The Welfare Effect of Quality Degradation in the Presence of Network Externalities[1]

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Abstract

This paper examines how the presence of network externalities affects a monopolist's incentive for quality degradation and its welfare consequence. The software and the Internet service industries provide our primary motivation. The network externality may lead to a Pareto-improving quality degradation that would not be realised in the absence of network externalities. However, it may also overturn a potentially Pareto-improving quality degradation to a welfare-reducing one, or result in the realisation of a welfare-reducing quality degradation that would be avoided without network externalities. We also endogenise the firm's forward and backward compatibility decisions between the original good and the degraded good.

Key Words : Damaged Goods, Quality Degradation, Network Externalities, Compatibility, Price Discrimination, Software

JEL classification : L12, L15, L86

1 Introduction

Firms often introduce a downgraded good by intentionally reducing the quality of its original good. This kind of phenomenon, sometimes called "damaged goods" in the literature, is widespread in both manufacturing and service industries.[1] Denekere and McAfee (1996) is the first to explain why a monopolist may have incentives to introduce a downgraded good even though it is more costly to produce than the original good. Extending the standard price-discrimination framework to a richer class of consumer preferences, they show that introducing a damaged good can be profitable if the preference structure satisfies a certain condition, i.e. consumers with a high willingness-to-pay for quality suffer much more from quality reduction than consumers with a low willingness-to-pay for quality so that the sales of the degraded good does not cannibalise the market for the original good very much. Furthermore, it may lead to a Pareto-improvement. As pointed out by the authors, however, the condition for the profitable quality degradation is somewhat unnatural and fails in many specifications of the environment, including the typical linear utility structure employed in the traditional monopoly quality differentiation model à la Mussa and Rosen (1972).

This article extends the discussion on damaged goods to markets with network externalities. The focus is on investigating how the presence of network externalities affects a monopolist's incentive for quality degradation and its welfare consequence. We find our primary motivation in the software and the Internet service industries that are subject to significant network externalities.[2] In fact, quality degradation seems increasingly popular in the software and Internet service market. Typical examples are student versions of software packages. Mathematica's student version consists of the original version with the floating-point coprocessor being disabled, slowing down

[1] See Denekere and McAfee (1996) for examples.

[2] See Gandal (1994) for some emperical evidence.

mathematical and graphical calculations. Also, Scientific WorkPlace comes with two downgraded versions, Scientific Word and Scientific Notebook. Shapiro and Varian (1999, ch.3) introduce numerous damaged-good examples in those industries.

The network externality is incorporated into the Denekere-McAfee's damaged goods model. We focus mainly on the multiplicative specification of network externalities, where the value that consumers attach to the network externality is assumed to be positively correlated with their value for the inherent service of the good.[3] It seems more plausible in the sense that someone who has a higher value for the good also assigns more importance to the network size. Under the multiplicative specification, a monopolist cannot capture all of the benefits the network provides to consumers. As a result, the presence of network externalities does not always raise the monopolist's incentive for quality degradation. The market expansion followed by the introduction of the degraded good implies a greater surplus extraction opportunity to the firm. At the same time, however, the firm has to offer a larger informational rent to the original-good buyers whose valuation of the network is higher than the degraded-good buyers. So, the network externality increases the firm's degradation incentive only when the former effect dominates the latter. The network externality can play an important role as well when the introduction of the degraded good does not involve any market expansion. Even though offering low-valuation consumers the degraded good instead of the original good gives rise to a loss in their network benefits, it can be used as a screening device that allows the firm to reduce the original-good buyers' informational rent attributed to network externalities. Again, the network externality increases the firm's degradation incentive only if the saving in the informational rents outweighs the loss in the degraded-good buyers' network

[3] Most of the previous work have used additive specifications of the network externality, where the value of the network is the same for all consumers regardless of their preferences for the good. An exception is Ellison and Fudenberg (2000) who highlight the difference between the two specifications in analysing a monopolist's upgrade decision in a market with network externalities.

benefits.

We fully endogenise the monopolist's decisions on forward and backward compatibility between the original and degraded goods.[4] The firm always wants the original good to be backward compatible with the degraded good since it can capture all of the externality benefits the backward compatibility provides to the original-good buyers. Here the externality is fully internalised, and so the firm's compatibility decision is aligned with the social optimum. Allowing forward compatibility provides the degraded-good buyers with externality benefits that the firm can fully extract. However, it also gives the high-valuation consumers a larger incentive to switch to the degraded good, which forces the firm to offer a larger informational rent to them. So, the firm may decide not to allow forward compatibility in order to reduce the informational rent, even though full forward compatibility is socially desirable.

