Functional Quality Degradation of Software with Network Externalities

Jong-Hee Hahn

Department of Economics,
Keele University,
Keele, Staffordshire,
ST5 5BG, UK

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Abstract

This paper considers a functional quality degradation of software with “two-way” features (such as reading and writing in word-processors). A software monopolist differentiates products by introducing a functionally down-graded version (e.g. the read-only version) by eliminating some functions of the full version. A simple two-type model is presented to explain the rm’s incentive to introduce a functionally down-graded version. It is shown that the functional quality degradation is an effective consumer screening device, especially when consumers’ valuation for each function is negatively correlated. With network externalities, the rm may wish to offer the down-graded good below cost or even free of charge in many cases (including the case where introducing the quality-degraded version does not involve a market expansion). The welfare consequence of this kind of quality degradation is generally ambiguous, and critically depends on how the total market size changes by the introduction of the quality-degraded version.

Key Words: Software, Network Externalities, Quality Differentiation.

JEL classification: L12, L15, L86

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Email: j.h.hahn@econ.keele.ac.uk.
1 Introduction

Nowadays we often find computer software, which can be downloaded on the Internet almost free of charge.\footnote{Most free software is now provided via the Internet, in which case consumers have to pay some telecommunications and time cost for downloading it. Considering this kind of specific distribution channel, consumers are in fact charged a small amount for the read-only version, although the software ...rm does not get the revenue.} Well-known examples are Acrobat Reader and RealPlayer - software designed to view and print (or play) contents written in a specific format, but are not capable of producing the contents in the specific format. The software manufacturers provide typically two different versions of a product, the read-only (or play-only) version and the full version. They offer the viewer or player almost free of charge by allowing consumers to download it on the Internet. However, the viewer (or player) is viewing and printing (or playing) only. To be able to create and edit contents (as well as viewing or playing them), users need to purchase the corresponding full version, which is of course sold at a positive price.\footnote{For example, Adobe Acrobat 4.0, which has the full functional features including creating and editing PDF files, is currently sold at US$249. Also, RealProducer Plus (a full version corresponding to RealPlayer), which enables users to turn video and audio files into streaming Internet media, is currently sold at US$149.95.} Other examples include various Microsoft Word, Excel, PowerPoint Viewers, all of which can be downloaded on the Internet free of charge.\footnote{I am very grateful to Martin Diedrich for providing these Microsoft examples.}

The purpose of this paper is to explain economic motivations underlying this kind of functional or unproportional product differentiation practice.

The normal practice of software versioning is initially to develop a complete full-featured version and then to introduce additional low-quality versions by degrading quality of the original version. This kind of quality degradation is widely used in software markets, since most of the production costs are fixed development costs, and once a complete version has been made low-quality versions can be cheaply produced using the original version.\footnote{Quality degradation is often observed in hardware industries as well (see Denekere and McAfee (1996) for examples).} In this respect, the above example is more like the damaged-goods model of Denekere and McAfee (1996), rather than the standard quality differentiation model à la Mussa and Rosen (1978) where each good in a quality spectrum is treated in an independent manner.\footnote{In Denekere and McAfee's model, a ...rm may introduces a low-quality product by intentionally impairing the quality of the existing good, even when the marginal cost for the degraded good is larger than that of the original high-quality good, in order to screen different customers. They derive a condition under which quality degradation leads to a Pareto improvement. Using a simple graphical analysis with two types of customers, Varian (1997) also discusses versioning information goods in the same spirit of quality degradation. Shapiro and Varian (1999) provide a non-technical treatment of versioning information goods, along with many real-world examples.} However, our model is still distinguished from the damaged-goods model in the way of degrading the original complete version. Here the ...rm degrades the quality of the original full version by removing some of its functions, unlike in the standard quality degradation (or differential) practice.
In this sense, we may call it functional (or unproportional) degradation. Exploring functional quality degradation, by its nature, requires a multi-dimensional quality measure, corresponding to several functional features of software. Imagining each function of software as an individual product, functional degradation is rather similar to the commodity bundling model. Here, however, the rm's decision problem lies in whether to unbundle (disaggregate) the already-bundled complete version -the opposite of the standard bundling model where rms usually wish to bundle individual products to maximise profts.

More interesting is that software rms often sell low-quality versions under cost (almost free of charge in the previous examples), subsidising the purchase of low-quality versions. In the standard quality degradation (differentiation) model, the rm never introduces a low-quality version when it does not cover its cost. One easy way of resolving this puzzle is to introduce network externalities into the analysis. It is well-known that software markets exhibit (direct) network externalities, mainly because of the compatibility among outputs produced by different users (e.g. interchangeability of les). The larger is the number of people who use a particular software, the greater is consumer valuation of the product. Introducing a low-quality version can create a new or larger market. With network externalities, this market expansion gives the high-quality-version-purchasing consumers larger surpluses compared with those they get without the low-quality version. Then we can expect that, provided there are sufficient network effects in the market, the rm may wish to introduce a low-quality version, even when it does not cover its cost, in order to extract larger surpluses from the high-valuation consumers. It should be noted, however,

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6In the standard damaged-goods model, a low-quality version is produced usually by putting limiting factors into the original complete version in order to restrict its quality (such as by reducing operation speed, graphic resolution, and user convenience).

7Then, the standard damaged-good model naturally corresponds to proportional degradation.

8On the other hand, the standard quality degradation (differentiation) model uses a one-dimensional index to measure consumer preferences for quality.

9For details on commodity bundling as a monopolist's sales strategy, see Adams and Yellen (1976) and McAfee et al. (1989), among others.

