *perfect foresight* if, at the time of purchase, they can correctly anticipate how many consumers purchase each brand.

services in digital markets, choose one of these goods according to their preferences.[5] We focus on the contributions of Kim (2000), Foros and Hansen (2001), and Sääskilahti (2006).

Kim (2000, Section 3 B) examines the effect of technological innovation such as an exogenous improvement in quality on prices and profits.[6] In particular, Kim (2000, Theorem 5 ii) demonstrates that the effect of an increase in compatibility on the profit of the innovative firm is ambiguous, whereas the profit of the noninnovative rival firm increases. In addition, Kim (2000, Theorem 6 and Corollary) shows that if the difference in net reservation values is small, there exists a socially optimal level of compatibility, that is, full compatibility. However, he/she derives this result assuming exogenously given technological innovation.

Foros and Hansen (2001) consider the investment in compatibility itself among Internet services, i.e., an endogenous decision on the level of network compatibility. However, in this paper, assuming that the degree of compatibility is exogenously given as a parameter, we examine how network compatibility promotion affects R&D activities, and consumer and producer surplus. In addition, we demonstrate how the outcomes depend on the difference in the formation of consumer expectations.

Sääskilahti (2006), which is most closely related to our approach, considers cost-reducing innovation and shows that network compatibility is neutralized in the decision regarding cost-reducing investment, given symmetric qualities between firms. Sääskilahti

[5] As an alternative approach, see Naskar and Pal (2020), Shrivastav (2021), and Buccella et al. (2023). The models in these studies apply the utility function of Hoernig (2012), in which a representative homogeneous consumer has a quadratic utility function including network externalities, and purchases all network goods provided in the market.

[6] Quality level in the model denotes net reservation value (prices).

(2006, Proposition 3) demonstrates that in the case of asymmetric qualities, that is, different strengths of network externalities between firms, the effect of an increase in compatibility on investments in the high (low) quality firm is negative (positive).[7] As we will show below, the case of active expectations in our model is the same as that in the symmetric Sääskilahti (2006) model. Sääskilahti (2006) finds that an increase in compatibility reduces consumer surplus, but increases social welfare. However, we will demonstrate that increasing compatibility increases consumer surplus in the case of rational expectations.

Finally, regarding the type of consumer expectations, the three previous related literatures assume active expectations. In addition, as in our model, they assume the case of full market coverage in a Hotelling linear market model.[8]

The remainder of the paper is organized as follows. In Section 2, using the framework of a Hotelling linear market, we provide demand functions supposing rational and active expectations and cost functions, including a fixed R&D activity (investment) cost. Furthermore, we define consumer surplus, producer surplus, and social welfare. In Section 3, we derive the equilibrium in R&D competition and examine the impact of compatibility on R&D activity and profit in the cases of rational and active expectations. In Section 4, we first compare the equilibrium outcomes and then consumer surplus, producer surplus, and social welfare in the cases of rational and active expectations. Then, we explore the impacts of network compatibility on consumer surplus, producer surplus, and social welfare, and then show that the socially optimal policy is perfect compatibility,

[7] Although we do not examine the case of an asymmetric quality level (i.e., intrinsic value), we can extend our model to the asymmetric case.
[8] Regarding the case of partial market coverage, see Toshimitsu (2024).

irrespective of the type of expectations. In addition, we consider the implications of network compatibility exploring the impacts on the surplus of a marginal consumer. Although policy analysis is beyond the scope of this paper, we investigate the policy implication of perfect compatibility. Finally, in Section 5, we summarize our findings and discuss some remaining problems.

2. Model

2.1 Demand functions and consumer expectations

We introduce network effects associated with compatibility (compatibility and horizontal interoperability) into a standard Hotelling model. In duopolistic competition, *firm i*, which locates at both ends of a unit-linear market, provides *network good i*, $i = 0,1$. We assume that consumers are uniformly distributed with density equal to one according to their individual preferences. In particular, consumer $\theta \in [0,1]$ has the following surplus (i.e., net utility) function:

$$U_\theta = \begin{cases} v_0 - t\theta - p_0 + N_0 & \text{if purchasing good 0} \\ v_1 - t(1-\theta) - p_1 + N_1 & \text{if purchasing good 1} \end{cases} \tag{1}$$

where v_i is the intrinsic (or stand-alone) value of *network good i*, $i = 0,1,$ which expresses the quality level of the good, t is a transportation cost, implying product substitutability, that is, a lower (higher) transport cost expresses higher (lower) substitutability, p_i is the price (or fee) of *good i*, and N_i is the total network effects of *good i*, that is, we assume $N_i \equiv n\left(x_i^e + \phi x_j^e\right),$ $i, j = 0,1,$ $i \neq j.$ Parameter $n(>0)$ is the strength of network externalities, where $\phi \in [0,1]$ is the degree of compatibility and $x_i^e\left(x_j^e\right)$ is the expected network size of *good i* (*j*). Thus, $x_i^e + \phi x_j^e$ expresses the total expected network size of network goods. In this case, nx_i^e denotes the within-group (direct and intra-) network effects for consumers purchasing *good i* from themselves, and $n\phi x_j^e$ signifies the cross-group (indirect and inter-) network effects for consumers purchasing *good i* from consumers purchasing *good j*.

2.1.1 Rational expectations

In the case of rational expectations, the expected network sizes are given for the firms providing the goods. That is, the firms must decide their prices, given that the network sizes for their goods are expected by consumers. Using Equation (1), we derive demand functions under full market coverage.[9] That is, consumer indexed θ^*, whose surplus is indifferent between *goods 0* and *1*, is given by $\theta^* = \frac{1}{2} + \frac{v_0 - v_1 - p_0 + p_1 + N_0 - N_1}{2t}$.