A simple comparative static analysis reveals how the welfare effect of quality degradation is affected by the presence of network externalities. One quite intuitive result is that the network externality may lead to a Pareto-improving quality degradation that would not be realised in the absence of network externalities. This can arise when the price discrimination role of the degraded good alone is not profitable, but the extra surplus extraction due to network externalities induces the firm to introduce the degraded good. However, there exist other possibilities that are less promising in terms of social welfare. These can happen when the nature of the benchmark equilibrium without quality degradation changes from partial participation to full participation due to the presence of network externalities.[5] First, suppose that the

[4] The previous work on compatibility issues have considered two-way compatibility only (notably the literature on planned obsolescence such as Choi (1994) and Waldman (1993)), or have assumed an exogenously given compatibility specification (e.g. backward compatible and forward incompatible as in Ellison and Fudenberg (2000)).

[5] Suppose that in the absence of network externalities it is not worth serving low-valuation consumers, probably because their valuation for the good is too low relative to high-valuation consumers and or their proportion in the population is too small. With network externalities, by serving more

firm would introduce the degraded good without network externalities. The firm may still find introducing the degraded good profitable in the presence of network externalities, but in this case the introduction of the degraded good reduces social welfare since low-valuation consumers are induced to purchase the degraded good instead of the original good. So, here the network externality overturns a potentially Pareto-improving quality degradation to a welfare-reducing one. Now suppose that the firm has no incentive to introduce the degraded good in the absence of network externalities. The extra surplus extraction due to network externalities may induce the firm to introduce the degraded good. Here, we observe the realisation of a welfare-reducing quality degradation that would be avoided without network externalities.

With additive specifications of network externalities, the monopolist can extract all the consumer benefit attributable to the network. So, the network externality always raises the firm's incentive for quality degradation provided the introduction of the degraded good increases the total demand. Also, the firm always prefers both forward and backward compatibility. In spite of the differences, the comparative statics analysis regarding how network externalities affect the welfare effect of quality degradation yields results that are analogous to those obtained under the multiplicative specification.

The monopolist's versioning problem here is similar to the one considered by Ellison and Fudenberg (2000), where a monopoly supplier of software introduces more upgrades than is socially optimal mainly because of the difference between the negative externality that upgrades impose on the marginal and average consumer. In their model compatibility is exogenously given as backward compatible and forward incompatible, while we endogenise the firm's decisions on both forward and backward

customers the firm can extract larger network benefits, but also has to offer larger informational rents to high-valuation buyers. If the former benefit is greater than the latter loss, the firm will choose to serve more consumers changing the equilibrium nature from partial (without network externalities) to full particiaption (with network externalities).

compatibility. Also, our analysis is more focused on examining the effect of network externalities on the firm's quality degradation incentive and its welfare consequence rather than the efficiency aspect of software versioning in the presence of network externalities. Unlike upgrades which impose negative externalities on those who do not upgrade, downgrades normally exert positive externalities to others, which makes the efficiency issue less interesting. In fact, inefficiencies involved here are similar to the standard monopoly quantity or quality distortions. A more recent contribution to the topic is Jing (2002), who extends the monopoly quality differentiation model of Mussa and Rosen (1978) to an environment with network externalities. He shows that the presence of network externalities is essential for a monopolist to introduce a downgraded version[6], and also characterises conditions under which the degraded version is offered free of charge. More interestingly in his framework the firm introduces one and only one degraded good due to the complementary effect between the two versions. The present model considers a more general preference structure, and characterises the exact condition under which the network externality raises the firm's degradation incentive. Also, we allow the firm to control forward and backward compatibility appropriately. A more significant difference, however, lies in that we analyse how the welfare effect of quality degradation is influenced by the presence of network externalities.

2 The model

The supply side is essentially the same as the damaged-goods model (the single use case) of Denekere and McAfee (1996). There is a monopoly supplier of a good of

[6] This slightly strong result, however, crucially depends on the linear utility specification employed in his model. In fact, the monopolist may have incentives to introduce a downgraded version in the absence of network externalities if we allow for more general preferences, as shown by Denekere and McAfee (1996).

certain quality. The firm may introduce a degraded version by reducing the quality of the original version. We assume that the quality level of the degraded good is also exogenously given by some technological constraints. The marginal production costs are constant for both goods and are further assumed to be zero, which seems a reasonable description of the industry we have in mind.[7] Any fixed costs of production and degradation are ignored without loss of generality.

