Compatibility, Intellectual Property, Innovation and Efficiency in Durable Goods Markets with Network Effects

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Compatibility, Intellectual Property, Innovation and Efficiency in Durable Goods Markets with Network Effects

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Abstract

This paper serves as a new contribution in understanding how firms' decisions regarding compatibility relate to their incentives to invest into improving their durable, network goods in the presence of forward looking consumers. It is the first attempt to introduce a new framework in the literature by using a sequential game where the smaller firm can build on the dominant firm's existing knowledge. Our first key result is that the market leader may indeed support compatibility with its rival and this happens when it anticipates a substantial quality improvement by the competitor allowing him to extract in the present market more of the higher total expected surplus that emerges when interoperability is present. On the other hand, the rival always supports compatibility because she can charge a higher price due to a larger network. Furthermore, we find that interoperability does not de-facto maximise social welfare and we identify no market failure when network effects are not particularly strong.

Keywords: Firms, Pricing, Compatibility, Innovation, Technological Change, Intellectual Property Rights, Antitrust Law, Competition, Externalities, Product Durability, Welfare

JEL classification: D43, L13, D71, D62, L15, L4, K21, L51, O34, O31.

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1 Introduction

Should dominant firms in economies with durable, network goods like software markets, have the duty to provide technical compatibility information to direct competitors? This fundamental question lies at the intersection of Antitrust and Intellectual Property Law and different countries give different answers.

The proponents of interoperability[3] argue that its presence guarantees that consumers' welfare is maximised at least in a static scenario. This is the dominant view in the European Union where market leaders should provide compatibility information to rivals as failure to do so is considered as a potential violation of Article 102 (ex article 82) of the European Competition Law and leads to regulation by Courts enforcing the dominant firms to allow compatibility[4]. A famous example comes from the most recent European Commission case against Microsoft in 2008. It was related to the computer software giant's refusal to provide its competitors technical information regarding its Office suite so that they could craft software interoperable with Microsoft Office 2007[5]. The case followed a complaint[6] from firms-members of the ECIS (European Committee of Interoperable Systems) and was put on hold in December 2009 after Microsoft's commitment to comply with the European Union Competition Law[7]. Nevertheless, there are other important cases where the Commission and European Courts ruled favouring a weaker protection for Intellectual Property Rights owners. In Magill, the Commission found that the refusal by broadcasting companies to license information protected by Copyright constituted an abuse of a dominant position. This decision was upheld by the European Court of Justice which stated that although the refusal to license copyright and lists of television programmes was not, per se, an abuse of a dominant position, the "exercise of an exclusive right by the proprietor may, in exceptional

[3] We use the terms interoperability, compatibility and connectivity interchangeably throughout the paper.
[4] See http://ec.europa.eu/competition/antitrust/legislation/handbook_vol_1_en.pdf
[5] See http://europa.eu/rapid/press-release_MEMO-08-19_en.htm

[6] See http://www.techhive.com/article/124813/article.html
[7] See http://europa.eu/rapid/press-release_IP-09-1941_en.htm?locale=en

circumstances, involve abusive conduct". The Court found that the exceptional circumstances involved the introduction of a new product which consumers wanted and the refusal to license blocked its emergence. Thus, broadcasters were required to supply copyrighted program schedules to a would-be supplier of a new product, not offered by the copyright owners, for which the schedule information was indispensable[8]. This was the first case that tipped the balance in Europe between the Competition Law and the Intellectual Property Law in favour of the former. In the case of IMS which is in the business of providing information to the pharmaceutical industry on sales of pharmaceutical products in Germany, the Commission and the Court of Justice faced the issue of whether a dominant service provider could refuse to license an input that is a de-facto industry standard. The Court of Justice affirmed that it is sufficient for the license applicant to satisfy the three "cumulative" Magill conditions. Thus, the refusal to license Intellectual Property may, in itself, constitute a breach of Article 82 where a) access is indispensable for carrying on a particular business, b) resulting in the elimination of competition on a secondary market and c) preventing the emergence of a new product for which there is potential consumer demand[9]. Conclusively, refusing a license to prevent price competition is not considered, per se, as abusive, whereas refusing a license with the effect of preventing innovation is. It also remains a requirement of the Magill test that denial of the license renders the introduction of the new product impossible.

On the other hand, there are voices which argue that by giving up intellectual property rights, dominant firms' incentives for innovation would be curbed. Among them, Thomas Barnett of the United States Department of Justice argues that: "U.S. courts recognize the potential benefits to consumers when a company, including a dominant company, makes unilateral business decisions, for example to add features to its popular products or license its intellectual property to rivals, or to refuse to do so"[10]. Indeed, the U.S antitrust author-

[8] See http://www.panix.com/~jesse/magill.html

[9] For more details on the IMS case see http://www.mofo.com/judgment-of-european-court-of-justice-in-ims-health-v-ndc-health-05-18-2004/

[10] See http://www.justice.gov/atr/public/press_releases/2007/226070.htm

ities conclude that "antitrust liability for mere unilateral, unconditional refusal to license patents will not play a meaningful part in the interface between patent rights and antitrust protections"[11].

Therefore, investigating firms' attitude towards interoperability and how these decisions are related with their incentives to invest into improving the existing technology is very important and this paper provides such an investigation. More precisely, it provides some answers to the following questions: Will the dominant firm block interoperability with its rivals or equivalently is exclusivity always generated in an unregulated market? Even if there is incompatibility, does this de-facto mean that it is socially undesirable? Could a market where compatibility is voluntary converge to interoperability when this is socially efficient?

To answer these questions, a sequential game is built where two firms take turns in deciding whether to invest in quality and allow interoperability with their rival. This model fits a common pattern in durable, technology goods markets where the smaller rival may have valuable ideas that emerge as follow-on innovations after the dominant firm's invention hits the market in a Schumpeterian scenario of creative destruction. Our analysis shows that the dominant firm supports compatibility even if it could use a patent and exclude rivals when the anticipated future quality improvement by the rival is relatively large. This is because strategic pricing allows the market leader to extract more of the higher future surplus in the present market. Regarding welfare, we find that mandated compatibility by Antitrust Bodies may lead to the inefficient introduction of a negligibly innovative product while the market where connectivity is not mandatory would maintain the previous version. On the other hand, when network effects are strong, a market where unilateral refusals to supply interoperability are not ruled out by Competition Law could potentially lead to inefficient technological slowdown. When network effects are weak, a laissez faire competition policy towards the exercise of IPRs leads to social efficiency and existing consumers are not better-off when interoperability is enforced. Our conclusions cast some doubts on whether mandatory

[11] See http://www.justice.gov/atr/public/reports/236681_chapter7.htm

interoperability, while trying to protect consumers from abusive behaviour, actually distorts the market and leads to socially undesirable results without benefiting them.

1.1 Related Literature

This paper contributes first to the literature regarding firms' incentives towards compatibility with their competitors. In a seminal paper, Katz and Shapiro (1985) show that firms with a larger installed base will prefer to be incompatible with their rivals. In the same vein, Cremer, Rey and Tirole (2000) analyze the competition between Internet backbone providers and predict that a dominant firm may want to reduce the degree of compatibility with smaller market players. Malueg and Schwartz (2006) find that a firm with the largest installed base will choose not to support connectivity with firms that are themselves compatible when its market share exceeds fifty percent or the potential to add consumers falls. A similar result appears in Chen, Doraszelski and Harrington (2007) who consider a dynamic setting with product compatibility and market dominance. They find that if a firm gets a larger market share, it may make its product incompatible. On the other hand, when firms have similar installed bases, they make their products interoperable in order to expand the market. Viecens (2009) differentiates between direct and indirect network effects by studying platform competition between two firms where users buy a platform and its compatible applications. By allowing for applications to be substitutes, complements or independent, she considers compatibility in two dimensions. First, compatibility of the complementary good, which she calls compatibility in applications. Second, she considers inter-network compatibility where direct network externalities are present. She finds that the dominant firm will never promote compatibility in applications. In contrast, both firms find inter-network compatibility profitable. Focusing on direct network effects and durable goods and contrary to the literature, we find that the dominant firm may support connectivity with its rival. This happens when the quality improvement expected to be introduced by the smaller firm is substantial.