Given the condition, all consumers in a unit-linear market purchase either of two network goods. Thus, the demand function for *firm 0* is given by:

$$x_0 = \theta^* = \frac{t + v_0 - v_1 - p_0 + p_1 + N_0 - N_1}{2t}. \tag{2}$$

[9] For the full market coverage case to hold, the following conditions must be met: $U_{\theta=\theta^*} \geq 0$ and $U_{\theta=0}\left(U_{\theta=1}\right) > 0$. Using Equation (1), we obtain the following conditions: $t \leq v_0 - p_0 + N_0 + v_1 - p_1 + N_1 \equiv T$ and $v_i - p_i + N_i > 0,\quad i = 0,1$. The conditions imply that there exists an upper bound of a transportations cost. In other words, the goods are sufficiently substitutable. Conversely, if the cost (i.e., the level of disutility) is sufficiently high, then the market can be partially covered and, thus, there are some consumers purchasing nothing. In this paper, we do not deal with the case of partial market coverage.

Regarding the demand function of *firm 1*, based on Equation (2), we have $x_1 = 1 - x_0 = \frac{t + v_1 - v_0 - p_1 + p_0 + N_1 - N_0}{2t}$.

2.1.2 Active expectations

In the case of active expectations, consumers believe the advance announcement of network sizes (i.e., the number of consumers) by firms. Thus, they form expectations for the network sizes of the goods, based on the announcement and prices. This implies that the following holds: $x_i^e = x_i[p_i, p_j, x_i^e, x_j^e], \quad i, j = 0,1, \quad i \neq j.$ Exploiting Equation (2), we derive the direct demand function that firms face as follows:

$$x_i = \frac{t - n(1-\phi) + v_i - v_j - p_i + p_j}{2\{t - n(1-\phi)\}}, \quad i, j = 0,1, \quad i \neq j, \tag{3}$$

where we assume $t > n\{\geq n(1-\phi)\}$.

2.2 Profit function and product R&D activity

The gross profit function of *firm i* is expressed as $\pi_i = (p_i - c_i)x_i$, where c_i is the marginal cost of *firm i*, $i = 0,1$. In this paper, we explore the competition of product (i.e., quality-improving) R&D activities, in which the quality level corresponds to the intrinsic (or stand-alone) value of network goods.[10] For the following analysis, with respect to the variables expressing the quality level, we assume as follows: $v_i = \underline{v}_i + \alpha_i, \quad i = 0,1,$

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[10] We can apply our mode to the case of process (i.e., cost-reducing) R&D activity. That is, regarding the marginal cost, we assume $c_i = \overline{c}_i - \alpha_i (\geq 0)$, where ε_i expresses a cost-reducing) R&D activity and $\overline{c}_i$ is the initial level of marginal cost before R&D activity. Here, by defining the following variable: $a_i \equiv v_i - \overline{c}_i > 0$, we have $V_i \equiv a_i + \alpha_i, \quad i = 0,1.$

where $\alpha_i\left(\geq 0\right)$ denotes a quality-improving R&D activity and $\underline{v}_i\left(>0\right)$ denotes the initial level of quality before the R&D activity. In addition, we define the following variable: $V_i \equiv a_i + \alpha_i$, where $a_i \equiv \underline{v}_i - c_i > 0$, $i = 0,1$, and a_i expresses the initial level of quality net of marginal cost.[11] For simplicity, we assume that the initial level of net quality of the firms is the same: $a_0 = a_1 = a > 0$.

Firms incur fixed costs for their R&D activity. In particular, we assume the following R&D activity (i.e., investment) cost function: $F\left(\alpha_i\right) = \frac{f}{2}\left(\alpha_i\right)^2$, $f > 0$. Thus, the net profit function of *firm i* is expressed as $\Pi_i = \pi_i - F\left(\alpha_i\right)$, $i = 0,1$.

2.3 Consumer and producer surplus, and social welfare

Using Equation (1), consumer surplus is defined as follows:

$$\begin{aligned} CS &= \int_0^{\theta^*}\left\{v_0 - t\theta - p_0 + N_0\right\}d\theta + \int_{\theta^*}^1\left\{v_1 - t(1-\theta) - p_1 + N_1\right\}d\theta \\ &= \int_0^{\theta^*}\left\{V_0 - t\theta - (p_0 - c_0) + N_0\right\}d\theta + \int_{l^*}^1\left\{V_1 - t(1-\theta) - (p_1 - c_1) + N_1\right\}d\theta, \end{aligned} \tag{4}$$

where $V_i = a + \alpha_i$, $i = 0,1$.

Second, producer surplus is the sum of net profits of the firms, so that we obtain as follows:

$$PS = \Pi_0 + \Pi_1 = (p_0 - c_0)x_0 - F(\alpha_0) + (p_1 - c_1)x_1 - F(\alpha_1). \tag{5}$$

Therefore, taking $x_0 = \theta^*$ and $x_1 = 1 - \theta^*$, social welfare (total surplus) is given as follows:

[11] Following the terminology of Hashizume and Nariu (2020), a_i represents the value of *firm i*'s efficiency at the initial situation before R&D activities in accordance with Zanchettine (2006) and implies a positive primary markup.

$$SW = CS + PS = \sum_{i=0}^{1}\left\{\left(V_i + N_i - \frac{t}{2}x_i\right)x_i - F\left(\alpha_1\right)\right\}. \tag{6}$$

3. Equilibrium and the Impact of Compatibility

3.1 Equilibrium under rational expectations

The structure of the game comprises two stages (see Table 1R). In the first stage, the firms decide the level of R&D activity, and in the second stage, the firms compete on prices. With rational expectations for network sizes of the goods, consumers form their expectations before the price decision. Following the concept of a fulfilled expectation equilibrium presented by Katz and Shapiro (1985), we derive a subgame perfect Nash equilibrium through backward induction.