10This argument can be proved as follows: Suppose that consumer preferences for quality are characterised by a one-dimensional continuous parameter . Let be the unique optimal marginal type when the rm sells the complete version only, and be the resulting profts. Now the rm introduces a low-quality version. Assuming that the valuation for quality improvement is increasing in consumer type, the rm will sell the original complete version to high types and the quality-degraded version to low types. Similarly, let and be the optimal marginal type and the type who is indifferent between the high and low quality versions. Denoting the resulting profts from selling the high and low quality versions and , the total proft is given by . By the definition of optimality, together with the fact that the rm has to give some informational rents to the high-valuation consumers with the introduction of the low-quality version, we have . Then, it always holds that if .

11For example, in the context of telecommunication pricing, Oren et al. (1982) and Hahn (2000a) show that, with network (and call) externalities, a monopolist's optimal nonlinear pricing may involve subsidisation of some low-valuation consumers. However, their models do not consider product differentiation.

12For example, Gandal (1994) provides some empirical evidence for the existence of network externalities in a computer software industry. For the classification of direct and indirect network externalities, see Katz and Shapiro (1994) and Economides (1996).
that subsidisation of the low-quality version may occur without market expansion, as will be shown later.

We now have a substantial body of literature on network externalities (for a survey, see Katz and Shapiro (1994) and Shapiro and Varian (1999)). However, its relation to quality differentiation (especially to the above specific kind of quality degradation) has not been addressed in the literature. A related analysis is contained in the article by Takeyama (1994), who discusses unauthorized copying of software in the presence of network externalities. Unlike most of the literature on intellectual-property protection, she focuses on positive implications of software piracy for firm’s profts as well as social welfare. She shows that with network externalities unauthorized reproduction of intellectual property can not only produce greater firm profts but also lead to a Pareto improvement, compared with the case of no copying. Another work showing the possibility that copying leads to greater firm profts with network externalities is Conner and Rumelt (1991).

Allowing consumers to copy is similar to introducing a low-quality version, in the sense that both can be strategically used by firms as a market expansion and/or consumer screening device. However, this paper considers firms’ pro-active strategy of enlarging their product-line by introducing a low-quality version, rather than the passive strategy of ignoring illegal copying. Also, here firms can choose the price for a degraded low-quality version, unlike the piracy model where the price of copying (i.e., the cost of illegal reproduction) is exogenously given as a consumer-side parameter (e.g. constant in Takeyama’s model). By enlarging the quality spectrum and choosing the price of the low-quality good, the firm in general makes greater profts (extracting more surplus from consumers) than by just ignoring piracy.

In this paper, we develop a simple model of functional quality degradation in software markets with network externalities. We focus on a class of software involving electronic exchange and distribution of files on the Internet, and possessing a two-way feature in the sense that a user can produce her own outputs on the one hand, and can also consume the outputs made by other users as nal products or inputs for her own production on the other. Usually the functional feature of this kind of software can be divided into two broad classes, such as reading and writing in word-processors and creating and playing audio/video in Internet media tools. For expositional convenience, we will hereafter call those two functions simply reading and writing by analogy with word-processors. Then, a consumer’s valuation for software can be divided into two elements corresponding to the two functions, i.e. the valuation for writing and the valuation for reading. Under the two-way feature, the effects...
of network externalities can also be classified into two components based on each function. Consumers’ valuations for the writing function are greater, the larger is the number of the consumers who are able to at least use (read) the outputs produced using the software, i.e. the owners of either the full or the read-only version. On the other hand, consumers’ valuations for the reading function are greater, the larger is the number of consumers who are able to produce (write) the outputs, i.e. the full-version owners. Based on this classification of network effects, a simple model will be presented to explain when and why a software rm has the incentive to introduce a quality-degraded version by eliminating some function of the full version, and sometimes offers the down-graded version for a price below its marginal cost or even free of charge.

The rest of the paper is as follows. In section 2 we introduce a simple two-type model of functional quality degradation of software. Section 3 discusses a benchmark case where the ..rm sells only the full version. In section 4 we analyse the ..rm’s incentive to introduce the read-only version. It is shown that the functional quality degradation is a very effective screening device, especially when consumers’ valuation for each function is negatively correlated in a favourable way for the ..rm. Also, with network externalities, the ..rm may wish to offer the down-graded good below cost or even free of charge in many cases (including the case where introducing the quality-degraded version does not involve a market expansion). Section 5 investigates the welfare effect of this kind of functional quality degradation. In section 6, we conclude with some discussions.

2 The model

Consider a software monopolist who has developed a complete full-featured version of a two-way functional software. She can sell either the complete version only or introduce a read-only version. The read-only version can be easily produced by deleting the writing function of the existing full version. There can be at most two products in the market, the full version and the read-only version. We assume that both versions are produced at constant marginal cost d > 0, and that there is no degradation cost.

Suppose there are two types of consumers denoted {h; l}. There is a continuum of homogeneous consumers of each type. Denote the proportion of type i as 0 < , i < 1 (i = h; l). The total population of potential consumers is normalised to unity (, h + , l = 1). The ..rm cannot observe consumer type. Consumers have unit demands

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16 The write-only version is irrelevant in software markets since writing something in general involves reading.