Regarding welfare, Economides (2006) argues that it is socially efficient to move towards compatibility and similarly, Katz and Shapiro (1985) show that interoperability would raise consumers' surplus. In a static environment, Viecens (2009) concludes that compatibility in the applications may be harmful for users and social welfare, particularly when asymmetries are strong. Moreover, inter-network compatibility should not be supported by consumers. We find that interoperability could lead to dynamic inefficiency depending on the industry characteristics that are observable or can be estimated. Unlike an unregulated market, a regime of compulsory compatibility may result in the inefficient introduction of the higher quality product while society would be better-off without it. This occurs when innovation is deterministic and the expected quality improvement is relatively small.

The second strand of literature that this paper relates to, has to do with firms' incentives to upgrade their durable, network goods and how these decisions affect social welfare. In a monopolistic environment, Ellison-Fudenberg (2000) show that upgrades may occur too frequently due to the firm's inability to commit to whether it will choose to upgrade in the future or not. The present paper indicates that in a market that operates under a laissez faire Competition Law with respect to IPR holders, the social and the private firrms' incentives for upgrading are aligned when quality improvements are deterministic and network effects are not particularly strong.

In the literature regarding sequential innovation, Scotchmer (1991, 1996), Scotchmer and Green (1996) among others also study the case of single follow-on innovations. They focus on the breadth and length of patents needed to secure the initial innovator's incentives to innovate when a second innovator threatens to innovate as well. They hold the view that patents for the first innovator should last longer when a sequence of innovative activity is undertaken by different firms compared to the case that innovation is concentrated in one firm. On the other hand, we are mainly interested in the interplay between IPRs protection through patents with firms' behaviour towards compatibility. Contrary to the papers discussed previously, we find that the first innovator will voluntarily offer compatibility to

rivals even if he can potentially use a patent because strategic pricing enables him to absorb more of the second period expected profit when he anticipates a large improvement from the second innovator. In a related paper, Maskin and Bessen (2009) find that when innovation is sequential, patent protection is not as useful for encouraging innovation as in a static setting. Our work shows that although the innovation incentives may indeed be curbed for the smaller rival under a laissez faire Competition Law towards the exercise of IPRs, this fact may be socially beneficial. We also depart from all the papers above by considering a market with durable, network goods and also the role of existing consumers in the determination of social efficiency.

2 The Model

Consider an industry where a durable, network good is currently supplied by the dominant market player. He needs to pay a fixed cost to improve his product quality and subsequently he must also decide whether to support interoperability after observing his competitor's choice of investing towards a follow-on innovative product.

A few remarks regarding an economy where compatibility is not mandatory are important. Following Malueg and Schwartz (2006), compatibility requires both parties' consent and cannot be achieved unilaterally by using converters or adapters. In particular, in software, office suites markets, interoperability is accomplished through the relevant parties' dissemination of interface information and through supporting a pre-existing Open Standard. Note that licensing of Intellectual Property through inter-firm payments for compatibility is not allowed and the rationale behind this decision is that royalties may lead to exclusion or collusion[12]. In a nutshell, the choice of compatibility involves no additional cost or benefit. Further to that and if connectivity is supported bilaterally, backward compatibility makes the upgraded good buyers able to open and save a document that was created with the

[12] The case that (F)RAND (Fair, reasonable and non-discriminatory) payments are allowed between firms that participate in Cooperative Standards Settings Organizations will be considered in future work.

lower quality product while non-forward compatibility prevents the purchasers of the initial versions from working with documents that are created with the upgrades.

The model is cast in discrete time and the sequence of events in the supply side is as follows in an economy where compatibility is not mandatory: originally ($t = 0$) there is no market as existing consumers (λ_0) have purchased the initial version of quality q_0 in a past date and the dominant firm pays a fixed amount F ($F > 0$) for the improvement of his product quality from q_0 to q_1[13]. At the beginning of the first period ($t = 1$), the rival needs to make a decision of whether to invest a fixed amount F ($F > 0$) to create a follow-on, substitute product of higher expected quality q_2^e. At the second stage of the first period, the market leader sets the price(s) for his product(s) and decides whether to support compatibility by eliciting interoperability information about its version of quality q_1. If the rival invests, Bertrand competition follows in the second period ($t = 2$). Note that it is important to stress that the dominant firm's potential choice of not supporting compatibility in the first period with the use of a short-lived patent for his file format does not, per se, deter the smaller rival from investing towards a better expected quality q_2^e. This happens as information about the product of quality q_1 is disseminated freely when it hits the market and the rival can still use the Open Document Format to make a better product which nevertheless, will be incompatible with q_1. Moreover, products are durable and in particular, all versions are assumed functional for two periods. Also note that firms are risk neutral and the marginal cost of production is normalized to zero for all products.

On the demand side, consumers are identical and while at first ($t = 0$) there is a mass λ_0 of customers in the economy, future generations arrive in constant flows λ_t ($t = 1, 2$). Their utility is linear in income and partially dependent on network effects captured by a parameter α. So, if the buyer joins a network of mass x, the network benefit is αx. In addition to the monetary cost, consumers also incur a learning cost c the first time they

[13] Our results would not change even if investment for the market leader becomes a decision and is not considered as just a cost when the rival is considered to have valuable ideas for follow-on products (q_2) and not for the initial invention (q_1).

start to use the product followed by an upgrade cost c_u (where $c_u < c$) when learning to use the new version(s) but without bearing any switching costs.

Customers present in the first period are forward looking and base their purchasing decisions on the products available and their prices as well as on their expectations. These expectations reflect the information they have regarding the future quality improvement, the market size and future prices at the time they are called to make their decision and are fully aligned in equilibrium. Unlike new customers (λ_1) who cannot postpone their purchase, old users (λ_0) are not guaranteed to buy the new generation because of the durability of the version they already own. Old customers' (λ_0) purchasing decisions given announced prices resemble a coordination game and although it can have multiple equilibria, we assume they coordinate to the Pareto optimal outcome. The same rule also holds for the old consumers in the second period ($\lambda_0 + \lambda_1$) if the rival introduces the version of quality q_2 in the market. In the similar coordination problem related to the new customers' purchasing decisions, the standard assumption is that buyers with the same preferences act as if they were a single player. Thus, after observing the available products and their prices, new customers in any period (λ_1, λ_2 in the first and the second period, respectively) coordinate to what is best for all of them. All consumers make their purchasing decisions simultaneously and are assumed to prefer a new product rather than an older version when they gain the same expected utility by either of these two choices. I also assume that since price discrimination between the old and the new consumers is possible, both the market leader (at $t = 1$) and the rival (at $t = 2$) have the ability to offer upgrade prices to old users. Also note that the same discount factor δ applies to all the agents in the economy.

Figure 1 in the next page summarizes the timing of the model and the agents' moves. We will characterize first the market equilibrium outcome followed by the problem faced by a social planner who wishes to maximise social disounted expected surplus under complete information of the cost functions.