In the second stage of price competition, a firm decides its price to maximize profit, given the expected network sizes by consumers. Taking Equation (2), the first-order condition (FOC) of profit maximization of *firm i* is given by $\frac{\partial \pi_i^R}{\partial p_i} = x_i - \frac{p_i - c_i}{2t} = 0,$ $i = 0,1.$ Superscript R denotes rational expectations. At the fulfilled expectation equilibrium, $x_i^e = x_i = \frac{p_i - c_i}{2t}$, we obtain the price–cost margin and output as follows:

$$p_i^R - c_i = t + \frac{\left(\alpha_i - \alpha_j\right)t}{3t - n(1-\phi)}, \tag{7}$$

$$x_i^R = \frac{p_i^R - c_i}{2t} = \frac{1}{2} + \frac{\alpha_i - \alpha_j}{2\left\{3t - n(1-\phi)\right\}}, \quad i, j = 0,1, \quad i \neq j, \tag{8}$$

where we assume $t > \frac{n}{3}\left(\geq \frac{n(1-\phi)}{3} \right)$.

In the first stage of R&D competition, the net profit function of *firm i* is expressed as $\Pi_i^R = \left(p_i^R - c_i\right)x_i^R - F\left(\alpha_i\right) = \frac{\left(p_i^R - c_i\right)^2}{2t} - \frac{f}{2}\left(\alpha_i\right)^2$, $i = 0,1$. The FOC is given by:

$$\frac{\partial \Pi_i^R}{\partial \alpha_i} = \frac{p_i^R - c_i}{3t - n(1-\phi)} - f\alpha_i = \frac{\left\{3t - n(1-\phi) + \alpha_i - \alpha_j\right\}t}{\left\{3t - n(1-\phi)\right\}^2} - f\alpha_i = 0. \tag{9}$$

In addition, we derive the second-order condition (SOC) and cross effect as follows:

$$\frac{\partial^2 \Pi_i^R}{\partial {\alpha_i}^2} = \frac{t}{\left\{3t - n(1-\phi)\right\}^2} - f < 0 \quad \text{and} \quad \frac{\partial^2 \Pi_i^R}{\partial \alpha_i \partial \alpha_j} = \frac{-t}{\left\{3t - n(1-\phi)\right\}^2} < 0.$$

Because the cross effect is negative, R&D activities are strategic substitutes.[12]

Based on Equation (6), it holds in equilibrium that

$$\alpha_i^R = \frac{t}{f\left\{3t - n(1-\phi)\right\}} \equiv \alpha^{R*}\left(\phi\right), \quad i = 0,1. \tag{10}$$

In view of Equation (10), the effect of an increase in compatibility on R&D activity is given by $\frac{d\alpha^{R*}(\phi)}{d\phi} = -\frac{nt}{f\left\{3t - n(1-\phi)\right\}^2} < 0$. Thus, we summarize the result as follows:

Proposition 1R

An increase in compatibility reduces R&D activity under rational expectations.

The question is why an improvement in compatibility between network goods

[12] The condition for the local maximum value is $f\left\{3t - n(1-\phi)\right\}^2 - 2t > 0$, because the sign of the determinant of the Hessian matrix is positive.

reduces the incentive to innovate. Using Equation (9), the effect on the marginal net profit is $\frac{\partial^2 \Pi_i^R}{\partial \alpha_i \partial \phi} = -\frac{n\left\{3t - n(1-\phi) + 2(\alpha_i - \alpha_j)\right\} t}{\left\{3t - n(1-\phi)\right\}^3}$, $i, j = 0,1, \quad i \neq j.$ At the symmetric equilibrium, it holds that $\left.\frac{\partial^2 \Pi_i^R}{\partial \alpha_i \partial \phi}\right|_{\alpha_0^R = \alpha_1^R = \alpha^{R*}} = -\frac{nt}{\left\{3t - n(1-\phi)\right\}^2} < 0.$ Because an increase in compatibility reduces the marginal net profit, it reduces the incentive to innovate.

3.2 Equilibrium under active expectations: Symmetric Sääskilahti (2006) model[13]

Regarding price competition in the second stage, using Equation (3) we derive the following FOC: $\frac{\partial \pi_i^A}{\partial p_i} = x_i - \frac{p_i - c_i}{2\left\{t - n(1-\phi)\right\}} = 0, \quad i = 0,1,$ where superscript A denotes active expectations. Similarly for firm j, and thus we obtain the following equations in this stage.

$$p_i^A - c_i = \left\{t - n(1-\phi)\right\} + \frac{\alpha_i - \alpha_j}{3}, \tag{11}$$

$$x_i^A = \frac{p_i^A - c_i}{2\left\{t - n(1-\phi)\right\}} = \frac{1}{2} + \frac{\alpha_i - \alpha_j}{6\left\{t - n(1-\phi)\right\}}, \quad i, j = 0,1, \quad i \neq j. \tag{12}$$

In the first stage of R&D competition, the net profit function of *firm i* is expressed as $\Pi_i^A = \left(p_i^A - c_i\right) x_i^A - F\left(\alpha_i\right) = \frac{\left(p_i^A - c_i\right)^2}{2\left\{t - n(1-\phi)\right\}} - \frac{f}{2}\left(\alpha_i\right)^2, \quad i = 0,1.$ The FOC is given by

$$\frac{\partial \Pi_i^A}{\partial \alpha_i} = \frac{p_i^A - c_i}{3\left\{t - n(1-\phi)\right\}} - f\alpha_i = \frac{1}{3} + \frac{\alpha_i - \alpha_j}{9\left\{t - n(1-\phi)\right\}} - f\alpha_i = 0. \tag{13}$$

[13] See Table 1A. Sääskilahti (2006) assumes both asymmetric network externalities and technological spillovers. However, we assume symmetric strength of network externalities and omit technological spillover effects.