17 This assumption is reasonable because the read-only version can be made by simply removing the writing function from the full version almost costlessly. There are at least two possible scenarios regarding how to produce and sell the read-only version. One is the case where the ..rm removes the writing function from the full version at every sale of the read-only version. The other is the case where the ..rm makes an original of the read-only version, and then produces read-only versions by copying the original. The examples introduced previously seem to be ..t for the second. However, the cost structures of the two cases are virtually identical under the assumptions of no degradation cost and constant marginal cost.
for either the full or the read-only version. Assume that utility from the two functions is additively separable. The gross utility of a type-i consumer is given by

\[ U_i = \begin{cases} (n_F + n_R)v_w^i + n_F v_r^i, & \text{if she purchases the full version} \\ n_F v_r^i, & \text{if she purchases the read-only version} \end{cases}; i = h; l \]

where \( v_w^i \geq 0 \) and \( v_r^i \geq 0 \) measure type-i consumer's valuations for the writing and reading functions, and \( n_F \) and \( n_R \) are the respective fractions of consumers who buy the full and the read-only versions.\(^{18}\) So, each type is characterised by a pair of index \( (v_w^i; v_r^i); i = h; l \). We proceed only with two types in a two-dimensional space. We first fix a type's preferences (type h) and then examine several possible cases depending on the other type's preferences (type l) in relation to the rst.\(^{19}\) Consumers' valuation for the writing function depends on the total participation level. However, consumers' valuation for the reading function depends only on the fraction of consumers who purchase the full version, since benefits from the reading function are realised only when reading the outputs produced by the full-version owners. Following the standard approach in the literature on network externalities, we assume that consumers form expectations about the sizes of \( n_F \) and \( n_R \), and require that their expectations be fulfilled in equilibrium (rational expectations).

3 Selling the full version only

Consider a benchmark case where the rm sells the full version only. For price \( P \) offered by the rm, the net surplus a consumer of each type obtains when purchasing the full version is \( n(v_w^i + v_r^i); i = h; l \), where \( n \) is consumers' expectation of the proportion of participating consumers. For future use, we assume that

\[ h(v_w^h + v_r^h) > v_w^l + v_r^l; \]

which implies that the two types' preferences for the full version is sufficiently differentiated. So, we can call type h the high-valuation consumer group and type l the low-valuation consumer group for the full version. As will be shown shortly, this condition is in fact necessary for the existence of a partial participation equilibrium with only type-h consumers being served. As usual in the literature on network externalities, multiple equilibria may arise given prices corresponding to various scenarios of consumer expectation and coordination.\(^{20}\) We avoid this problem by assuming

\(^{18}\)One may wish to set up \( (n_F + n_R)\frac{1}{\lambda}v_w^i + n_R v_r^i \) for the consumer utility from purchasing the full version, where parameter \( \frac{1}{\lambda} \) measures the relative strength of the network effect related to the writing function compared with that related to the reading function.

\(^{19}\)Of course, this approach is far from the standard two-dimensional screening problem. One would prefer a 2 x 2 model with four types, rather than this 2-type model. But, it generally generates too many cases to consider without much contribution to our understanding of the problem. An ideal way to express the problem would be to model consumer type continuously. However, the general two-dimensional continuous-type model seems intractable, similarly to the standard bundling model (in fact, it would be much more difficult with network externalities).

\(^{20}\)This has been found by Rohlfs (1974), Farrell and Saloner (1985), and Katz and Shapiro (1985), among others.
that the homogeneous consumers in each group coordinate their decisions to achieve their collective optimum, and also the .rm chooses the best equilibrium price. The assumption of perfect consumer coordination implicitly implies that the .rm takes a very pessimistic (or risk-averse) view for its pro..t-maximisation.\textsuperscript{21} With only two types of consumers there are at most two cases to consider.\textsuperscript{22}

\textsuperscript{2} Equilibria with partial participation: Under condition (1), the .rm will intend to serve type-h consumers, excluding type-l consumers. Given that consumers expect only type-h consumers will participate, equilibrium price $P$ should satisfy \( h(v^w_h + v^f_h) > v^w_l + v^f_l \). Under condition (1) there exists at least one feasible $P$ that satisfies the two conditions. The .rm's optimal strategy is to extract all the gross surplus of type-h consumers by charging \( h(v^w_h + v^f_h) \). The resulting pro..t is given by $\frac{1}{2}F_1 = h(v^w_h + v^f_h) - d$.

\textsuperscript{2} Equilibria with full participation: Given that consumers expect both types will participate, equilibria are characterised by $v^w_l + v^f_l > P$. Note that under condition (1) type-h consumers always wish to buy the full version if type-l consumers decide to purchase it. In this case, the .rm will charge $P = v^w_l + v^f_l$ for the good, and get pro..ts of $\frac{1}{2}F_2 = v^w_l + v^f_l - d$. Serving type-l consumers, who value the full version less than type-h consumers, forces the .rm to give informational rents $v^w_h + v^f_h (v^w_l + v^f_l)$ to type-h consumers.

Note that if condition (1) does not hold the .rm always choose to serve both types, regardless of the proportion distribution of the two types ($\frac{1}{2}F_1 < \frac{1}{2}F_2$). We exclude this case to highlight the role of the product differentiation using functional degradation which we will consider in the next section. Additionally, to ensure there exists at least one equilibrium where the .rm can make a positive pro..t we assume that

\[ h(v^w_h + v^f_h) > d \]  \hspace{1cm} (2)

The .rm will choose the price that induces the partial participation equilibrium if $\frac{1}{2}F_1 > \frac{1}{2}F_2$, i.e.

\[ h(v^w_h + v^f_h) > i(v^w_l + v^f_l) - d; \] \hspace{1cm} (3)

which is more likely the larger is $h$ relative to $i$, the larger is the difference of $v^w_h + v^f_h$ and $v^w_l + v^f_l$, and the larger is the marginal cost $d$. Otherwise, the .rm will decide to sell to both types.\textsuperscript{24}

\textsuperscript{21} One advantage of this approach is that any results obtained under the pessimistic view will hold under an optimistic view as well. However, the model structure will resemble more closely a general continuous type case when we assume completely individualistic consumers.