On the demand side, we incorporate network externalities into a simplified type-type version of the Denekere-McAfee model. There are two types of consumers indexed by $i = l, h$. The consumer type is private information. Each type is consisted of a continuum of homogeneous individuals with measure $\mu > 0$ for type h and $1 - \mu$ for type l. So, consumers are price-takers. Consumers have unit demands for either the original or the degraded good. A type-i consumer's utility is

$$V_i = \begin{cases} v_i + (\alpha n_o + \beta^b n_d) v_i & \text{when buying the original good} \\ u_i + (\alpha n_d + \beta^f n_o) u_i & \text{when buying the degraded good} \end{cases}, \qquad (1)$$

where $v_l < v_h$, $u_l < u_h$, $u_h < v_h$, $u_l < v_l$, and $v_h - u_h > v_l - u_l$. The last parameter restriction implies the well-known single-crossing condition. The consumer's value for a good is the sum of the so-called stand-alone value of the good and the value of the network. Note that n_o and n_d respectively denotes the fraction of consumers who end up buying the original and the degraded good. The parameter $\alpha \geq 0$ measures the intensity of the network effect related to the group of users consuming the same product, and β^i $(i = b, f)$ the intensity of the network effect related to the group of users consuming the other quality-differentiated product. The former effect is usually at least as strong as the latter effect, $0 \leq \beta^i \leq \alpha$. The latter effect is usually influenced by the firm's compatibility decision, and is often classified into two kinds according to the way in which compatibility is working. One is backward compatibility, the compatibility from the original good to the degraded good, and the other is forward

[7] Allowing for some degradation costs would not affect our conclusions.

compatibility, the compatibility from the degraded good to the original good. We treat β^i as a decision variable of the firm: $\beta^i = \alpha$ implies full compatibility whereas $\beta^i = 0$ implies no compatibility.[8] We first focus on the multiplicative specification of network effects. That is, consumers who have a higher valuation for a product place a greater value on the network benefit and also the network effect is stronger when it is related to the original version than the degraded version for a given type of consumer. Later, we analyse the traditional additive specification case as well, and compare the results obtained in the two different settings. The following assumption is made in order to ensure the existence of partial participation equilibrium in the benchmark case (see section 3 below). It simply says that the two types of consumers are sufficiently differentiated in terms of the valuation for the original good.

Assumption 1: $(1 + \alpha\mu)v_h > (1 + \alpha)v_l$.

Following the standard in the network externality literature, we proceed our analysis using the fulfilled-expectation equilibrium concept (see Rohlfs (1974), Farrell and Saloner (1985), and Katz and Shapiro (1985) among others). Consumers form expectations about the network sizes (n_o and n_d), and the expectations are required to be fulfilled in equilibrium (*rational expectations*). As usual in models with network externalities, multiple equilibria may arise. For a given set of prices there can exist more than one equilibrium with different network sizes. This is due to the fundamental coordination problem among consumers: individual incentives do not always lead to the collective optimum. Such a problem is beyond the scope of the present paper, and we simplify this by assuming that the consumers in each group coordinate their decisions to achieve the collectively optimal outcome.[9]

[8] One may wish to allow for the intensity of the network effect to differ between the two groups of users even in the case of full compatibility, i.e. $0 \leq \beta^i \leq \overline{\beta} < \alpha$ $(i = b, f)$. It however does not affect our results as long as $\overline{\beta}$ is close to α, and we assume that $\overline{\beta} = \alpha$ for expositional convenience.

[9] For more on the coordination issue, see Ellison and Fudenberg (2000) among others.

3 No degradation benchmark

Let us consider the benchmark case where the firm sells the original good alone without introducing the degraded good. A type-i consumer's utility when purchasing the original good is given by

$$(1 + \alpha n_o)v_i - P,$$

where P is the price of the good. The assumption that consumers perfectly coordinate their decisions allows us to focus on the following two equilibria.