Furthermore, we derive the SOC and cross effect as follows:

$$\frac{\partial^2 \Pi_i^A}{\partial \alpha_i^2} = \frac{1}{9\{t-n(1-\phi)\}} - f < 0 \quad \text{and} \quad \frac{\partial^2 \Pi_i^A}{\partial \alpha_i \partial \alpha_j} = \frac{-1}{9\{t-n(1-\phi)\}} < 0.$$

Because the cross effect is negative, R&D activities are strategic substitutes.[14] Based on Equation (13), it holds in the equilibrium that

$$\alpha_i^A = \frac{1}{3f} \equiv \alpha^{A*}, \quad i = 0,1. \tag{14}$$

It is plausible that the effect of an increase in compatibility on R&D activity is given by $\frac{d\alpha^{A*}}{d\phi} = 0$. Thus, we summarize the result as follows.

Proposition 1A

An increase in compatibility does not affect R&D activity under active expectations.

Under active expectations, firms can decide prices after considering consumer expectations of network sizes in advance because they internalize consumption externalities. Thus, changing compatibility does not affect the decision regarding R&D activity.[15] This implies network neutrality with respect to compatibility under the assumption that consumers have *perfect foresight*, as mentioned by Shy (2001) and Sääskilahti (2006).

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[14] In addition, the condition for the local maximum value is $9f\{t-n(1-\phi)\}-2>0$, because the sign of the determinant of the Hessian matrix is positive.

[15] Using Equation (13), we obtain the following effect of compatibility on the marginal net profit: $\frac{\partial^2 \Pi_i^A}{\partial \alpha_i \partial \phi} = -\frac{n(\alpha_i - \alpha_j)}{\{t-n(1-\phi)\}^2}$, $i, j = 0,1,\ i \neq j$. Thus, at the symmetric equilibrium, the effect is zero.

3.3 Comparison: rational expectations vs. active expectations

3.3.1 Equilibrium outcomes

In view of Equations (7), (8), (10), (11), (12) and (14), comparing the equilibrium outcomes in the cases of rational and active expectations, we summarize the results shown in Table 2, in which we exclude the perfect compatibility case.[16]

As shown in Table 2.1, the outcomes, i.e., price-cost margin, R&D activity, and net profit, under rational expectations, are larger than those under active expectations. In view of Equations (2) and (3), the demand function under active expectations is more elastic than under rational expectations. As mentioned in the introduction, accordingly, the market under active expectations is more competitive than under rational expectations and, thus, the price-cost margin under active expectations is lower than under rational expectations. This reduces the incentive to innovate under active expectations. As a result, the net profit under active expectations is also lower than under rational expectations.

3.3.2 Consumer and social welfare

In view of Table 2.1, it is clear that producer surplus, i.e., aggregate profits, under rational expectations, is larger than that under active expectations. So, how about consumer surplus, and thus, social welfare?

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[16] In the perfect compatibility case, the equilibrium outcomes are the same, irrespective of the type of consumer expectations. This depends on the assumption of symmetric firms in the full market coverage. In addition, the market share of the firms is the same, i.e., half, even though compatibility is not perfect, regardless of the type of consumer expectations.

Because $\theta^* = x_0$ $\left(1-\theta^* = x_1\right)$, Equation (4) is expressed as follows:

$$CS^m = \sum_{i=0}^{1}\left\{a+\alpha_i^m - \frac{t}{2}x_i^m - (p_i^m - c_i) + N_i^m\right\}x_i^m,\ m = R, A.$$

In the symmetric equilibrium, i.e., $x_0^m = x_1^m = \frac{1}{2}$, $\alpha_0^m = \alpha_1^m$, $p_0^m - c_0 = p_1^m - c_1$, and $N_0^m = N_1^m = \frac{n(1+\phi)}{2}$, the above equation can be rewritten as follows:

$$CS^m = a + \alpha_i^m - \frac{t}{4} - (p_i^m - c_i) + \frac{n(1+\phi)}{2},\ m = R, A. \tag{15}$$

Substituting the equilibrium outcomes under each expectation into Equation (15), we derive the relationship as follows:

$$CS^R > (<) CS^A \Leftrightarrow \alpha_i^R - \alpha_i^A > (<)\ n(1-\phi), \tag{16}$$

where $n(1-\phi) = \left(p_i^R - c_i\right) - \left(p_i^A - c_i\right) \geq 0$ for $0 \leq \phi \leq 1$.[17] The left-hand side expresses the difference in the benefit from an improvement in the quality level and the right-hand side expresses the difference in the price-cost margin (or the difference in the price). Taking Equations (10) and (14), Equation (16) is rewritten as: $CS^R > (<) CS^A \Leftrightarrow 1 > (<) 3f\left\{3t - n(1-\phi)\right\}$. By the maximum value condition under active expectations, i.e., $9f\left\{t - n(1-\phi)\right\} - 2 > 0$, we obtain the following result: $CS^R < CS^A$. That is, consumer surplus under active expectations is larger than under rational expectations, expect in the case of perfect compatibility. Under rational expectations, a higher price overcomes weights the improvement in the quality level of the network products by R&D activities, compared with under active expectations.

[17] Under the perfect compatibility, consumer surplus under rational expectations is the same as that under active expectations.

As mentioned above, producer surplus under rational expectations is larger than under active expectations. On the other hand, regarding consumer surplus, the opposite result arises. Thus, using Equation (6) and by the similar procedure above, we investigate total surplus, i.e., social welfare, under each expectation.

$$SW^m = a + \alpha_i^m - \frac{t}{4} + \frac{n(1+\phi)}{2} - f\left(\alpha_i^m\right)^2,\ m = R, A. \tag{17}$$

Substituting the equilibrium outcomes under each expectation into the above equation, we derive the relationship as follows:

$$\begin{aligned} &SW^R > (<) SW^A \Leftrightarrow \alpha_i^R - f\left(\alpha_i^R\right)^2 > (<)\ \alpha_i^A - f\left(\alpha_i^A\right)^2 \\ &\Leftrightarrow \alpha_i^R - \alpha_i^A > (<) f\left(\alpha_i^R\right)^2 - f\left(\alpha_i^A\right)^2. \end{aligned} \tag{18}$$