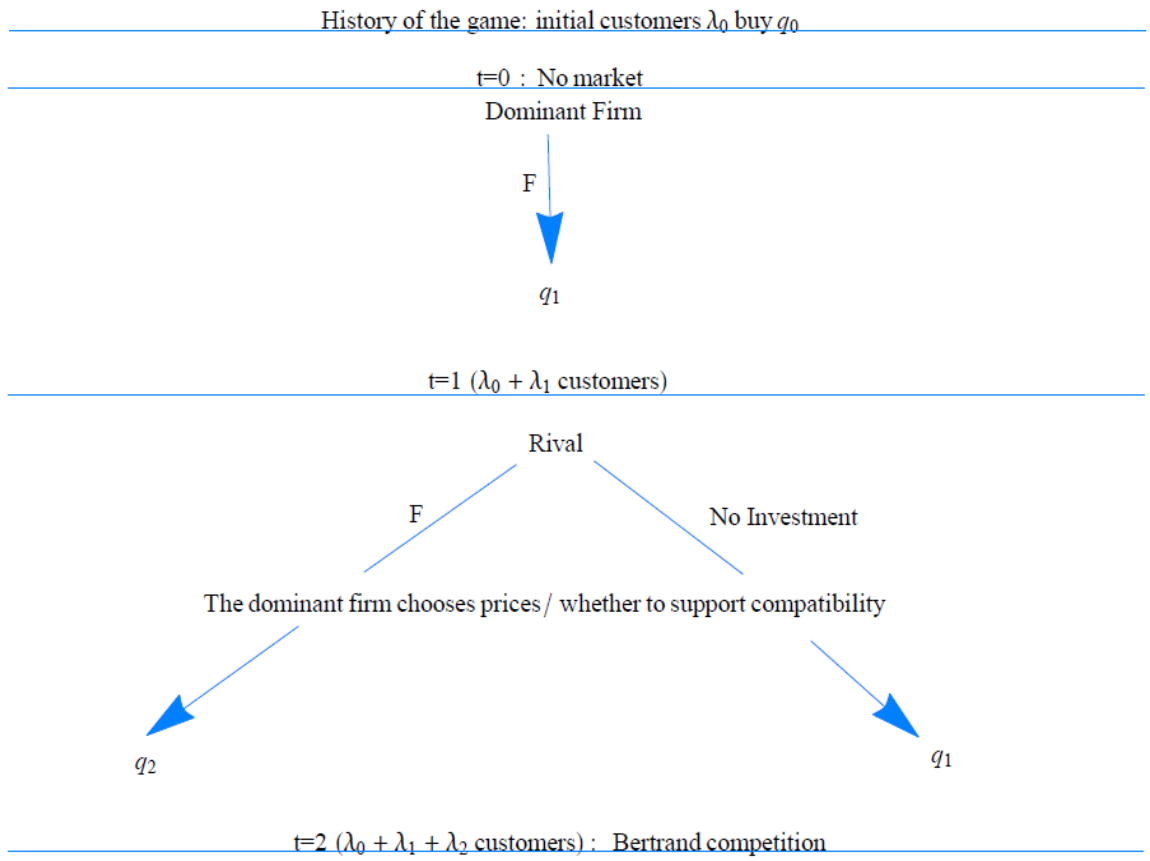

Figure 1: Timing of the firms' moves. Note that in the European Union (in contrast to the US), the dominant firm is regulated if it refuses to supply interoperability information to the rival.

3 Results

We will analyze first the rival firms' incentives to invest and support compatibility as well as their optimal pricing decisions. We will then proceed to the computation of the social efficient outcome.

3.1 Market outcome

In the supply side, the following assumption are made:

Assumption 1 (A1) a) $F < \lambda_2 \Delta q^e$, $F < \lambda_2[\Delta q^e - \alpha(\lambda_0 + \lambda_1)]$ when $\Delta q^e \geq \alpha(\lambda_0 + \lambda_1)$.

This assumption says that the cost of development does not, per se, deter the rival firm

from investing into the new product of expected quality q_2^e and although it limits the number of cases that we analyze, it allows us to focus on the consequences of the dominant firm's expected compatibility choices to the rival's investment decisions. Note that the scenarios where the development cost is relatively high are not interesting as they make the market leader's anticipated compatibility decisions irrelevant for the rival's actions as she would be anyway deterred to invest.

We will start by computing the market equilibrium outcome when compatibility is mandatory.

Period two New customers in the second period (λ_2) can choose to buy either the rival firm's product of quality q_2 or the market leader's previous version q_1[14]. If they buy the improved product of quality q_2, they join a network of size $\lambda_0 + \lambda_1 + \lambda_2$ independently of what others do, where without loss of generality, the size in the second period is normalized to unity. Thus, given the price charged by the rival, their utility if they buy the version of quality q_2 is $q_2 + \alpha - c - p_{22}$, where the first and the second subscripts in the price (p_{22}) are related to the quality level of the product purchased and the type of customers buying the good, respectively. If they choose to buy q_1, their utility given the price set by the dominant firm (p_{12}) is $q_1 + \alpha\lambda_2 x_2 + \alpha(\lambda_0 + \lambda_1)x_1 - c - p_{12}$ where x_1, x_2 are the old and new second period customers' fractions that stick and buy q_1, respectively[15]. New customers are assumed to coordinate, given prices, to what is best for all of them and thus, they will choose to buy q_2 if:

$$p_{22} - p_{12} \leq \Delta q + \alpha(\lambda_0 + \lambda_1)(1 - x_1), \tag{1}$$

where $\Delta q = q_2 - q_1$ denotes the quality improvement from purchasing the product of quality q_2 instead of q_1.

Let's now turn our attention to the old second period customers ($\lambda_0 + \lambda_1$). If they purchase

[14] Note that it will become apparent in the first period analysis that the product of quality q_0 is not sold in the second period and thus, there is not a third choice of purchasing q_0 for the new second period customers.

[15] It will become apparent in the first period analysis that the old second period customers ($\lambda_0 + \lambda_1$) purchased q_1 in the previous period.

the product of quality q_2, their utility given the rival's upgrade price to q_2, p_{21}, is $q_2 + \alpha - c_u - p_{21}$ independently of other customers' choices.

If they stick to q_1, their utility will be $q_1 + \alpha\lambda_2 x_2 + \alpha(\lambda_0 + \lambda_1)x_1$, where x_1, x_2 are the $\lambda_0 + \lambda_1, \lambda_2$ customers' fractions that either stick or buy q_1 in the second period, respectively. Old consumers are assumed to make their purchasing decisions independently of what other old customers do and thus, they upgrade to q_2 even if all other $\lambda_0 + \lambda_1$ stick to q_1 when:

$$p_{21} \leq \Delta q + \alpha\lambda_2(1 - x_2) - c_u. \tag{2}$$

Period one The next assumption holds regarding the magnitude of the expected second period quality improvement:

Assumption 2 (A2) Let $\Delta q^e = q_2^e - q_1$ be the expected quality improvement from the introduction of the product of quality q_2^e in the second period. We assume that $\Delta q^e + \alpha\lambda_2 - c_u \geq 0$.

This assumption says that given that the old first period customers (λ_0) choose to purchase the product of quality q_1 in the first period, the anticipated second period quality improvement (Δq^e from the first period perspective) is such that the first period customers expect to be better-off by upgrading in the second period to the new product of quality q_2^e when they correctly anticipate (in equilibrium) that the new second period customers will also buy it.

Moving back to the first period, let's first think of the maximum price the dominant firm can charge to the new first period customers (λ_1) by selling the product of quality q_1[16]. If these customers buy the superior version q_1, their total discounted expected utility given the price set by the dominant firm (p_{11}) if they expect they will upgrade to q_2^e in the second period is $q_1 + \delta q_2^e + \alpha(\lambda_0 + \lambda_1) + \delta\alpha - c - \delta c_u - p_{11} - \delta p_{21}^e$ independently of what other customers do where p_{21}^e is the price they expect to pay in order to upgrade to

[16] It will become apparent that the dominant firm will not sell the product of quality q_0 as it cannibalizes his profits. The Appendix includes the maximum price the dominant firm would set if it sold the initial version, which is strictly lower than its maximum price set if it sells q_1.

q_2^e in the second period. Thus, the maximum first period price the firm can charge them is $p_{11} = q_1 + \delta q_2^e + \alpha(\lambda_0 + \lambda_1) + \delta\alpha - c - \delta c_u$ inducing the rival to upgrade them tomorrow for free. Note that the dominant firm is strictly better-off when these customers expect to upgrade tomorrow because otherwise, the expected total price they are willing to pay is lower due to the smaller network they would belong to in the future period[17].