The partial participation equilibrium: Given that $v_h > v_l$, the firm will serve type-h consumers excluding type-l consumers. A Nash equilibrium is then characterised by

$$(1 + \alpha\mu)v_h \geq P$$

and

$$(1 + \alpha)v_l < P.$$

Under Assumption 1, there exists at least one P satisfying the above conditions, and we expect that the monopolist will extract the whole surplus of type-h consumers by setting $P = (1 + \alpha\mu)v_h$. The resulting profit is $\Pi^1 = \mu(1 + \alpha\mu)v_h$.

The full participation equilibrium: An equilibrium where both types of consumers purchase is characterised by

$$(1 + \alpha)v_l \geq P.$$

The monopoly price is $P = (1 + \alpha)v_l$, and the resulting profit is $\Pi^2 = (1 + \alpha)v_l$. By serving type-l consumers the firm has to offer type-h consumers informational rent of $(1 + \alpha)(v_h - v_l)$.

The comparison of Π^1 and Π^2 shows that the monopolist serves both types of consumers (full participation) if

$$v_l - \mu v_h + \alpha(v_l - \mu^2 v_h) > 0, \tag{2}$$

and serves only type-h consumers (partial participation) otherwise.

It is useful for the proceeding analysis to examine how the presence of network externalities can affect the nature of the equilibrium in this benchmark case. It can be easily observed from condition (2) that the network externality increases the firm's incentive to serve both types (full participation) if

$$v_l > \mu^2 v_h, \tag{3}$$

and the opposite is true otherwise. The intuition for condition (3) is as follows. With partial participation, the network externality gives a type-h consumer extra benefit of $\alpha\mu v_h$ that can be fully captured by the monopolist. With full participation, on the other and, the network externality provides a type-h consumer with extra benefit of αv_h and a type-l consumer with extra benefit of αv_l. Here, however, the monopolist can capture only part of those extra benefits (αv_l from an individual customer) but from a larger customer base relative to the partial participation case. The total amount of surplus extraction in each case determines the relative attractiveness of the partial and full participation equilibrium. If the valuation difference for the good is relatively small between the two types, serving both types is a better option for the firm in exploiting the network externality effect. Otherwise, it is more profitable to serve only the high-valuation customers who value the network externality more.

This additional effect due to network externalities can be crucial in determining the nature of the equilibrium, i.e. partial versus full participation. Suppose first that $v_l > \mu v_h$. Then, the monopolist will decide to serve both types of consumers even in the absence of network externalities, and in fact the presence of network externalities further increases the firm's incentive to choose the full participation equilibrium (condition (3) is always satisfied under $v_l > \mu v_h$). Now suppose that $v_l < \mu v_h$. Then, the firm would serve only type-h consumers without network externalities. The presence of network externalities, however, may lead the firm to serve both types provided condition (3) holds and the intensity of network externalities is sufficiently

large, i.e.

$$\alpha > \frac{\mu v_h - v_l}{v_l - \mu^2 v_h}. \tag{4}$$

This is the case where the extra surplus extraction due to network externalities induces the firm to choose a pricing policy leading to the full participation equilibrium that would not be realised without network externalities. This result will be useful for analysing the welfare effect of quality degradation later, and is summarised in the following proposition.

Proposition 1 *Suppose the firm sells the original good only. Then, the presence of network externalities may alter the nature of equilibrium from partial participation to full participation.*

4 Equilibrium with the degraded good

Now we consider the case where the firm sells two quality-differentiated products by introducing a degraded good. Let p_o denote the price for the original good and p_d the price for the degraded good. The firm's problem is to choose the profit-maximising pair of prices inducing two types of consumers to sort themselves into two different purchasing groups. Given that the incremental value for quality increase is larger for type-h consumers than type-l consumers (i.e. $v_h - u_h > v_l - u_l$), the firm will sell the original good to type-h consumers and the degraded good to type-l consumers. Since there are only two types of consumers, there will be full participation in equilibrium with the introduction of the degraded good (i.e. $n_o = \mu$ and $n_d = 1 - \mu$). Equilibria are characterised by

$$v_h + [\alpha\mu + \beta^b(1-\mu)]v_h - p_o \geq u_h + [\alpha(1-\mu) + \beta^f\mu]u_h - p_d \tag{5}$$