Equation (18) shows the difference in the benefit from an improvement in the quality level and the incurred investment cost under each expectation. Taking Equations (10) and (14), based on Equation (18), we derive the relationship as follows:

$$\begin{aligned} &SW^R > (<) SW^A \Leftrightarrow \frac{t}{f\left\{3t - n\left(1-\phi\right)\right\}} - \frac{1}{f}\left\langle \frac{t}{\left\{3t - n\left(1-\phi\right)\right\}} \right\rangle^2 > (<) \frac{1}{3f} - \frac{1}{9f} \\ &\Leftrightarrow 9t\left\{2t - n\left(1-\phi\right)\right\} > (<)\ 2\left\{3t - n\left(1-\phi\right)\right\}^2 \Leftrightarrow 3t - 2n\left(1-\phi\right) > (<) 0. \end{aligned}$$

Because it holds that $t - n(1-\phi) > 0$ under active expectations, we derive $SW^R > SW^A$. That is, although consumer surplus under rational expectations is smaller than that under active expectations, producer surplus under rational expectations is greater than that under active expectations. As a result, social welfare under rational expectations is larger than that under active expectations.

We summarize the results derived above as Corollary (see Table 2.2).

Corollary

Except for perfect compatibility, consumer surplus is smaller under rational expectations than under active expectations; however, producer surplus and social welfare are greater under rational expectations than under active expectations.

In view of the Corollary, and Tables 2.1 and 2.2, we can identify an interesting issue that there exists a dilemma for both consumers and firms related to the difference in consumer expectations regarding network sizes. That is, if consumers make rational (passive) expectations about the network sizes, firms will get higher net profits and, therefore, higher producer surpluses than if consumers made active (responsive) expectations, but lower consumer surpluses. Conversely, if consumers believe the firms' announcements about their network sizes as credible ones and make active expectations based on the announcements, consumer surpluses will be higher, but net profits (producer surpluses) will be lower. Thus, the firms do not want consumers to make expectations based on such announcements.

Therefore, rational expectation is not preferable to consumers whereas active expectation is not desirable for the firms.

4. Welfare Analysis of Network Compatibility and The Role of Consumer Expectations

We investigate welfare effects of compatibility in the cases of rational and active expectations. In particular, how does an improvement in compatibility affect consumers, producers, and social welfare? Do the effects depend on the type of consumer expectations?

4.1 The rational expectations case

First, Equation (15) can be expressed under rational expectations as follows.

$$CS^R(\phi) = a + \alpha_i^R(\phi) - \left(p_i^R - c_i\right) + \frac{n(1+\phi)}{2} - \frac{t}{4}.$$

where $\alpha_i^R(\phi) = \dfrac{t}{f\left\{3t - n(1-\phi)\right\}}$ and $p_i^R - c_i = t.$ Thus, the effect of an increase in compatibility on consumer surplus is given as follows:

$$\frac{dCS^R}{d\phi} = \frac{d\alpha_i^R(\phi)}{d\phi} + \frac{n}{2} = -\frac{nt}{f\left\{3t - n(1-\phi)\right\}^2} + \frac{n}{2} > 0.\text{[18]} \tag{19}$$

Equation (19) demonstrates that an increase in compatibility reduces R&D activity and, thus, worsens consumer surplus (i.e., degrading network products), although it directly improves consumer surplus through cross-group network effects. As a result, because the positive direct effect is greater than the negative indirect effect, as network compatibility improves, consumer surplus increases.

Second, producer surplus, i.e., aggregate profits, in the symmetric equilibrium is expressed as: $PS^R(\phi) = \Pi_0^R + \Pi_1^R = t - f\left\{\alpha_i^R(\phi)\right\}^2$. Thus, the effect is given as follows:

$$\frac{dPS^R(\phi)}{d\phi} = -2f\alpha_i^R(\phi)\frac{d\alpha_i^R(\phi)}{d\phi} > 0. \tag{20}$$

Equation (20) shows that an increase in compatibility reduces R&D activity, although it does not affect the price-cost margin. Consequently, an improvement in

[18] As mentioned earlier, for the local maximum condition, the Hessian determinant is positive: $f\left\langle f - \dfrac{2t}{\{3t - n(1-\phi)\}^2}\right\rangle > 0.$

compatibility increases producer surplus.

Finally, although the positive effect on social welfare is plausible, let us confirm the effect on social surplus. Social welfare is expressed as follows:

$$W^R(\phi) = CS^R + PS^R = a + \alpha_i^R(\phi) + \frac{n(1+\phi)}{2} - \frac{t}{4} - f\left\{\alpha_i^R(\phi)\right\}^2.$$

In this case, we derive as follows:

$$\frac{dSW^R(\phi)}{d\phi} = \underbrace{\frac{d\alpha_i^R(\phi)}{d\phi} + \frac{n}{2}}_{dCS^R/d\phi(>0)} \underbrace{-2f\alpha_i^R(\phi)\frac{d\alpha_i^R(\phi)}{d\phi}}_{dPS^R/d\phi(>0)} > 0. \tag{21}$$

Therefore, we summarize the results regarding the welfare effects of compatibility as Proposition 2R.

Proposition 2R

An improvement in compatibility increases both consumer and producer surplus and, thus, social welfare under rational expectations.

4.2 The active expectations case

By the same procedure as in the rational expectations case, using Equation (15), consumer surplus is expressed as follows:

$$CS^A(\phi) = a + \alpha_i^A - \left(p_i^A - c_i\right) + \frac{n(1+\phi)}{2} - \frac{t}{4},$$

where $\alpha_i^A = \frac{1}{3f}$ and $p_i^A - c_i = t - n(1-\phi)$. Regarding the effect on consumer surplus, we easily obtain:

$$\frac{dCS^A(\phi)}{d\phi} = -n + \frac{n}{2} = -\frac{n}{2} < 0. \tag{22}$$

Equation (22) demonstrates that an increase in compatibility raises the price–cost margin but does not affect R&D activity, although it does increase the direct network effects. The negative indirect effect is larger than the positive direct network effect. As a result, an improvement in compatibility reduces consumer surplus. This result differs from that in the case of rational expectations. We will explore the economic implications in the next subsection, in which we examine the effects in the short run given R&D activities.