\textsuperscript{22} We ignore the trivial case with no consumer participation.

\textsuperscript{23} The second part of the inequality reflects the pessimistic view. The .rm chooses price so that each member of type-l consumers has no incentive to purchase the full version, even though they coordinate their decisions perfectly.

\textsuperscript{24} We assume that the .rm chooses to serve both types when $\frac{1}{2}F_1 = \frac{1}{2}F_2$. 

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4 Introducing the read-only version

Now the firm sells both the full and the read-only versions. The firm’s problem is to choose the profit-maximising pair of prices among those which induce consumers to sort themselves into two different groups (the full version purchasing group and the read-only version purchasing group). The desirability of introducing the read-only version from the point of view of the firm and the social planner can only be judged by comparing the two regimes of selling the full version alone and of selling both versions. Unlike the well-known result in the standard bundling model that mixed bundling (weakly) dominates pure bundling (Adams and Yellen, 1976), here it is not clear whether introducing the read-only version always yields profits at least as large as selling the full version only, because of the specific cost structure in software production.

Let $P_F$ and $P_R$ denote the prices of the full and the read-only version. With only two types of consumers, the introduction of the read-only version, provided it is sold, leads to a full participation equilibrium ($n_F + n_R = 1$). When the firm sells the full version to type-$i$ consumers and the read-only version to type-$j$ consumers ($i; j = h; l$), equilibria are characterised by joint satisfaction of the following conditions:

\begin{align}
&v_i^w + \lambda_i v_i^r \geq P_F; \\
&v_j^w + \lambda_j v_j^r \geq P_R; \\
&\lambda_i v_i^r + \lambda_j v_j^r \geq P_F; \\
&\lambda_i v_i^r \geq P_R;
\end{align}

where conditions (4) and (5) are the incentive and participation constraints for type-$i$ consumers, and conditions (6) and (7) are the incentive and participation constraints for type-$j$ consumers. Note that the two incentive constraints reflect the firm’s pessimistic view (i.e., consumers’ perfect coordination). The inequality in (4) states that each member of type $i$ has no incentive to switch individually from the targeted full version to the read-only version (Notation $\lambda_i$ takes into account the individual contribution to the network). Similarly, the inequality in (6) implies that type-$j$ consumers have no incentive to switch from the targeted read-only version to the full version, even though they perfectly coordinate on purchasing the full version together. With a continuum of consumers in each type, an individual’s contribution to the size of the network is negligible, and therefore assume that $\lambda_i = \epsilon_i$.

We know that, under condition (1), the value for the full version is greater for type-$h$ than for type-$l$ consumers. However, each type’s incremental value of switching

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25 Selling the read-only version only is generally irrelevant, since all consumers get zero gross surplus with no consumers buying the full version.

26 In the standard bundling model (where the marginal cost of the bundled good is equal to the sum of the marginal costs of individual goods), the firm with mixed bundling can obtain at least the same profit it can get with pure bundling, by choosing the profit margins for individual goods as large as that for the bundled good. This property, however, is not always true in the present setting because the marginal cost of the read-only version (an individual good) is in fact the same as that of the full version (a bundled good). With the same margin on both versions, i.e. the same price for both versions, consumers will always choose the full version.
individually from the read-only version to the full version is given by $v_i^w$ ($i = h;l$). We can divide the problem into two cases depending on which type’s incremental value is larger than other’s.

4.1 When $v_h^w < v_l^w$

The incremental value of switching is larger for type $l$, while the value for the full version is greater for type $h$. With a negative correlation of the valuations for writing and reading (under condition (1)), this case might look ideal for segmenting the market using quality differentiation. However, considering the distribution of the valuations of the two types carefully, it turns out to be an extremely inappropriate case for consumer screening by introducing the read-only version. Introducing the read-only version targeting type-$l$ consumers is not suitable since type-$l$ consumers’ valuation is more biased for the writing function than that of type-$h$ consumers. In fact, if the firm tries to sell the read-only version to type-$l$ consumers (while choosing $P_F$ so that type-$l$ consumers are not tempted to buy the full version), type-$h$ consumers always have the incentive to switch individually to the read-only version from the originally targeted full version. Another possibility is to sell the full version to type-$l$ and the read-only version to type-$h$, in spite that the valuation for the full version is greater for type-$h$ consumers. Under the assumption of perfect consumer coordination, however, this option also turns out to be infeasible. If the firm tries to sell the full version to type-$l$ consumers (while choosing $P_R$ so that type-$l$ consumers are not tempted to buy the read-only version), type-$h$ consumers always have the incentive to switch collectively to the full version from the originally targeted read-only version.\footnote{Note that, however, this strategy is usually feasible if we assume that consumers behave completely non-cooperative way (e.g. perfect individualism), although it is not certain whether it produces a larger profit than the case of selling the full version only.} So, the firm never introduces the read-only version. We will exclude this case from the analysis.

Lemma 1 Under condition (1), for $v_h^w < v_l^w$ there exists no pair of prices $(P_F; P_R)$ dividing the two types of consumers into the full version and the read-only version purchasing groups.