and

$$u_l + [\alpha(1-\mu) + \beta^f\mu]u_l - p_d \geq 0, \tag{6}$$

where the first inequality is the type-h consumers' incentive constraint and the second is the type-l consumers' participation constraint. Observe that in condition (5) we are ignoring an individual consumer's contribution to the network size, which seems reasonable given a continuum of consumers in each type. Under the single-crossing property, the type-l consumers' incentive constraint and the type-h consumers' participation constraint are non-binding at the optimum. From conditions (5) and (6), the optimal prices are given by

$$p_d^* = [1 + \alpha(1-\mu) + \beta^f \mu]u_l$$

for the degraded good and

$$p_o^* = [1 + \alpha\mu + \beta^b(1-\mu)]v_h - [1 + \alpha(1-\mu) + \beta^f \mu](u_h - u_l)$$

for the original good. In the equilibrium, type-l consumers get zero surplus, and type-h consumers get surplus of $[1 + \alpha(1-\mu) + \beta^f \mu](u_h - u_l)$ as informational rent.

4.1 Compatibility decision

Plugging in p_d^* and p_o^* above, the profit can be written as a function of β^b and β^f as follows:

$$\begin{aligned} \pi(\beta^b, \beta^f) &\equiv \mu p_o^* + (1-\mu)p_d^* \\ &= \mu[1 + \alpha\mu + \beta^b(1-\mu)]v_h + [1 + \alpha(1-\mu) + \beta^f \mu](u_l - \mu u_h). \end{aligned}$$

The firm's compatibility decision problem is equivalent to choosing β^b and β^f to maximise the profit. Since the profit function is linear in β^b and β^f, the optimal compatibility decision is easily determined as follows:[10]

$$\beta^{b^*} = \alpha$$

[10] We assume that the firm chooses full compatibility when it is indifferent between compatibility and incompatibility.

and

$$\beta^{f^*} = \begin{cases} \alpha & \text{if } u_l \geq \mu u_h \\ 0 & \text{if } u_l < \mu u_h \end{cases}.$$

Backward compatibility is clearly beneficial to the firm, since it provides type-h consumers with extra network benefits and the firm can fully extract those extra utilities.[11] Forward compatibility is, however, not always profitable. It certainly increases the type-l consumers' network benefit that can be fully extracted by the firm. At the same time, however, it increases the type-h consumers' incentive to switch to the degraded version, and forces the firm to offer them larger informational rents. So, the firm will allow forward compatibility only when the net effect is positive, and the decision critically depends on the valuation difference for the degraded good between the two types. This may explain why some downgraded software are forward compatible (e.g. student versions with slower operation speed like Mathematica) and some are not (e.g. low-end versions with some functions being disabled) in reality.

Proposition 2 *The monopolist always allows backward compatibility, but forward compatibility is attained only when the valuation difference for the degraded good is sufficiently close between the two types.*

Note that the socially optimal policy is to guarantee both forward and backward compatibility. Hence, we may face a situation where the monopolist's compatibility decision diverges from the social planner's one in respect of forward compatibility. This result crucially depends on the multiplicative specification of network externalities, under which the firm cannot capture all of the externality benefits that the network provides to consumers. As will be shown later, with the traditional additive

[11] The full extraction of the externality benefit would not be valid in a more general environment with more than two types of consumers. Nevertheless, the present simple two-type setup is useful to examine different implications of forward and backward compatibility in relation to consumer screening.

specification of network externalities the firms' compatibility decision always coincides with the social planner's one in both directions.

4.2 The effect of network externalities on quality degradation

Taking into account the compatibility decisions, the resulting profit can be rewritten as

$$\pi \equiv (1+\alpha)\mu v_h + (1+z\alpha)(u_l - \mu u_h),$$

where $z = 1$ for $u_l \geq \mu u_h$ and $(1-\mu)$ for $u_l < \mu u_h$. The firm's incentive for quality degradation and its welfare consequence are summarised in the following lemma. As usual, social welfare is defined as the sum of consumer surplus and firm profit.

Lemma 1 *i) Suppose the firm serves only type-h consumers when selling the original good alone (condition (2) is violated). Then, introducing the degraded good is profitable if and only if*

$$\alpha[(1-\mu)\mu v_h + z(u_l - \mu u_h)] + u_l - \mu u_h > 0, \tag{7}$$

and it leads to a weak Pareto-improvement.

ii) Suppose the firm serves both types of consumers when selling the original good alone (condition (2) holds). Then, introducing the degraded good is profitable if and only if

$$\alpha[\mu v_h - v_l + z(u_l - \mu u_h)] + \mu v_h - v_l + u_l - \mu u_h > 0, \tag{8}$$

and it leads to a welfare reduction, and furthermore type-h consumers become worse-off.