Let's now turn our attention to the old consumers (λ_0). By upgrading to q_1 in the first period and if they expect to purchase the new version q_2^e in the future period (which is true in equilibrium), their total expected discounted utility given the price p_{10} for upgrading is $q_1 + \delta q_2^e + \alpha(\lambda_0 + \lambda_1) + \delta\alpha - c_u - \delta c_u - p_{10} - \delta p_{20}^e$ independently of what others do where p_{20}^e is the price they expect to pay in the second period to buy the superior product q_2^e over the alternative of sticking to q_1 tomorrow[18]. If they choose to stick to q_0 in the first period, they may expect to keep it or either upgrade to q_1 or q_2^e in the second period. Their total discounted expected utility if they expect to upgrade to q_2^e in the second period is $q_0 + \delta q_2^e + a\lambda_0 x_0^{''} + \alpha\lambda_1 x_1^{''} + \delta\alpha - \delta c_u - \delta p_{20}^{e\prime}$, where $p_{20}^{e\prime}$ is the price they expect to pay in order to upgrade to q_2^e in the second period and $x_0^{''}, x_1^{''}$ are the λ_0, λ_1 customers' fractions who stick or buy q_0 in the first period, respectively[19]. So, they will prefer to buy q_1 in the first period when they make their purchasing decisions independently of what other old first period customers do if they expect to upgrade to q_2^e after either purchasing q_1 or sticking to q_0 if:

$$p_{10} + \delta p_{20}^e \leq \Delta q + \Delta q^e + \alpha\lambda_1(1 - x_1^{''}) + \delta\alpha\lambda_2(1 - x_2^{'}) + \delta\alpha\lambda_1(1 - x_1^{'}) - c_u$$

where from the first period perspective, $\Delta q = q_1 - q_0$, $\Delta q^e = q_2^e - q_1$ are the first and second period quality improvements, respectively and $x_1^{'}, x_2^{'}$ are the λ_1 and λ_2 customers' fractions that stick to the product of quality q_1 in the second period. The price p_{10} is a decreasing

[17] The interested reader could look at this case in the Appendix.

[18] As it will be apparent shortly, in equilibrium, this price is equal to zero as the dominant firm will induce the rival to upgrade all old customers for free. The reader can check the Appendix for the customers' expected payoff if they decide to stick to q_1 in the second period.

[19] Check the Appendix for the price these customers expect to pay to upgrade to q_2^e.

function of the number of the new customers who buy the product of quality q_0 in the first period ($x_1^{''}$). Thus, the optimal dominant firm's choice is to stop selling the product of quality q_0 in the first period and the pricing decisions satisfy the expressions:

$$p_{11} + \delta p_{21}^e = q_1 + \delta q_2^e + \alpha(\lambda_0 + \lambda_1) + \delta\alpha - c - \delta c_u,$$

$$p_{10} + \delta p_{20}^e = \Delta q + \delta \Delta q^e + \alpha\lambda_1 + \delta\alpha\lambda_2(1 - x_2^{'}) + \delta\alpha\lambda_1(1 - x_1^{'}) - c_u.$$

We observe that the total maximum expected payment that new and old customers are willing to pay is fixed. So, the dominant firm's optimal choice is to set:

$$p_{11} = q_1 + \delta q_2^e + \alpha(\lambda_0 + \lambda_1) + \delta\alpha - c - \delta c_u \tag{3}$$

$$p_{10} = \Delta q + \delta \Delta q^e + \alpha\lambda_1 + \delta\alpha\lambda_2(1 - x_2^{'}) + \delta\alpha\lambda_1(1 - x_1^{'}) - c_u \tag{4}$$

which will induce the smaller firm to upgrade all old customers $(\lambda_0 + \lambda_1)$ for free in the second period.

Note that (1) and (2) provide the second period equilibrium prices:

$$p_{22} = \Delta q + \alpha(\lambda_0 + \lambda_1),\ p_{12} = 0,\ p_{21} = 0,$$

where given these prices, new second period customers (λ_2) buy the new product and all old customers upgrade for free to q_2 (and thus, the old customers' fraction that sticks to q_1 is $x_1 = 0$ in (1)). From (3) and (4), we get the equilibrium first period prices:

$$\begin{aligned} p_{11} &= q_1 + \delta q_2^e + \alpha(\lambda_0 + \lambda_1) + \delta\alpha - c - \delta c_u, \\ p_{10} &= \Delta q + \delta \Delta q^e + \alpha\lambda_1 + \delta\alpha\lambda_2 + \delta\alpha\lambda_1 - c_u \end{aligned}$$

where in (4), there is no second period customer who is expected to buy or stick to q_1

given the price p_{11} and the correct expectations about the equilibrium second period play ($x_2^{'} = x_1^{'} = 0$).

The next proposition summarizes the market equilibrium outcome in an economy where compatibility is mandatory:

Proposition 1 *Under assumptions A1, A2 and in equilibrium, the dominant firm decides to stop selling the old product of quality q_0 in the first period and instead, it sells the product q_1 to the new and the old first period customers. In the second period, the product of quality q_2 is sold by the rival to the whole market. In particular, old customers ($\lambda_0 + \lambda_1$) upgrade for free.*

We will analyze next the market equilibrium outcome under a regime where the dominant firm does not support compatibility.

Period two If there is a product of quality q_2 in the market and all new second period customers (λ_2) buy it, their utility given the price charged by the rival firm (p_{22}) is $q_2 + \alpha\lambda_2 + \alpha(\lambda_0 + \lambda_1)(1 - x_1) - c - p_{22}$ and if they all buy q_1, their utility given the price p_{12} by the dominant firm is $q_1 + \alpha\lambda_2 + \alpha(\lambda_1 + \lambda_0)x_1 - p_{12}$, where x_1 is the old customers' fraction that sticks to q_1 in the second period[20]. Thus, λ_2 customers will buy q_2 if:

$$p_{22} - p_{12} \leq \Delta q + \alpha(\lambda_0 + \lambda_1)(1 - 2x_1). \tag{5}$$

Let's turn our attention to the old second period customers ($\lambda_0 + \lambda_1$). Their utility if they purchase q_2 is $q_2 + \alpha(\lambda_0 + \lambda_1)(1 - x_1) + \alpha\lambda_2(1 - x_2) - c_u - p_{21}$ given the rival's price p_{21} while if they stick to q_1, their utility is $q_1 + \alpha\lambda_2 x_2 + \alpha(\lambda_1 + \lambda_0)x_1$, where x_1, x_2 are the old and new customers' fractions that stick or buy q_1 in the second period. Old customers make their purchase decision independently of what other old customers do and thus, they

[20] Note that the facts that the product of quality q_0 is not sold in the second period and thus, there is not a third choice of purchasing q_0 for the new second period customers as well as that old second period customers ($\lambda_0 + \lambda_1$) have purchased q_1 in the first period will become apparent in the first period analysis.

will choose to buy q_2 even if all other old customers stick or buy q_1 ($x_1 = 1$) when:

$$p_{21} \leq \Delta q + \alpha\lambda_2(1 - 2x_2) - \alpha(\lambda_0 + \lambda_1) - c_u. \tag{6}$$

Period one We make the following assumption with respect to the expected second period quality improvement:

Assumption 3 (A3) $\Delta q^e + \alpha\lambda_2 - \alpha(\lambda_0 + \lambda_1) - c_u < 0$.

This assumption says that given that customers buy the product of quality q_1 in the first period, they expect not to be better-off, in equilibrium, by upgrading to the product of quality q_2^e when compatibility is not present and gives an upper bound for the second period quality improvement. If the sign of the inequality is reversed and given the small values of the development cost, the dominant firm's equilibrium first period prices would be the same under a regime where compatibility is mandatory or not and his choice of compatibility would be irrelevant and thus not interesting to analyze.

Case 1: $\Delta q^e < \alpha(\lambda_0 + \lambda_1)$. In this scenario, the rival is deterred to invest and the dominant firm remains the sole supplier in the market. Thus, if the new customers (λ_1) buy the good of quality q_1 in the first period, their total expected discounted utility given the price charged by the dominant firm p_{11} is $q_1 + \delta q_1 + \alpha(\lambda_0 + \lambda_1) + \delta\alpha - c - p_{11}$[21].