Related to this result, Economides and White (1994) argue that compatibility is equivalent to the more general concept of complementarity and conclude that compatibility may lead to *anticompetitive consequences*. Shy (2001) also argues that compatibility is anticompetitive. We understand their statements as follows: an improvement in compatibility may be anticompetitive and, thus, lead to a deterioration in consumer welfare in the case of active expectations, in which the firms can commit to their announcement of network sizes and consumers believe the announcement as credible commitment.

Second, producer surplus is expressed as follows: $PS^A(\phi) = t - n(1-\phi) - f\left(\alpha_i^A\right)^2$. Although the impact on R&D activity is zero, an increase in compatibility raises the price–cost margin. Thus, we obtain $\dfrac{dPS^A}{d\phi} = n > 0$.

Finally, the effect on consumer surplus is negative, whereas that on producer surplus is positive. We examine the effect on social welfare, which is expressed as follows: $SW^A(\phi) = CS^A + PS^A = a + \alpha_i^A + \dfrac{n(1+\phi)}{2} - \dfrac{t}{4} - f\left(\alpha_i^A\right)^2$. Thus, we derive as follows:

$$\frac{dSW^A(\phi)}{d\phi} = \underbrace{-\frac{n}{2}}_{dCS^A/d\phi(<0)} \underbrace{+n}_{dPS^A/d\phi(>0)} = \frac{n}{2} > 0. \quad (23)$$

That is, when compatibility increases, an increase in producer surplus is greater than a decrease in consumer surplus, so that social welfare increases. Therefore, we summarize the results regarding the social welfare effects of compatibility as Proposition 2A.

Proposition 2A

An improvement in compatibility decreases consumer surplus but increases producer surplus under active expectations. As a result, social welfare improves because the positive effect on producer surplus is greater than the negative effect on consumer surplus.

4.3 Implications of the effect on consumer welfare in the short run and long run

As summarized in Propositions 1R and 1A, we remind that the effects on consumer surplus depend on the type of consumer expectations. Here, using the utility function as in Equation (1), we explore the economic implications of an improvement in compatibility on consumer surplus in detail. The point is whether an improvement in compatibility shifts the utility function up or down focusing on how it affects the surplus of a marginal consumer. In addition, we investigate the effect on consumer surplus in the short run, in which the firms' R&D activities remain given, and in the long run, in which the R&D activities are endogenously decided by the firms, as demonstrated above.

The net utility (surplus) of the marginal consumer $\theta^* = x_0$ purchasing *network good 0* is expressed as follows:

$$U_0(\theta^* = x_0) = v_0 - p_0 - tx_0 + N_0 = a + \alpha_0 - (p_0 - c_0) - tx_0 + n(x_0 + \phi x_1), \quad (24)$$

where α_0 is the quality-improving R&D activity of *firm 0*, $p_0 - c_0$ is the price–cost margin, $-tx_0$ expresses the disutility for the marginal consumer, and $n(x_0 + \phi x_1)$ is the total network effects.[19]

Using Equation (24), the effect of an increase in compatibility on the net utility of the marginal consumer is generally expressed as follows:

$$\frac{dU_0(x_0)}{d\phi} = \underbrace{\frac{d\alpha_0}{d\phi} - \frac{d(p_0 - c_0)}{d\phi}}_{Indirect\ \ effects} \underbrace{-t\frac{dx_0}{d\phi} + n(1-\phi)\frac{dx_0}{d\phi} + nx_1}_{Direct\ \ effects}. \tag{25}$$

As in Equation (25), we divide the effects on the net utility into indirect and direct effects; the indirect effects are the changes through R&D activity and price–cost margin, and the direct effects are the changes in disutility and total network effects.

4.3.1 In the short run, i.e., $\frac{d\alpha_0}{d\phi} = 0$

(i) Rational expectations case:

First, the indirect effect is rewritten as follows:

$$-\frac{d(p_0 - c_0)}{d\phi} = \frac{n(\alpha_0 - \alpha_1)t}{\{3t - n(1-\phi)\}^2} > (<) 0 \Leftrightarrow \alpha_0 > (<) \alpha_1. \tag{26}$$

We denote this term the price (cost margin) effect, whose sign depends on the difference in the firms' R&D activities. If the R&D activity of *firm 0* is larger (smaller) than that of *firm 1*, the price effect is positive (negative).

Second, regarding the direct effects, we derive the following parts:

[19] Regarding *network good 1*, we can demonstrate the same results as for *network good 0* at the symmetric equilibrium.

$-t\dfrac{dx_0}{d\phi}=\dfrac{n(\alpha_0-\alpha_1)t}{2\{3t-n(1-\phi)\}^2}$ implies the disutility effect by changing the market share (the distance of the marginal consumer) and

$$n(1-\phi)\frac{dx_0}{d\phi}+nx_1 = \underbrace{n\frac{dx_0}{d\phi}}_{\text{"within-group" network effect}} + \underbrace{n\phi\frac{dx_1}{d\phi}+nx_1}_{\text{"cross-group" network effect}}$$

denotes the total network effects, which are composed of two terms (i.e., the within-group and cross-group network effects). We should note as follows:

$$\frac{dx_0}{d\phi}=-\frac{dx_1}{d\phi}=-\frac{n(\alpha_0-\alpha_1)}{2\{3t-n(1-\phi)\}^2}>(<)0 \Leftrightarrow \alpha_1>(<)\alpha_0$$

and $nx_1=\dfrac{n}{2}+\dfrac{n(\alpha_1-\alpha_0)}{2\{3t-n(1-\phi)\}}>0.$ Thus, the total network effects can be rewritten as: $n(1-\phi)\dfrac{dx_0}{d\phi}+nx_1=\dfrac{n}{2}+3t\dfrac{n(\alpha_1-\alpha_0)}{2\{3t-n(1-\phi)\}^2}$. Thus, we derive the direct effects as follows:

$$-t\frac{dx_0}{d\phi}+n(1-\phi)\frac{dx_0}{d\phi}+nx_1=\frac{n}{2}-\frac{n(\alpha_0-\alpha_1)t}{\{3t-n(1-\phi)\}^2}. \quad (27)$$