The intuition is basically similar to the standard damaged-good model without network externalities. The profitable introduction of the degraded good requires high-valuation consumers suffer much more from quality reduction than low-valuation consumers, so that the firm can increase the sales of the degraded good without

reducing the price of the original good very much. Here, however, we are more interested in the effect of network externalities on the firm's incentive for quality degradation and on social welfare. It is easily observed, for example from (7), that the presence of network externalities does not always increase the firms' incentive for quality degradation. This is mainly due to the multiplicative specification of network externalities where the firm is restricted in extracting the network benefits from consumers, and contrasts with the additive specification case analysed later. In order to investigate how the equilibrium result can be affected by the presence of network externalities, it will be convenient to examine the following two cases separately.

Partial participation without the degraded good ($\mu v_h > v_l$)

Suppose that the partial participation equilibrium prevails when the firm sells the original good only in the absence of network externalities (i.e. condition (2) is violated with $\alpha = 0$). First, consider the case where the equilibrium nature is not affected by the presence of network externalities, i.e. it is sustained as partial participation (either condition (3) or (4) is violated). If the valuation for the degraded good is close enough between the two types (i.e. $u_l \geq \mu u_h$), quality degradation is profitable even without network externalities. In this case, the firm can extract a sufficiently large portion of the network benefit. Therefore, the presence of network externalities in fact strengthens the incentive for quality degradation. Moreover, the firm maximises the benefit of network effects by choosing compatibility in both directions. On the other hand, if the two types are sufficiently differentiated in their valuation for the degraded good (i.e. $u_l < \mu u_h$), the firm would have no incentives to introduce the degraded good without network externalities (the price-discrimination role of the quality degradation alone is not profitable in this case). With network externalities, however, the firm's incentive can be overturned provided he can extract a sufficiently large portion of the extra surplus created by the network effect (i.e. $\mu v_h >$

$\mu u_h - u_l$ and α is sufficiently large). Here, the firm will minimise the informational rent (due to network externalities) offered to type-h consumers by choosing forward noncompatibility. This case shows that we may have a Pareto-improving quality degradation that would not be realised in the absence of network externalities.

Second, consider the case where the nature of the benchmark equilibrium is changed from partial participation to full participation due to network externalities (i.e. both conditions (3) and (4) holds). If the valuation for the degraded good is sufficiently close between the type types (i.e. $u_l \geq \mu u_h$), the firm would introduce the degraded good even without network externalities. Since the monopolist can also extract a large proportion of the network benefit in this case, the presence of network externalities further encourages the firm to introduce the degraded good.[12] Here, it is optimal for the firm to choose forward compatibility. The welfare consequence of quality degradation is, however, dramatically changed. Without network externalities, quality degradation would lead to a Pareto improvement serving type-l consumers who would be excluded from consumption otherwise. But in this case with network externalities introducing the degraded good induces the type-l consumers to buy the degraded good instead of the original, leading to a welfare reduction. Another negative result can appear if the two types' valuations for the degraded good are sufficiently differentiated (i.e. $u_l < \mu u_h$). The quality degradation would not be profitable without network externalities. The monopolist, however, may find it profitable to introduce the degraded good if it can capture a sufficiently large portion of the consumers' network benefits (i.e. $\mu v_h - v_l + (1-\mu)(u_l - \mu u_h) > 0$). The firm optimally chooses forward noncompatibility in this case. Here, the network externality leads to a welfare-reducing quality degradation that does not appear in the absence of network externalities.

[12] Recall that we are considering a situation where $\mu v_h > v_l$, which together with the condition $u_l \geq \mu u_h$ implies that $\mu v_h - v_l + u_l - \mu u_h > 0$.

Proposition 3 *Suppose that without network externalities the partial participation equilibrium would prevail when the firm sells the original good only. Then, the presence of network externalities*

i) may lead to a Pareto-improving quality degradation that would not be realised without network externalities when the equilibrium is sustained as partial participation, and

ii) may alter a potentially Pareto-improving quality degradation to a welfare-reducing one or lead to a welfare-reducing quality degradation that would be avoided without network externalities when the equilibrium nature is changed to full participation.