Let's now turn our attention to the old consumers in the first period (λ_0). If they buy the product of quality q_1, their total expected discounted utility given the upgrade price charged by the dominant firm (p_{10}) is $q_1 + \delta q_1 + \alpha(\lambda_0 + \lambda_1) + \delta\alpha - c_u - p_{10}$, independently of what other customers do. If they stick to q_0, their expected utility by upgrading in the second period to q_1 is $q_0 + \delta q_1 + \alpha\lambda_0 x_0 + \alpha\lambda_1 x_1 + \delta\alpha - \delta c_u - \delta p_{10}^e$, where p_{10}^e is the price they expect to pay tomorrow in order to upgrade[22]. Since old customers in any period are

[21] Note that as it will become clear, the dominant firm's optimal choice is to stop selling q_0 at $t = 1$. The interested reader can also find customers' total expected utility in this case in the Appendix.

[22] Check the Appendix for the expected total discounted utility if they expect to stick to q_0 in the second

assumed to make their purchasing decisions independently of what other old customers do, they upgrade to q_1 in the first period even if all other old λ_0 consumers stick to q_0 if:

$$p_{10} \leq \Delta q + \alpha\lambda_1(1 - x_1) - c_u + \delta c_u + \delta p_{10}^e.$$

Notice that since the dominant firm's profits are a decreasing function of the number of λ_1 customers that buy q_0 in the first period (x_1), its optimal choice is to stop selling the initial version in the first period (and $x_1 = 0$ in the last inequalities above). Thus, the first period prices are given by the expressions:

$$p_{11} = q_1 + \delta q_1 + \alpha(\lambda_0 + \lambda_1) + \delta\alpha - c, \tag{7}$$

$$p_{10} = \Delta q + \alpha\lambda_1 - c_u + \delta c_u + \delta p_{10}^e, \tag{8}$$

$$p_{12} = q_1 + \alpha - c, \tag{9}$$

where

$$p_{10}^e = \Delta q + \alpha\lambda_1 + \alpha\lambda_2 - c_u, \tag{10}$$

where p_{12} is the dominant firm's equilibrium price set to the new second period customers.

Case 2: $\Delta q^e \geq \alpha(\lambda_0 + \lambda_1)$.

The next assumption holds:

Assumption 4 (A4) $\Delta q^e \leq \Delta q$, that is, the expected improvement from the follow-on innovation is at most equal to the quality differential in the first period.

This assumption says that a given investment leads to a smaller quality improvement in the second rather than in the first period, stressing the fact that innovative ideas become more difficult after the initial invention hits the market.

Let's first think of the new customers in the first period (λ_1). If they buy the product

period and the determinantion of p_{10}^e.

of quality q_1, their total expected utility given the dominant firm's price p_{11} if they expect they will not upgrade to q_2^e in the second period is $q_1 + \delta q_1 + \alpha(\lambda_0 + \lambda_1) + \delta\alpha\lambda_1\eta_1 + \delta\alpha\lambda_0\eta_0 + \delta\alpha\lambda_2\eta_2 - c - p_{11}$ where n_0, n_1, n_2 are the different classes' fractions that buy or stick to q_1 in the second period[23].

Let's now turn our attention to the old customers in the first period (λ_0). If they upgrade to q_1, given the dominant firm's upgrade price p_{10}, their total expected discounted utility is $q_1 + \delta q_1 + \alpha(\lambda_0 + \lambda_1) + \delta\alpha\lambda_0 x_0 + \delta\alpha\lambda_1 x_1 + \delta\alpha\lambda_2 x_2 - c_u - p_{10}$ if they anticipate that they will not buy the superior product of quality q_2^e in the second period and x_0, x_1, x_2 are the new and the old second period customers' fractions that are expected to buy or stick to the product of quality q_1 in the second period[24]. If they keep q_0, their total discounted expected utility if they expect to upgrade to q_2^e in the second period is $q_0 + \delta q_2^e + \alpha\lambda_0 x_0^{'''} + \alpha\lambda_1 x_1^{'''} + \delta\alpha\lambda_0 x_0^{iv} + \delta\alpha\lambda_1 x_1^{iv} + \delta\alpha\lambda_2 x_2^{iv} - \delta c_u - \delta p_{20}^{'e}$ where $p_{20}^{'e}$ is the price they expect to pay in order to upgrade to q_2^e tomorrow and $x_0^{'''}, x_1^{'''}, x_0^{iv}, x_1^{iv}, x_2^{iv}$ are the first and second period customers' fractions that stick to q_0 today and upgrade to q_2 tomorrow[25]. These consumers will buy q_1 in the first period even if all other customers of the same class choose q_0 ($x_0^{'''} = 1$) if:

$$p_{10} \leq \Delta q - \delta\Delta q^e + \alpha\lambda_1(1 - x_1^{'''}) + \delta\alpha\lambda_0(x_0 - x_0^{iv}) + \delta\alpha\lambda_1(x_1 - x_1^{iv}) + \delta\alpha\lambda_2(x_2 - x_2^{iv}) - c_u + \delta c_u + \delta p_{20}^{'e}.$$

Since p_{10} is a decreasing function of the number of λ_1 customers who buy q_0 in the first period ($x_1^{'''}$), the dominant firm's optimal choice is to stop selling q_0 in the first period (thus, $x_1^{'''} = 0$ in the inequality above). Thus, the maximum total payment that old first period

[23] The interested reader can also check in the Appendix these customers expected total utility if they expect to upgrade to q_2^e. It will also become apparent that the dominant firm will stop selling q_0 in the first period and thus we also relegated this case in the Appendix.

[24] Check the Appendix for these customers' expected total discounted utility if they expect to upgrade to q_2^e.

[25] See the Appendix for the cases where they either expect to keep q_0 tomorrow or buy q_1 instead of q_2^e.

customers expect to pay to upgrade to q_1 in the first period is:

$$\begin{aligned} p_{10} &= \Delta q + \alpha\lambda_1 + \delta\alpha\lambda_0(x_0 - x_0^{iv}) + \delta\alpha\lambda_1(x_1 - x_1^{iv}) + \delta\alpha\lambda_2(x_2 - x_2^{iv}) - c_u + \\ &\quad \delta c_u - \delta\alpha\lambda_0 + \delta\alpha\lambda_1(x_1^{iv} - \zeta_1) + \delta\alpha\lambda_2(x_2^{iv} - \zeta_2). \end{aligned}$$

In equilibrium, first period customers expect not to upgrade to q_2^e and they also expect the second period customers to purchase q_2^e. Thus, the optimal market leader's price set to the old first period customers is:

$$p_{10} = \Delta q + \alpha\lambda_1 - c_u + \delta c_u \tag{11}$$

and the optimal dominant firm's price to λ_1 customers is:

$$p_{11} = q_1 + \delta q_1 + \alpha(\lambda_0 + \lambda_1) + \delta\alpha(\lambda_0 + \lambda_1) - c \tag{12}$$

In the second period, the rival firm's equilibrium price set to the new customers (λ_2) is:

$$p_{22} = \Delta q^e - \alpha(\lambda_0 + \lambda_1) \tag{13}$$

The dominant firm compares its expected profit under the two regimes and decides whether to support compatibility or not.

Depending on the quality improvement expected to be introduced by the competitor (Δq^e) and for different values of the investment (F), we identify the following three different scenarios that lead to different equilibrium market outcomes:

A5 $\Delta q^e - (\lambda_0 + \lambda_1)c_u < F < (\lambda_0 + \lambda_1)(\Delta q^e + \alpha\lambda_2 - c_u)$. This scenario implies that the expected quality improvement in the second period is relatively small ($\Delta q^e < \alpha(\lambda_0 + \lambda_1)$).

A6 $F \leq \Delta q^e - (\lambda_0 + \lambda_1)c_u$, $\Delta q^e \geq \alpha(\lambda_0 + \lambda_1)$. This scenario occurs when the quality differential anticipated to be introduced by the competitor is relatively large.