Using Equations (26) and (27), we obtain the effect on the net utility of the marginal consumer in the short run as follows:

$$\frac{dU_0(x_0)}{d\phi}=\underbrace{-\frac{d(p_0-c_0)}{d\phi}}_{\text{Indirect (price) effects}}\underbrace{-t\frac{dx_0}{d\phi}+n(1-\phi)\frac{dx_0}{d\phi}+nx_1}_{\text{Direct effects}}=\frac{n}{2}>0. \quad (28)$$

Therefore, the net utility of the marginal consumer increases as compatibility increases. This implies that consumer surplus increases in the short run.

(ii) Active expectations case:

Using a similar procedure as in the previous case, the indirect price effect is given by

$-\dfrac{d(p_0-c_0)}{d\phi}=-n<0$. Regarding the direct effects, we can similarly divide the following parts: $-t\dfrac{dx_0}{d\phi}=\dfrac{n(\alpha_0-\alpha_1)t}{6\{t-n(1-\phi)\}^2}$ is the disutility effect by changing the distance of the marginal user. The total network effects are given as follows:[20]

$$n(1-\phi)\frac{dx_0}{d\phi}+nx_1=\underbrace{n\frac{dx_0}{d\phi}}_{\text{"within-group" network effect}}+\underbrace{n\phi\frac{dx_1}{d\phi}+nx_1}_{\text{"cross-group" network effect}}$$
$$=\frac{n}{2}+\frac{n(\alpha_1-\alpha_0)t}{6\{t-n(1-\phi)\}^2}.$$

Thus, regarding the direct effects, we obtain $-t\dfrac{dx_0}{d\phi}+n(1-\phi)\dfrac{dx_0}{d\phi}+nx_1=\dfrac{n}{2}>0$.

In view of the price (indirect) effect and the direct effects, we obtain the effect on the net utility of the marginal consumer in the short run:

$$\frac{dU_0(x_0)}{d\phi}=\underbrace{-\frac{d(p_0-c_0)}{d\phi}}_{Indirect(price)\ effects}\underbrace{-t\frac{dx_0}{d\phi}+n(1-\phi)\frac{dx_0}{d\phi}+nx_1}_{Direct\ effects}=-\frac{n}{2}<0. \qquad (29)$$

Therefore, the net utility of the marginal consumer decreases as compatibility increases. This implies that consumer surplus decreases in the short run.

Based on Equations (28) and (29), in the short run, in which the firms' R&D activities do not affect consumer surplus, as network compatibility increases, consumer surplus increases (decreases) in the case of rational (active) expectations.

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[20] We note as follows: $\dfrac{dx_0}{d\phi}=-\dfrac{dx_1}{d\phi}=-\dfrac{n(\alpha_0-\alpha_1)}{6\{t-n(1-\phi)\}^2}>(<)0\Leftrightarrow\alpha_1>(<)\alpha_0$ and $nx_1=\dfrac{n}{2}+\dfrac{n(\alpha_1-\alpha_0)}{6\{t-n(1-\phi)\}}>0$.

4.3.2 In the long run

Although we have already demonstrated the effects in sections 4.1 and 4.2, we reconfirm the effect on surplus of the marginal consumer. In the symmetric equilibrium, irrespective of the types of consumer expectations, it holds that $x_0^m = x_1^m = \frac{1}{2}.$ Thus, we have

$$\frac{dx_i^m}{d\phi} = 0, \quad i = 0,1, \quad m = R, A.$$

(i) Rational expectations case:

In the long run, the effects on the net utility of the marginal consumer are given by: $\frac{dU_0(x_0)}{d\phi} = \underbrace{\frac{d\alpha_0^R}{d\phi}}_{Indirect(R\&D)\ effect} \underbrace{+nx_1^R}_{Direct\ effect}$, where $-\frac{d(p_0^R - c_0)}{d\phi} = 0,$ because the price–cost margin is constant, i.e., $p_0^R - c_0 = t.$

Thus, the effects on the net utility of the marginal consumer are given by $\frac{dU_0(x_0)}{d\phi} = \frac{d\alpha_0^R}{d\phi} + \frac{n}{2} > 0,$ where $\frac{d\alpha_0^R}{d\phi} = -\frac{nt}{f\left\{3t - n(1-\phi)\right\}^2} < 0.$ This result implies that consumer surplus improves as compatibility increases. See Equation (19).

(ii) Active expectations case:

Similarly, we derive as follows: $\frac{dU_0(x_0)}{d\phi} = \underbrace{-\frac{d(p_0^A - c_0)}{d\phi}}_{Indirect(\text{price-cost margin})\ effect} \underbrace{+nx_1^A}_{Direct\ effect}$, where $\frac{d\alpha_0^A}{d\phi} = 0,$ because the R&D activities are independent of compatibility. The price–cost margin is given by $p_0^A - c_0 = t - n(1-\phi).$ Thus, we derive $\frac{dU_0(x_0)}{d\phi} = -n + \frac{n}{2} = -\frac{n}{2} < 0.$

This result implies that consumer surplus decreases as compatibility increases. See Equation (22).