Proof. See Appendix. $\blacksquare$

4.2 When $v_h^w > v_l^w$

Both the value for the full version and the incremental value of switching are larger for type $h$. Then, the firm will wish to sell the full version to type-$h$ consumers and the read-only version to type-$l$ consumers.\footnote{Similarly to lemma 1, it can be easily shown that for $v_h^w > v_l^w$ there exists no pair of prices $(P_F; P_R)$ inducing type-$l$ consumers to buy the full version and type-$h$ consumers to buy the read-only version.} Equilibria are characterised by joint satisfaction of conditions (4), (5), (6) and (7) with $i = h$ and $j = l$.  

\[9\]
First, suppose that the firm can observe consumer type, and chooses the prices so that both participation constraints are binding, i.e. $P_F = v_{wh} + \lambda h v'_h$ and $P_R = \lambda h v'_l$. At those complete information prices, the incentive constraint can be rewritten as $h(v'_l v'_h) > 0$ for type $h$, and $v_{wh} - h v'_h = v_{wl} + v'_l$ for type $l$. Under condition (1), the incentive constraint for type $l$ is always satisfied. However, the satisfaction of type $h$'s incentive constraint depends upon the sign of $v'_l v'_h$ (the relative magnitude of each type's value for the reading function). So, it will be convenient to examine separately two subcases, one for negative correlations and the other for positive correlations between the two types' valuations of writing and reading functions. For a fixed $(v_{wh}; v_{rh})$, Figure 1 exhibits the three possible cases in the value plane under condition (1).

![Figure 1: Three possible cases in the value plane](image)

Negative correlation of values ($v'_h < v'_l$ and $v_{wh} > v_{wl}$).

Type-$l$ consumers' valuations are more biased for the reading function, compared with those of type-$h$ consumers. This corresponds to the case where customers are clearly divided into two groups, one interested in writing and the other interested in reading. Unlike the previous case of $v_{wh} < v_{wl}$, however, this negative correlation case is very favourable for the firm wishing to screening the two types of consumers by introducing the read-only version. We know that in this case the incentive constraint for type $h$ is nonbinding given $P_F$ and $P_R$, as well as the incentive constraint

\[29\] Note that, however, the valuation for the full version is still larger for type $h$ than for type $l$. 

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for type l. Therefore, the complete information prices ($P_F; P_R$) are feasible, and in fact optimal. The rm can extract all the surpluses of the participating consumers, in spite of selling two differentiated products to two different groups.\textsuperscript{30} This result contrasts with the ordinary (one-dimensional or equi-proportional) quality differentiation, where the rm cannot extract all of the consumer surplus once a low-quality product is introduced because the high-valuation consumers' incentive constraint is always-binding with the introduction of the low-quality product.\textsuperscript{31} So, it is this (favourable) negative correlation case in which the rm can make the most of the virtue of functional (unproportional) quality disaggregation.\textsuperscript{32} The resulting profit is given by

$$\frac{1}{P} = \sum (\sum v^w + \sum h_v l - d) + \sum (\sum v^r l - d).$$

**Proposition 2** Suppose that $v^r h < v^r l$ and $v^w h > v^w l$. Then, under condition (1), (i) the rm always wishes to introduce the read-only version, and (ii) may sell the read-only version at a price below cost.

**Proof.** See Appendix.

First, consider the case of partial participation equilibrium with the full version only. Introducing the read-only version induces type-l consumers, who would be excluded with the full version alone in the market, to participate by purchasing the read-only version. This newly-created market yields profits of $\sum (\sum v^r l - d)$. With network externalities, this market expansion also boosts type-h consumers' utility from the full version. We know that, in this case of favourable negative correlation, the rm can extract the whole of the additional surplus ($\sum (\sum v^w h)$) type-h consumers get due to the network effect. This extra surplus extraction is always positive. So, if the marginal cost is small so that the rm can make positive profits by selling the read-only version ($\sum (\sum v^r l > d)$), introducing the read-only version is clearly more profitable. Interestingly, this is true even when the rm has to sell the read-only version below its marginal cost ($\sum (\sum v^r l < d)$, because the amount of extra surplus extraction is always greater than the possible profit loss from selling the read-only version below cost given condition (2) ($\frac{1}{P} > 0$).

Next, consider the case of full participation equilibrium with the full version only. Here, the introduction of the read-only version has nothing to do with market size. With (favourably) negatively correlated valuations, however, it is a very effective tool of screening consumers. Also, the rm can maintain most of the surplus extraction

\textsuperscript{30}In the context of standard commodity bundling, Adams and Yellen (1976) showed that a similar first-best outcome can be obtained by bundling with a perfect negative correlation. The full-rent-extraction story is not always true with more than two types. However, we can nd a situation where the rm can extract all the consumers' surpluses if the consumers' valuations for the two functions are sufficiently negatively correlated.

\textsuperscript{31}See Hahn (2000b, Ch 3.2) for a one-dimensional model of quality degradation with network externalities.

\textsuperscript{32}Another merit of functional degradation is its implementational convenience and cost effectiveness. The rm does not have to worry about how to determine the level of quality degradation. Also, a low-quality version can be produced easily by removing some functions from the existing full version without additional degradation costs (which are usually required in the ordinary quality degradation).
opportunity from type-h consumers (due to network effects) by keeping the type-l consumers staying in the market. In fact, the net pro.t gain from screening type-h consumers (\(\lambda_h(v^w_i + \lambda_h v^f_i) - \lambda_l(v^w_l + v^r_l)\)) is always greater than the net pro.t loss from selling the read-only version instead of the full version to type-l consumers (\(\lambda_l(v^w_l + v^r_l) - \lambda_h v^r_l\)), provided condition (1) holds (i.e. consumers' preferences for the full version is sufficiently differentiated). Even without any expansion of the market size, the rm may wish to introduce the read-only version selling it under cost, provided the net pro.t gain from screening type-h consumers is larger than the pro.t it could make from type-l consumers when selling the full version only.

Therefore, in this (favourable) negative correlation case, the rm always has the incentive to introduce the read-only version, even when it has to sell the read-only version under cost. The subsidisation case is a situation where the rm loses money on every sale of the read-only version, but gains more than enough to make up for it by charging a high price for the full version due to network effects.