A7 $F \leq \Delta q^e - (\lambda_0 + \lambda_1)c_u$, $\Delta q^e < \alpha(\lambda_0 + \lambda_1)$. This scenario necessarily implies that the network parameter is greater than the upgrading cost ($\alpha \geq c_u$).

The next proposition summarizes the market equilibrium outcome in the economy that operates under a laissez faire Competittion Law towards the exercise of IPRs:

Proposition 2 *(a) If assumptions A1-A5 hold, in equilibrium, the dominant firm does not support compatibility with its rival who is deterred to invest and all customers purchase the product of quality q_1.(b) If assumptions A1-A4 and A6 hold, in equilibrium, both competitors support compatibility. In the first period, all customers use q_1 and in the second, the whole market purchases the product of quality q_2^e.*

Think first of (a) where the quality improvement expected to be introduced by the competitor is relatively small ($\Delta q^e < \alpha(\lambda_0 + \lambda_1)$). By not supporting compatibility, the dominant firm deters the rival from investing and when product functionality cannot be imitated, this allows him to be the sole supplier in the second period. But this is not a sufficient condition for not supporting compatibility as the dominant firm impedes interoperability even if product functionality could be copied. To see this fact, think of the old customers in the first period (λ_0). They are ready to pay more in the first period if the dominant firm does not allow compatibility with the rival mainly because the quality improvement under a regime of no compatibility (Δq) is larger compared to the case that interoperability is present (Δq^e). The relatively small second period quality differential if compatibility is supported also makes the new customers in the first period (λ_1) willing to pay less if compatibility is allowed because the cost of upgrading is larger than the expected quality improvement. On the other hand, in (b), the expected quality differential by the competitor is large ($\Delta q^e \geq \alpha(\lambda_0 + \lambda_1)$) and the rival firm will unambiguously invest introducing the product of quality q_2^e in the market in the second period. In anticipation of this fact, the dominant firm's optimal strategy is to offer connectivity under a free licensing scheme to its competitor because it can absorb in the first period more of the expected discounted future total surplus which is higher when compatibility is present.

3.2 Social optimum

It is important to analyze the social efficiency of the results obtained previously and this section considers the problem faced by a planner that maximizes social surplus.

In general, the planner desires compatibility between rival firms' products because due to network effects, customers' utility and social welfare is maximised when interoperability is present. After normalizing the market size in the second period to unity ($\lambda_0 + \lambda_1 + \lambda_2 = 1$) and if the product of quality q_1 is sold in both periods, social welfare is:

$$W_N = \lambda_0[q_1 + \delta q_1 + \alpha(\lambda_0 + \lambda_1) + \delta\alpha - c_u] + \lambda_1[q_1 + \delta q_1 + \alpha(\lambda_0 + \lambda_1) + \delta\alpha - c] + \delta\lambda_2(q_1 + \alpha - c) - F.$$

If the superior product of quality q_2^e is sold to everyone, social welfare becomes:

$$\begin{aligned} W_U &= \lambda_0[q_1 + \delta q_2^e + \alpha(\lambda_0 + \lambda_1) + \delta\alpha - c_u - \delta c_u] + \lambda_1[q_1 + \delta q_2^e + \alpha(\lambda_0 + \lambda_1) + \delta\alpha - c - \delta c_u] + \\ &\quad + \delta\lambda_2(q_2^e + \alpha - c) - F - \delta F. \end{aligned}$$

Comparing the expressions above yields the socially optimal outcome:

Proposition 3 *It is socially efficient if (a) the product of quality q_1 is sold for two periods when assumptions A2 and A5 hold, (b) the product of quality q_2^e is introduced and purchased by the whole market if assumptions A2 and A6 hold.*

It is socially efficient if the good of quality q_1 is sold in the market for both periods when the net benefit from everyone purchasing it is smaller than the total investment and upgrading cost ($\Delta q^e < F + c_u(\lambda_0 + \lambda_1)$). When the last inequality is reversed, social optimality is achieved when the superior product is introduced and purchased by the whole market.

Depending on the industry characteristics and the expected quality improvement, the market outcome may lead to socially undesirable results. More precisely, the next proposition highlights the potential inefficiency that may arise in markets that operate under a laissez faire Antitrust Law towards IPRs or not:

Proposition 4 *(a) If assumption A5 holds and unlike the market that operates under a laissez faire Competition Law towards IPRs, a regime of mandatory interoperability leads to the inefficient introduction of the product of quality q_2^e. (b) There is no inefficiency in the market where refusals to support interoperability are possible if the network parameter is bounded and smaller than the cost of upgrading ($\alpha < c_u$). (c) If network effects are strong ($\alpha \geq c_u$), the market that operates under a laissez faire Competititon Law towards IPRs may lead to an inefficient technological slowdown when assumption A7 holds.*

Let's first think of the case where network effects are not particularly strong and the upgrading cost is relatively high ($\alpha < c_u$). When the total cost (investment plus consumers' upgrading cost) is relatively high ($F \geq \Delta q^e - c_u(\lambda_0 + \lambda_1)$), social efficiency is obtained when the version of quality q_1 is retained in the market for both periods. At the same time, if the expected quality improvement is relatively small ($\Delta q^e < \alpha(\lambda_0 + \lambda_1)$), non-compatibility in a market where refusal to support compatibility is possible leads to the socially efficient use of the product of quality q_1 for both periods. On the other hand, in a regime of compulsory interoperability, the smaller firm introduces the product of quality q_2^e and the old and the new customers buy it while society would be better-off without it. Note that old consumers in the second period ($\lambda_0 + \lambda_1$) are not worse-off in the market where refusals to supply interoperability information do not violate Competition Law.

When network effects are greater than the learning cost ($\alpha \geq c_u$), the same inefficiency potentially arises in a market that mandates compatibility. Note that for relatively small values of the cost of development ((c) holds), it is socially efficient to introduce the product of quality q_2^e in the market in the second period and nevertheless, the market where firms can unilaterally refuse to supply interoperability information leads to technological slowdown by inefficiently withholding the product of quality q_2^e from the economy.

4 Applications/ Discussion/ Future Research

This paper analyses firms' behaviour towards compatibility and the relation of these decisions with their incentives to invest into improving their durable, network goods. By using a sequential game where the dominant firm plays first, we give its competitor the ability to build on innovations previously introduced by the market leader. Recognizing the intertemporal linkage in forward looking customers' purchasing choices, we find that in anticipation of a relatively large quality improvement by the rival, strategic pricing leads the dominant firm to support compatibility even if it could exclude its rivals by using a patent for its invention.

Moreover, an economy where refusal to supply interoperability information potentially violates the antitrust Law may lead to the inefficient introduction of a negligibly innovative product. We also find that when network effects are present but not particularly strong, a market where compatibility is not mandatory converges to social efficiency. On top of that, existing customers are not worse-off in an economy where interoperability is not enforced by Law. When network effects are strong, the refusal to support connectivity may lead to the inefficient slowdown of technological progress. To the best of my knowledge, these are new results in the literature.

An important application captured by the model comes from the European Union case against Microsoft regarding its office suite highlighted earlier in the Introduction. Although Microsoft's compliance to compatibility was enforced by regulation, this mandate in favour of interoperability was unnecessary and may have been socially harmful. In particular, Microsoft Office 2007 was followed by Corel's WordPerfect Office suite in 2008 that introduced negligible quality improvements with a high upgrading cost. In anticipation of this, Microsft decided not to support compatibility in the first place. As proposition 4(a) shows, society would be better-off without the new product and the market under a laissez faire Competition policy towards IPRs would lead to social efficiency assuming that network effects are relatively weak and smaller than the cost of upgrading.

The policy implication of these findings is that the Antitrust Entities should investigate whether mandating compatibility may sometimes be socially unwelcome without necessarily benefiting consumers and instead markets that allow unilateral refusals to supply interoperability information possibly lead to efficient outcomes without necessarily hurting consumers' welfare. In an economy where network effects are present, this exercise is not trivial but one conclusion is certain: if network effects are not too strong and when the planner has the same information as the market participants, an economy operating under a laissez faire Competition Law towards IPs generates social efficiency guaranteeing that existing consumers are not worse-off than in an economy under mandatory compatibility.