Summing up the above results, whether in the short or long run, under rational (active) expectations, an increase in compatibility increases (decreases) consumer surplus. In particular, in the long run, under both expectations, although the positive direct network effect is the same, i.e., $\frac{n}{2}$, and the indirect effect is negative, the magnitude of the negative indirect effect under active expectations are greater than that under rational expectations. As a result, consumer welfare decreases (increases) under active (rational) expectations as compatibility increases.

Under active expectations, which corresponds to the case in which consumers have *perfect foresight*, based on the terminology of Shy (2001), we should reconfirm whether an improvement in compatibility leads to an anticompetitive outcome. That is, as mentioned above, the price–cost margin in the short and long run increases as compatibility increases. In addition, we can easily find that the markup ratio, which expresses the degree of market power, also increases. This is because the firms internalize network externalities and reflect this internalization in their pricing. Accordingly, this also affords network neutrality and, thus, makes R&D activities zero.

4.4 A policy implication: Is perfect compatibility "optimal"?

Drawing on Propositions 2R and 2A, which demonstrate that perfect compatibility is socially optimal, we may suggest that the construction of a common network system and formation of a standardization (complete compatibility and interoperability) policy would improve social welfare.

However, in the case of active expectations, an improvement in compatibility does not affect quality-improving R&D activities and increases the price (i.e., markup ratio). As a result, consumer welfare worsens. In other words, an increase in social welfare can only be achieved through an increase in producer surplus. Furthermore, in the case of rational expectations, although an improvement in compatibility increases consumer surplus, it also reduces R&D activity. This implies the degrading of network goods. As an increase in consumer welfare can only be achieved by the direct network effects exceeding the negative effects of degrading network goods, we cannot unconditionally suggest that perfect compatibility is an optimal policy.

5. Concluding Remarks

Introducing network externalities into a standard Hotelling linear market model, we considered the impacts of compatibility between network goods. Focusing on the difference in the formation of consumers' expectations for network sizes, we demonstrated as follows. In the case of rational (active) expectations, an improvement in compatibility reduces (does not affect) R&D activity, and increases (decreases) consumer surplus. However, because an improvement in compatibility increases producer surplus, irrespective of the type of expectations, social welfare increases. See Table 3 for summary. In addition, excluding the perfect compatibility case, producer surplus and social welfare under rational expectations are larger than those under active expectations. On the other hand, regarding consumer surplus, the opposite result arises.

From the viewpoint of social welfare maximization, perfect compatibility is optimal. However, under active expectations, consumer surplus decreases and R&D activity does not change, whereas under rational expectations, while consumer surplus increases, R&D activity decreases. If we place more importance on consumer surplus and technological progress, then surely there may be some policy merit in choosing incompatibility, even if it does not maximize social surplus. The incompatibility implies a firm-specific network system, such as the Apple and Android operating systems.

While policy analysis is not within the scope of this paper, we do note some implications of our model. Here, we have assumed the case of full market coverage of a Hotelling linear city model. For example, whether standardization policy facilitates R&D activities in digital markets may depend on the characteristics of market structure. In the case of a mature digital market (i.e., full market coverage in our model), a policymaker should accept and retain the environment where firms (providers) freely operate under their own specific (closed) network systems. Conversely, in uncovered markets with room for future growth, policymakers should consider implementing policies that promote compatibility (interoperability), as the participation of potential consumers in the market will lead to an expansion of the market, thereby encouraging firms to undertake R&D activities and increase consumer surplus. Accordingly, we should examine the case of partial (imperfect) market coverage.

We appreciate that there are some remaining problems, all of which suggest directions for future research. For example, we have assumed symmetric firms and two-way compatibility. Assuming asymmetry intrinsic (stand-alone) value, the strength of network externalities, and one-way compatibility, we can derive more plentiful results. In addition, we have conducted a one-sided market model in which the firm (i.e., provider) itself is a platform and there are two groups of consumers (i.e., users) each purchasing network goods. Thus, an improvement in network compatibility between the firms (i.e., network goods and services) implies an increase in the cross-consumer group network effects. We should then extend our model to the case of a two-sided market, where there are many firms (providers) supplying network goods, such as applications based on specific platforms.

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Table 1R. Two-stage game under rational expectations

1st. Stage R&D competition	2nd. Stage Market competition		
Decision of R&D activities (α_0, α_1)	Formation of consumer's expectation for network sizes $(x_0^e = x_0^R, x_1^e = x_1^R)$	Decision of prices (p_0, p_1)	Decision of demand (x_0, x_1)

Table 1A. Two-stage game under active expectations

1st. Stage R&D competition	2nd. Stage Market competition		
Decision of R&D activities (α_0, α_1)	Decision of prices (p_0, p_1)	Formation of consumer's expectation for network sizes $(x_0^e = x_0, x_1^e = x_1)$	Decision of demand (x_0, x_1)

Table 2.1 Comparison of equilibrium outcomes $\left(0 \le \phi < 1\right)$

Price-cost margin	$p_i^R - c_i = t > p_i^A - c_i = t - n(1-\phi)$
R&D activity	$\alpha_i^R = \dfrac{t}{f\left\{3t - n(1-\phi)\right\}} > \alpha_i^A = \dfrac{1}{3f}$
Net profit	$\Pi_i^R = \dfrac{t}{2} - \dfrac{f}{2}\left(\alpha_i^R\right)^2 > \Pi_i^A = \dfrac{t - n(1-\phi)}{2} - \dfrac{f}{2}\left(\alpha_i^A\right)^2$

Table 2.2 Comparison of consumer surplus, producer surplus, and social welfare $\left(0 \le \phi < 1\right)$

Producer surplus	$PS^R > PS^A$
Consumer surplus	$CS^R < CS^A$
Social surplus	$SW^R > SW^A$

Table 3. Impacts of compatibility on consumer surplus, producer surplus, and social welfare

	Rational Expectations	Active Expectations
Consumer Surplus	+	–
Producer Surplus	+	+
Social Welfare	+	+