FULL PARTICIPATION WITHOUT THE DEGRADED GOOD ($\mu v_h < v_l$)

Now consider the case where the full participation equilibrium prevails when the firm sells the degraded good only in the absence of network externalities (i.e. condition (2) holds with $\alpha = 0$). Recall from the previous analysis that the equilibrium nature does not change in this case. If the two types' valuations of the degraded good are not so much differentiated (i.e. $u_l \geq \mu u_h$), the firm will choose forward compatibility. Here, the introduction of the degraded good is profitable in the absence of network externalities if and only if $u_l - \mu u_h > v_l - \mu v_h$, under which the network externality further increases the profitability of quality degradation. So, in this case the presence of network externalities boosts the firm's incentive for quality degradation which is welfare-reducing. If $u_l - \mu u_h < v_l - \mu v_h$, we observe no quality degradation regardless of the presence of network externalities. If the two types' valuations of the degraded good are sufficiently differentiated (i.e. $u_l < \mu u_h$), the firm will choose forward noncompatibility. Given that $\mu v_h < v_l$, it is clear from condition (8) that the firm would have no incentive to introduce the degraded good without

network externalities, and the network externality further discourages the firm's incentive for quality degradation. Hence, we do not observe any qualitatively different results between the two regimes with and without network externalities.

5 Additive preferences

We now examine the case where consumers preferences are additively separable in the stand-alone value and the network value. The model is exactly the same as before, except that a type-i consumer's utility is now given by

$$V_i = \begin{cases} v_i + (\alpha n_o + \beta^b n_d) & \text{when buying the original good} \\ u_i + (\alpha n_d + \beta^f n_o) & \text{when buying the degraded good} \end{cases}.$$

As in the multiplicative specification case, we assume that the two types of consumers are sufficiently differentiated in their valuation for the original good in order to guarantee the existence of the partial participation equilibrium when the firm sells the original good alone.

Assumption 2: $v_h + \alpha\mu > v_l + \alpha$.

Let us first consider the benchmark case without quality degradation. A type-i consumer's utility when purchasing the original good at price P is given by

$$v_i + \alpha n_o - P.$$

Again, the assumption that consumers perfectly coordinate their decisions allows us to focus on the following two equilibria. The *partial participation* equilibrium is characterised by $v_h + \alpha\mu \geq P$ and $v_l + \alpha < P$. The monopolist will set $P = v_h + \alpha\mu$ extracting the whole surplus of type-h consumers, and the resulting profit is $\Pi^1 = \mu(v_h + \alpha\mu)$. The *full participation* equilibrium is characterised by $v_l + \alpha \geq P$. Here, the optimal price is $P = v_l + \alpha$, and the resulting profit is given by $\Pi^2 = v_l + \alpha$.

Then, it is clear that the monopolist wishes to serve both types of consumers if

$$v_l - \mu v_h + \alpha(1-\mu^2) > 0, \tag{9}$$

and serve type-h consumers only otherwise. With additive specifications of network externalities, the presence of network externalities *always* increases the firm's incentive to serve more customers, and accordingly may change the nature of equilibrium from partial participation to full participation as in the case of multiplicative specification.

Now suppose that the monopolist introduces the degraded good. Equilibria are characterised by the type-h consumers' incentive constraint and the type-l consumers' participation constraint:

$$v_h + [\alpha\mu + \beta^b(1-\mu)] - p_o \geq u_h + [\alpha(1-\mu) + \beta^f\mu] - p_d$$

and

$$u_l + [\alpha(1-\mu) + \beta^f\mu] - p_d \geq 0,$$

where as before an individual consumer's contribution to the network size is ignored. The optimal prices are given by

$$p_d^* = u_l + \alpha(1-\mu) + \beta^f\mu$$

for the degraded good and

$$p_o^* = v_h + [\alpha\mu + \beta^b(1-\mu)] - (u_h - u_l)$$

for the original good. Note that the type-h consumers' informational rent is given as $u_h - u_l$, which is not associated with the network effect. Plugging in the optimal prices, the profit is given by

$$\pi(\beta^b, \beta^f) \equiv \mu[v_h + \alpha\mu + \beta^b(1-\mu)] + (u_l - \mu u_h) + (1-\mu)[\alpha(1-\mu) + \beta^f\mu].$$

So, it is optimal for the firm to choose $\beta^{f^*} = \beta^{b^*} = \alpha$. The monopolist always prefers both forward and backward compatibility, given that it can extract all the benefit

associated with the network. So, under the additive specification the monopolist's compatibility decisions are always consistent with the social planner's one.