Nevertheless, there are a number of issues that are important and are not addressed in the paper. Firstly, a model that will test empirically our results could validate our predictions. In addition, further analysis could allow for interfirm payments for compatibility on a (F)RAND (fair, reasonable, non-discriminatroy) basis which is still not clearly defined in the European Union. Finally, it would be interesting to study the same interoperability/investment decisions from the rival firms in the presence of stochastic demand.

5 Appendix

5.0.1 Mandatory interoperability/ Maximum first period price set to the new customers λ_1 for the product q_0

If they buy the product of quality q_0, their expected utility given the price set by the market leader (p_{10}) is $q_0 + \delta q_2^e + \alpha\lambda_0\psi_0 + \alpha\lambda_1\psi_1 + \delta\alpha - c - \delta c_u - p_{10} - \delta p_{21}^{e'}$ if they expect to upgrade to q_2^e in the future period where ψ_0, ψ_1 are the old and new first period customers that stick and buy the version of quality q_0 in the first period, respectively and $p_{20}^{e\prime}$ is the price they expect to pay in order to upgrade to q_2^e in the second period. So, the maximum price the dominant firm can set is $p_{10} = q_0 + \delta q_2^e + \alpha\lambda_0\psi_0 + \alpha\lambda_1\psi_1 + \delta\alpha - c - \delta c_u$. These customers' total expected utility after purchasing the initial version q_0, given the price p_{01} charged by the dominant firm is $q_0 + \delta q_1 + \alpha\lambda_0\psi_0 + \alpha\lambda_1\psi_1 + \delta\alpha\lambda_0\psi_0^{'} + \delta\alpha\lambda_1\psi_1^{'} + \delta\alpha\lambda_2\psi_2^{'} - c - \delta c_u - p_{10} - \delta p_{11}^{e'}$ if they expect to upgrade to the product of quality q_1 in the second period where $p_{11}^{e'}$ is the price they expect to pay to upgrade to the product of quality q_1 and $q_0 + \delta q_0 + \alpha\lambda_0\psi_0 + \alpha\lambda_1\psi_1 + \delta\alpha\lambda_0\psi_0^{''} + \delta\alpha\lambda_1\psi_1^{''} + \delta\alpha\lambda_2\psi_2^{''} - c - \delta c_u - p_{10}$ if they expect they will stick to q_0 in both periods. Thus, the maximum price the market leader can charge them is $p_{01} = q_0 + \delta q_1 + \alpha\lambda_0\psi_0 + \alpha\lambda_1\psi_1 + \delta\alpha\lambda_0\psi_0^{'} + \delta\alpha\lambda_1\psi_1^{'} + \delta\alpha\lambda_2\psi_2^{'} - c - \delta c_u$ or $p_{01} = q_0 + \delta q_0 + \alpha\lambda_0\psi_0 + \alpha\lambda_1\psi_1 + \delta\alpha\lambda_0\psi_0^{''} + \delta\alpha\lambda_1\psi_1^{''} + \delta\alpha\lambda_2\psi_2^{''} - c - \delta c_u$, if they expect to upgrade to q_1 or stick to q_0 after initially buying q_0, respectively. Note that the dominant firm would be better-off if consumers expect to upgrade to q_2^e in the second period because this would allow him to set $p_{11} = q_1 + \delta q_2^e + \alpha(\lambda_0 + \lambda_1) + \delta\alpha - c - \delta c_u$ by selling q_1 and $p_{01} = q_0 + \delta q_2^e + \alpha\lambda_0\psi_0 + \alpha\lambda_1\psi_1 + \delta\alpha - c - \delta c_u$ by selling q_0. Indeed, in equilibrium, customers expect to upgrade to q_2^e and the market leader can charge a higher price by selling his product of quality q_1 rather than q_0.

5.0.2 Mandatory compatibility/ Maximum first price set to customers if they expect not to upgrade in the second period to q_2^e

If they expect not to upgrade tomorrow to q_2^e after purchasing q_1 , their total expected discounted utility given p_{11} if they buy q_1 is $q_1+\delta q_1+\alpha(\lambda_0+\lambda_1)+\delta\alpha\lambda_1\eta_1+\delta\alpha\lambda_0\eta_0+\delta\alpha\lambda_2\eta_2-p_{11}$, where η_0, η_1, η_2 are the second period customers' fractions that stick to q_1. Thus, the maximum price in this case would be $p_{11} = q_1+\delta q_1+\alpha(\lambda_0+\lambda_1)+\delta\alpha\lambda_1\eta_1+\delta\alpha\lambda_0\eta_0+\delta\alpha\lambda_2\eta_2$. It is clear that the dominant firm would be better-off by setting a higher price to these customers if they are expected to upgrade to q_2^e tomorrow.

5.0.3 Mandatory compatibility/ Old customers' first period total expected utility if they buy q_1 today and stick to it

If they buy q_1 and expect to stick to it in the second period, their total discounted expected utility given the price set by the market leader (p_{10}) is $q_1+\delta q_1+\alpha(\lambda_0+\lambda_1)+\delta\alpha(\lambda_0+\lambda_1)x_1+\delta\alpha\lambda_2 x_2-c_u-p_{10}$ where x_1, x_2 are the new (λ_2) and old $(\lambda_0+\lambda_1)$ second period customers' fractions that stick to the product of quality q_1.

5.0.4 Mandatory compatibility/ Old customers' first period total expected utility if they don't upgrade to q_1 today and expect either to stick to it or upgrade to q_1 tomorrow

Similarly, their total expected utility if they expect to upgrade to q_1 tomorrow is $q_0+\delta q_1+a\lambda_0 x_0^{''}+\alpha\lambda_1 x_1^{''}+\delta\alpha\lambda_0 x_0^{'}+\delta\alpha\lambda_1 x_1^{'}+\delta\alpha\lambda_2 x_2^{'}-\delta c_u-\delta p_{10}^{e\prime}$ where $p_{10}^{e\prime}$ is they price they expect to pay in order to upgrade to q_1 in the following period while it is $q_0+\delta q_0+a\lambda_0 x_0^{''}+\alpha\lambda_1 x_1^{''}+\delta\alpha\lambda_0 x_0^{iv}+\delta\alpha\lambda_1 x_1^{iv}+\delta\alpha\lambda_2 x_2^{iv}$ if they expect to stick to q_0 for both periods. So,

5.0.5 Mandatory interoperability/ New first period customers' choices (λ_1) if

they buy q_0 in the first period

If λ_1 customers buy the product of quality q_0 in the first period, they may either keep it in the second period or upgrade to either q_1 or q_2^e. Note that the new first period customers are expected to make their purhasing decision in the second period independently of what other customers (λ_1) of the same class do. Thus, they will upgrade to q_2^e tomorrow if:

$$q_2^e + a - c_u - p_{21}^{e'} \geq$$

$$\max\{q_0 + \alpha\lambda_1 + \alpha\lambda_0 x_0^{''} + \alpha\lambda_2 x_2^{''},\ q_1 + \alpha\lambda_1 + \alpha\lambda_0 x_0^{'} + \alpha\lambda_2 x_2^{'} - c_u - p_{11}^{e'}\},$$

where $x_0^{''}, x_2^{''}, x_0^{'}, x_2^{'}$ are the fractions of λ_0, λ_2 customers that either stick to q_0 or own q_1 in the second period, respectively or equivalently if:

$$p_{21}^{e'} - p_{11}^{e'} \leq \Delta q^e + \alpha\lambda_0(1 - x_0^{''}) + \alpha\lambda_2(1 - x_2^{''})$$

So, their total expected discounted utility if they purchase (given p_{01}) the product of quality q_0 in the first period is $q_0 + \delta q_2^e + \alpha\lambda_0\psi_0 + \alpha\lambda_1\psi_1 + \delta\alpha - c - \delta c_u - p_{10} - \delta p_{21}^{e'}$, where ψ_0, ψ_1 are the old and new first period customers that stick and buy the version of quality q_0 in the first period, respectively and $p_{21}^{'e}$ is the price they expect to pay tomorrow in order to upgrade to q_2^e.