**Positive correlation of values** \((v^f_h > v^f_l\) and \(v^w_h > v^w_l)\).

Here, the two types' valuations for the writing and reading functions are more or less aligned, similarly to the ordinary (one-dimensional or equi-proportional) quality differentiation. The incentive constraint for type h is not satisfied at the complete information prices \((P_F; P_R)\). The rm is then forced to lower the price of the full version to the level at which type-h consumers are indifferent between purchasing the full version and purchasing the read-only version. The rm's optimal strategy is to charge \(P^*_R\) for the read-only version and to set the price for the full version equal to \(P^*_F = v^w_h + \lambda_h v^f_i\), leaving type-h consumers informational rents \(\lambda_h(v^f_h - v^f_l)\).

Similarly to the standard screening model, at price \(P^*_F\) type-l consumers do not have the incentive to buy the full version. The resulting pro.t is given by

\[
\frac{1}{2} = \lambda_h(v^w_i + \lambda_h v^f_i) + \lambda_l(v^f_i) \Rightarrow 0 \quad \text{for} \quad \frac{1}{2}^* \quad \text{and} \quad \frac{1}{2}^*.
\]

**Proposition 3** Suppose that \(v^f_h > v^f_l\) and \(v^w_h > v^w_l\). Then, (i) the rm will introduce the read-only version if

\[
\lambda_h(v^f_i + \lambda_h v^f_i) + \lambda_l(v^f_i) > 0 \quad \text{for} \quad \frac{1}{2}^* \quad \text{and} \quad \text{and} \quad \frac{1}{2}^*\]

and (ii) may offer the read-only version under cost.

**Proof.** See Appendix.
Here the table introduction of a degraded version needs certain conditions, similar to the standard model of quality degradation. Consider the case of partial participation equilibrium with the full version only. The first bracketed term in (8) denotes the sum of the (positive) extra surplus extraction gain due to network effects and the (negative) informational rent offered to type-h consumers by the introduction of the read-only version. The second term is the profit (or deficit) obtained in the newly created market. So the rm is more likely to introduce the read-only version, the smaller is the difference between \( \nu_h \) and \( \nu_l \) (making the informational rent smaller), and the larger is \( \nu_h \) relative to \( \nu_l \) (making the network effect greater). This is a case where consumers’ valuations are largely biased to the writing function for type-h and to the reading function for type-h (while the difference in the total valuation for the full version is large enough between the two types so that the rm chooses to serve type-h only when selling the full version alone, i.e. \( \frac{\nu_h}{\nu_l} > \frac{\nu_l}{\nu_h} \)). The rm may wish to introduce the read-only version even if it does not cover its cost, provided the extra surplus extraction gain due to network effects is larger than the informational rent offered to type-h consumers. Moreover, in the extreme case where \( \nu_l = 0 \) and \( \nu_h(\nu_h + \nu_l) > \nu_l(\nu_l + \nu_h) \) (i.e. type-h consumers’ valuations are extremely biased for the writing function and the marginal cost is small), the rm would provide the read-only version almost free of charge. The examples of functionally down-graded (almost) free software such as Acrobat Reader and RealPlayer can be well explained by this case.\(^{36}\)

For the case of full participation equilibrium with full version only, the rm will introduce the read-only version if and only if the gain from screening \( \nu_h(\nu_h + \nu_l) > \nu_l(\nu_l + \nu_h) \) is larger than the net profit loss from selling the read-only version instead of the full version to type-l consumers \( \nu_l(\nu_l + \nu_h) \). Note that there is no network effects here. Condition (9) indicates that the introduction of the read-only version is likely to occur when the rm serves type-l consumers, when selling the full version only, because of their large proportion in the population even though the difference of valuation for the full version between the two types are large. Similarly to the previous negative correlation case, the rm may wish to subsidise the purchase of the read-only version, provided the net profit gain from screening type-h consumers is larger than the profit it could make from type-l consumers when selling the full version only.

With positively correlated valuations the rm is less likely to introduce the read-only version, relative to the previous negative correlation case, in the sense that...

\(^{36}\) Let us consider, for example, the academic market for Acrobat programs. Professionals (like lecturers and professors) are generally keen on writing relative to reading. On the other hand, students are more interested in reading papers written by professionals rather than writing their own papers. However, professionals value both writing and reading functions larger than students (i.e. positive correlation of values). If the rm sells the full version only at a certain price, students would not buy it. The software company attracts students into the market by allowing them to download Acrobat Reader almost free of charge (students actually pay download costs), and extracts the increased surpluses (due to network effects) from professionals. Professionals would be better-off by the introduction of the read-only version getting a positive surplus, even though they may pay a higher price. Without the read-only version, their surplus (which must be smaller with a smaller market) would be fully extracted by the rm. The provision of Acrobat Reader for completely free may not be optimal, but seems a good approximation of the profit-maximising pricing policy.
conditions (8) and (9) are required while the rm always wish to introduce the read-only version with (favourably) negatively correlated valuations. This is mainly due to the informational rent the rm has to offer to type-h consumers. However, it is still possible for the rm to subsidise the purchase of the read-only version.

5 Welfare effects

Similarly to the conventional wisdom in the standard price discrimination, the welfare consequence of introducing the read-only version crucially depends on whether the introduction of the read-only version expands the total market size or not. We exclude the case of \( v^w_h < v^w_l \), where the rm never introduces the read-only version.

**Proposition 4** If condition (3) holds (partial participation equilibrium with the full version only), the profitable introduction of the read-only version is Pareto-improving. Otherwise (full participation equilibrium with the full version only), it is welfare-reducing.