Given the optimal compatibility decisions, the optimal profit is given by

$$\pi \equiv \mu v_h + (u_l - \mu u_h) + \alpha.$$

The following result is then immediate. First, suppose the firm serves only type-h consumers when selling the original good alone (condition (9) is violated). Then, introducing the degraded good is profitable if and only if

$$\alpha(1 - \mu^2) + u_l - \mu u_h > 0, \tag{10}$$

and it leads to a weak Pareto-improvement. Second. suppose the firm serves both types of consumers when selling the original good alone (condition (9) holds). Then, introducing the degraded good is profitable if and only if

$$\mu v_h - v_l + u_l - \mu u_h > 0, \tag{11}$$

and it leads to a welfare reduction. Here the presence of network externalities always increases the monopolist's incentive for quality degradation when the market expands following the introduction of the degraded good. This is mainly because with the additive specification the firm can fully extract all the consumer surplus attributed to the network. Contrary to the multiplicative specification, however, the network externality has nothing to do with the firm's degradation incentive if the market size dose not change as shown in condition (11).

The impact of network externalities on the welfare effect of quality degradation is similar to the previous multiplicative specification case. Suppose that the partial participation equilibrium is obtained when the firm sells the original good alone in the absence of network externalities (i.e. $\mu v_h > v_l$). If the equilibrium is sustained as partial participation even with network externalities, the network effect may lead to a Pareto-improving quality degradation that would not be realised without network

externalities. This arises when the two types are sufficiently differentiated in their valuation for the degraded good (i.e. $u_l < \mu u_h$), where the firm would have no incentives to introduce the degraded good without network externalities but the network effect makes the introduction of the degraded good profitable. If the equilibrium nature is changed to full participation due to network externalities, two different cases can arise. First, when the two types' valuations for the degraded good are sufficiently close (i.e. $u_l \geq \mu u_h$), the firm would introduce the degraded good even without network externalities and it would be Pareto-improving. The network externality in fact increases the firm's degradation incentive (see condition (11)), but introducing the degraded good now reduces welfare. So, the presence of network externalities alters a potentially Pareto-improving quality degradation to a welfare-reducing one. Second, when the two types' valuations for the degraded good are sufficiently differentiated (i.e. $u_l < \mu u_h$), the quality degradation would not be profitable without network externalities. The network externality, however, induces the monopolist to serve more consumers when selling the original good only, and if the valuation difference for the original good is sufficiently large between the two types (i.e. condition (11) is satisfied) the firm finds it profitable to introduce the degraded good. Hence, the presence of network externalities here leads to a welfare-reducing quality degradation that would be avoided without network externalities. Finally, if the full participation equilibrium is obtained when the firm sells the original good alone in the absence of network externalities, the presence of network externalities has no impact on the welfare effect of quality degradation.

6 Conclusion

We have discussed how the presence of network externalities can affect a monopolist's incentive for quality degradation and its welfare consequence. The network externality can be crucial in leading the firm to introduce a degraded good when its

price discrimination alone is not profitable. This may explain why quality degradation is more frequently observed in markets with network effects such as software and Internet service industries compared to other ordinary markets. Its welfare effect, however, can be much less promising with network externalities. In particular, the presence of network externalities may overturn a potentially Pareto-improving quality degradation to a welfare-reducing one, or result in the realisation of a welfare-reducing quality degradation that would be avoided without network externalities. This result suggests that we should be more careful in evaluating the welfare effect of quality degradation in markets with network effects, and may need to consider policy measures such as minimum quality standards.

Although we have focused mainly on the damaged good framework, most of the results and intuitions would carry over to the traditional quality differentiation or product-line decision setup with marginal cost increasing with quality. Introducing marginal costs of production in the model would yield additional interesting points such as selling the degraded good below costs. The monopolist may wish to introduce the degraded version even though the sale of the degraded version does not cover the cost. This can arise if the surplus extraction gain from high-valuation consumers due to network externalities is large enough to compensate for the profit loss. This is qualitatively similar to the penetration pricing strategy of a single-product monopolist in a dynamic setting with network externalities (see, for example, Bensaid and Lense (1996) and Cabral *et al.* (1999)). In the present static setting, however, the firm uses quality degradation instead of controlling prices over time.

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