First, consider the partial participation case when selling the full version only. In the case of \( v^f_h < v^f_l \) and \( v^f_h > v^f_l \) (favourable negative correlation of valuations), the rm always becomes better-off by introducing the read-only version (Proposition 1). The net surpluses of both types of consumers are unchanged at zero since the rm fully extracts all the surpluses of the participating consumers. In the case of \( v^f_h > v^f_l \) and \( v^f_h > v^f_l \) (positive correlation of valuations), provided condition (8) holds the rm becomes better-off by introducing the read-only version. Type-h consumers are better-off with a strictly positive net surplus, while type-l consumers end up with zero net surplus.\(^{37}\) So, the introduction of the read-only version by the profit-maximising rm is Pareto-improving.\(^{38}\) In the case of positive correlation of valuations, however, the rm will not introduce the read-only version if condition (8) does not hold. In this case, the total surplus change by the introduction of the read-only version is \( \int [h(v^h_l + v^f_l) - d] \), which can be positive or negative depending on the parameters. Suppose that \( \int [h(v^f_l + v^f_l) - d] > 0 \). Then rm then does not introduce the read-only version. So, we may face a situation where introducing the read-only version is socially desirable, but the rm never introduces it.

Next, consider the full participation case when selling the full version only. Type-l consumers (who would buy the full version in the absence of the read-only version) are now induced to purchase the read-only version, and therefore get a smaller gross surplus, while type-h consumers are always allocated the same full version. The total cost is identical regardless of the introduction of the read-only version because the...

\(^{37}\)However, in both cases, they now do participate by purchasing the read-only version rather than being excluded from the market.

\(^{38}\)This strong result is not always true for more than two types. When there are more than two types, the introduction of the read-only version may induce some consumers, who would buy the full version when selling the full version only, to switch to the read-only version, and a Pareto-improvement would require some condition ensuring those consumers get at least the same net surplus they would get with the full version only.
total demand is all the same. So, the introduction of the read-only version reduces
the total social surplus, compared with the case of selling the full version to both
types. The introduction of the read-only version as a result of the ..rm’s pro..t-
maximising behaviour is socially undesirable in this case. This immediately means
that the pro..table introduction of the read-only version makes type-h consumers
worse-off because type-l consumers always get zero surplus. Table 1 below provides
a brief summary of our discussion.

<table>
<thead>
<tr>
<th>Selling the Full Version Only</th>
<th>Introducing the Read-only Version</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sell to type-h only</td>
<td>Negatively-correlated: 4 ( \dagger )</td>
</tr>
<tr>
<td>(Partial participation)</td>
<td>Subsidisation: possible</td>
</tr>
<tr>
<td></td>
<td>Positively-correlated: 4 ( \dagger )</td>
</tr>
<tr>
<td></td>
<td>Subsidisation: possible</td>
</tr>
<tr>
<td>Sell to both types</td>
<td>Negatively-correlated: 4 ( \dagger )</td>
</tr>
<tr>
<td>(Full participation)</td>
<td>Subsidisation: possible</td>
</tr>
<tr>
<td></td>
<td>Positively-correlated: 4 ( \dagger )</td>
</tr>
<tr>
<td></td>
<td>Subsidisation: possible</td>
</tr>
</tbody>
</table>

(4 \( \dagger \) : change in pro..t, 4 W : change in welfare, * : favourable negative correlation)

| Table 1. Comparison of equilibria with and without the read-only version. |

Example 1 \( h = 1 = \frac{1}{2}; (v^h_l; v^h_h) = (5; 1) \) and \( d = \frac{3}{2} \).

Figure 2 below illustrates the welfare effects of introducing the read-only version.
The region A depicts the cases where the introduction of the read-only version pro-
duces not only a larger pro..t but also a welfare increase, i.e. Pareto-improving. On
the other hand, the region B depicts the cases where the introduction of the read-
only version by the pro..t-maximising ..rm leads to a welfare reduction. Finally, the
region C depicts the cases where the introduction of the read-only version would be
welfare-improving, but the pro..t-maximising ..rm never does. By construction, the
..rm always subsidises the purchase of the read-only version in this case.

\[ 39 \text{This ineficiency is more likely to be overcome by the traditional proportional degradation, rather than unproportional functional degradation.} \]
6 Discussion

Using a simple two-type model, we have examined functional quality degradation in software markets with two-way features, focusing on the effect of network externalities on the firm’s incentive for the quality degradation. Apart from implementational convenience and cost effectiveness, introducing a functionally down-graded software by removing some functions of the original full version is a very effective screening tool, especially when consumers’ valuations for the functions are (favourably) negatively correlated. With network externalities, the firm may wish to offer the quality-degraded software at a price under cost or even free of charge. Interestingly, this kind of subsidisation is possible even when the introduction of the low-quality version does not involve a market-size expansion. This result is in fact qualitatively similar to the penetration-pricing strategy in dynamic monopoly pricing with network externalities, where firms sometimes have the incentive to offer an introductory price below cost at an early stage in order to build a large installed base of customers, and then increase the price later. In the present static setting, however, firms use quality degradation instead of controlling prices over time. Finally, its welfare effect is generally ambiguous, and is not always consistent with the social planner’s objective.

In future work, we need to ask whether the results obtained under the two-type case generalises to a general continuous-type case, although it seems to involve techni-

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Figure 2: Welfare effects of introducing the read-only version
cal difficulties similarly to the standard bundling model.\footnote{In fact, with network externalities the problem looks much more difficult than the standard bundling model.} Another interesting topic is the mix of ordinary (proportional) and functional (unproportional) quality degradations. For example, RealNetworks inc. is now selling at least two more products related to RealPlayer. One is RealPlayer Plus (currently sold at $29), which is a more advanced version of RealPlayer but still has no capability of creating Internet media files. The other is RealProducer Basic (free of charge), which is a down-graded version of RealProducer Plus. Besides the functional degradation between RealPlayer and RealProducer Plus, we find traditional proportional quality degradations (between RealPlayer and RealPlayer Plus as well as between RealProducer Basic and RealProducer Plus) and two more functional degradations (between RealPlayer Plus and RealProducer Plus as well as between RealPlayer and RealProducer Basic). With many possible combinations of strategies, however, it looks very complicated to develop an economic model.

Noting that a large portion of computer software products are provided by several competing firms, extending the model to a competitive environment would certainly be useful. The practice of offering quality-degraded goods below cost might be a more general phenomenon with competition for market shares. However, it is not so obvious considering the fact that with network effects one firm’s introduction of the read-only version gives benefits to its rivals as well, provided there is compatibility among different firms’ products.

Appendix

Proof of lemma 1.

First, suppose that the firm tries to sell the full version to type-$h$ consumers and the read-only version to type-$l$ consumers. Equilibria are characterised by joint satisfaction of conditions (4), (5), (6) and (7) with $i = h$ and $j = l$. Rearranging the two incentive constraints, we have

\[ v^w_h - P_F \times v^w_l + \lambda \lambda v^l_l : \]

Given that $v^w_h < v^w_l$, $\lambda > 0$, and $v^l_l > 0$, there exists no pair of prices $(P_F; P_R)$ satisfying these condition.

Next, suppose that the firm tries to sell the full version to type-$l$ consumers and the read-only version to type-$h$ consumers. Similarly, equilibria are characterised by joint satisfaction of conditions (4), (5), (6) and (7) with $i = l$ and $j = h$. A necessary condition to satisfy both participation constraints is that

\[ v^w_l + \lambda v^l_l + \lambda v^h_h - P_F \times v^w_h + h v^h_h : \]

Combining type-$h$’s incentive constraint with condition (10) yields

\[ v^w_l + \lambda v^l_l + \lambda v^h_h - P_F \times v^w_h + h v^h_h : \]
Given condition (1), \( v^w < 0, v^f < 0 \), there exists no pair of prices \( (P_F; P_R) \) satisfying this constraint and \( 0 < \lambda < 1 \) since we have \( v^w + \lambda h v^f > \lambda (v^w + v^f) > v^f > v^w + \lambda v^f \).

**Proof of proposition 1.**

First, suppose that condition (3) holds (the partial participation equilibrium when selling the full version only). The incremental profit from introducing the read-only version is

\[
\frac{\partial^2}{\partial v^w} \frac{\partial^2}{\partial v^f} = \lambda (v^w + v^f) + \lambda h (v^w + v^f) + \lambda h (v^w + v^f)
\]

which is always positive given assumption (2) and condition \( v^f > v^w \). Since the second term of the RHS of (11) is strictly positive, the first term of the RHS of (11) can be negative \( \lambda h v^f + \lambda h (v^w + v^f) \), i.e. the price of the read-only version being below its cost.

Next, suppose that condition (3) does not hold (the full participation equilibrium when selling the full version only). The incremental profit from introducing the read-only version is

\[
\frac{\partial^2}{\partial v^w} \frac{\partial^2}{\partial v^f} = \lambda (v^w + v^f) + \lambda h (v^w + v^f) + \lambda h (v^w + v^f)
\]

which is always positive given assumption (1) and condition \( v^f > v^w \). Rearranging the incremental profit, \( \frac{\partial^2}{\partial v^w} \frac{\partial^2}{\partial v^f} = (v^w + v^f) + \lambda h (v^w + v^f) + \lambda h (v^w + v^f) \) so, if the bracketed term is strictly positive we can have a case where \( \lambda h v^f + \lambda h (v^w + v^f) + \lambda h (v^w + v^f) \), i.e. the price of the read-only version to be below its cost.

**Proof of proposition 2.**

i) Conditions (8) and (9) are immediate from \( \lambda \frac{\partial^2}{\partial v^w} \frac{\partial^2}{\partial v^f} = \lambda \frac{\partial^2}{\partial v^w} \frac{\partial^2}{\partial v^f} \) and \( \lambda \frac{\partial^2}{\partial v^w} \frac{\partial^2}{\partial v^f} > \lambda \frac{\partial^2}{\partial v^w} \frac{\partial^2}{\partial v^f} \). ii) For the case of partial participation equilibrium with the full version only, the incremental profit \( \lambda \frac{\partial^2}{\partial v^w} \frac{\partial^2}{\partial v^f} \) can be still positive even when \( \lambda h v^f + \lambda h (v^w + v^f) + \lambda h (v^w + v^f) \), combined with condition \( \lambda \frac{\partial^2}{\partial v^w} \frac{\partial^2}{\partial v^f} > \lambda \frac{\partial^2}{\partial v^w} \frac{\partial^2}{\partial v^f} \), a necessary condition for the price of the read-only version to be below its cost at the optimum is \( v^f + v^w + \lambda h (v^w + v^f) + \lambda h (v^w + v^f) \), provided \( \lambda h v^f + \lambda h (v^w + v^f) + \lambda h (v^w + v^f) \). Similarly, for the case of full participation equilibrium the incremental profit \( \lambda \frac{\partial^2}{\partial v^w} \frac{\partial^2}{\partial v^f} \) can be still positive even when \( \lambda h v^f + \lambda h (v^w + v^f) + \lambda h (v^w + v^f) \), a necessary condition for the subsidisation of the read-only version is \( \lambda h v^f + \lambda h (v^w + v^f) + \lambda h v^f + \lambda h (v^w + v^f) \).

**References**