5.0.6 Regime of interoperability/ Old first period customers' second period payoffs after sticking to q_0 in the first period.

Old customers expect to buy q_2^e when all customers of their class either buy q_1 or stick to q_0 if:

$$q_2^e + a - c_u - p_{20}^{e'} \geq$$

$$\geq \max\{q_0 + \alpha\lambda_0 + \alpha\lambda_1 x_1^{''} + \alpha\lambda_2 x_2^{''},\ q_1 + \alpha\lambda_0 + \alpha\lambda_1 x_1^{'} + \alpha\lambda_2 x_2^{'} - c_u - p_{10}^{e'}\},$$

or equivalently: $p_{20}^{e'} \leq \Delta q^e + \alpha\lambda_1(1 - x_1^{'}) + \alpha\lambda_2(1 - x_2^{'})$.

5.0.7 No interoperability: First period maximum price charged to λ_1 customers if they buy q_0 at $t = 1$

If they buy q_0, their total expected utility by upgrading in the second period to q_1 is $q_0 + \delta q_1 + \alpha\lambda_0\psi_0 + \alpha\lambda_1\psi_1 + \delta\alpha - c - \delta c_u - p_{01} - \delta p_{11}^e$, where p_{11}^e is the price they expect to pay in order to upgrade tomorrow and ψ_0, ψ_1 are the λ_0 and λ_1 customers' fractions that stick or buy the product of quality q_0 in the initial period. If they buy q_0 and they expect to keep it in the second period, their total expected utility given the first period price charged by the dominant firm (p_{01}) is $q_0 + \delta q_0 + \alpha\lambda_0\psi_0 + \alpha\lambda_1\psi_1 + \delta\alpha\lambda_0 x_0 + \delta\alpha\lambda_1 x_1 + \delta\alpha\lambda_2 x_2 - c - p_{01}$. It is clear that the dominant firm can charge a higher price in the first period by selling the product of quality q_1 to the new customers (p_{11}) rather than the product of quality q_0 (p_{01}).

5.0.8 Regime of no interoperability/ λ_1 customers' expectations if they buy q_0/ $\Delta q^e < \alpha(\lambda_0 + \lambda_1)$

If λ_1 buy q_0 in the first and stick to it in the future period, their second period utility will be $q_0 + \alpha\lambda_0 x_0 + \alpha\lambda_1 x_1 + \alpha\lambda_2 x_2$, where x_0, x_1, x_2 are the fractions of $\lambda_0, \lambda_1, \lambda_2$ who own the initial version, respectively while if they buy q_1 tomorrow, their utility is $q_1 + \alpha - c_u - p_{11'}$ independently of what other customers do. Thus, λ_1 customers will buy the product of quality q_1 even if all other λ_1 stick to q_0 if:

$$q_1 + \alpha - c_u - p_{11}^{'} \geq q_0 + \alpha\lambda_1 + \alpha\lambda_0 x_0 + \alpha\lambda_2 x_2.$$

Given that the first period quality improvement is relatively high ($\Delta q \geq c_u$), their total expected discounted utility if they buy q_0 in the first period is $q_0 + \delta q_1 + \alpha\lambda_0\psi_0 + \alpha\lambda_1\psi_1 + \delta\alpha - c - \delta c_u - p_{01} - \delta p_{11}^{'e}$, where ψ_0, ψ_1 are the old and new first period customers that stick and buy the version of quality q_0 in the first period, respectively and $p_{11}^{'e}$ is the price they

expect to pay tomorrow in order to upgrade to q_1.

5.0.9 Regime of no interoperability/ λ_0 customers' expectations if they stick to $q_0/\Delta q^e < \alpha(\lambda_0 + \lambda_1)$

If λ_0 customers stick to q_0 in the first period, there are some possibilities in the following period: if they keep q_0, their second period utility is $q_0 + \alpha\lambda_0 x_0^{'} + \alpha\lambda_1 x_1^{'} + \alpha\lambda_2 x_2^{'}$. If they buy q_1, their second period utility will be $q_1 + \alpha - c_u - p_{10}$. Thus, they will buy the higher quality product in the second period when they make their purchasing decisions independently of what other λ_0 customers do if:

$$\begin{aligned} q_1 + \alpha - c_u - p_{10} &\geq q_0 + \alpha\lambda_0 + \alpha\lambda_1 x_1^{'} + \alpha\lambda_2 x_2^{'} \Leftrightarrow \\ p_{10} &\leq \Delta q + \alpha\lambda_1(1 - x_1^{'}) + \alpha\lambda_2(1 - x_2^{'}) - c_u. \end{aligned}$$

Thus, the price expected to be set by the dominant firm in the second period is $p_{10}^e = \Delta q + \alpha\lambda_1(1 - x_1^{'}) + \alpha\lambda_2(1 - x_2^{'}) - c_u$ and λ_0 customers buy the product of quality q_1. Thus, their expected total discounted utility if they stick to the initial version q_0 is $q_0 + \delta q_1 + \alpha\lambda_0 x_0 + \alpha\lambda_1 x_1 + \delta\alpha - \delta c_u - \delta p_{10}^e$.

5.0.10 Regime of no interoperability/ λ_1 customers' potential second period payoffs if they buy q_0 in the first period/ $\Delta q^e \geq \alpha(\lambda_0 + \lambda_1)$

If these customers expect to upgrade to q_2^e after purchasing q_1 today, their total expected discounted utility is $q_1 + \delta q_2^e + \alpha(\lambda_0 + \lambda_1) + \delta\alpha\lambda_1\eta_1^{'} + \delta\alpha\lambda_0\eta_0^{'} + \delta\alpha\lambda_2\eta_2^{'} - c - \delta c_u - p_{11} - \delta p_{21}^e$, where p_{21}^e is the price they expect to pay to upgrade to the rival's q_2^e in the future period. If they buy q_0, their total expected discounted utility given the market leader's price (p_{01}) is $q_0 + \delta q_2^e + \alpha\lambda_0\psi_0 + \alpha\lambda_1\psi_1 + \delta\alpha\lambda_0\psi_0^{'} + \delta\alpha\lambda_1\psi_1^{'} + \delta\alpha\lambda_2\psi_2^{'} - c - \delta c_u - p_{01} - \delta p_{21}^e$ where p_{21}^e is the price they expect to pay to upgrade to q_2^e tomorrow. If these customers expect to upgrade to q_1 after buying q_0 in the first period, their total discounted expected utility is $q_0 + \delta q_1^e +$

$\alpha\lambda_0\psi_0+\alpha\lambda_1\psi_1+\delta\alpha\lambda_0\psi_0^{''}+\delta\alpha\lambda_1\psi_1^{''}+\delta\alpha\lambda_2\psi_2^{''}-c-\delta c_u-p_{01}-\delta p_{11}^e$ where p_{11}^e is the price they expect to pay to upgrade tomorrow to q_1 while if they expect to stick to q_0 for both periods, their total expected discounted expected utility is $q_0+\delta q_0+\alpha\lambda_0\psi_0+\alpha\lambda_1\psi_1+\delta\alpha\lambda_0\psi_0^{'''}+\delta\alpha\lambda_1\psi_1^{'''}+\delta\alpha\lambda_2\psi_2^{'''}-c-p_{01}$. If they stick to q_0, their utility is $q_0+\alpha\lambda_0x_0+\alpha\lambda_1x_1+\alpha\lambda_2x_2$. If they buy q_1, their second period utility is $q_1+\alpha\lambda_0x_0^{'}+\alpha\lambda_1x_1^{'}+\alpha\lambda_2x_2^{'}-c_u-p_{11}$ while if they buy q_2, their utility is $q_2+\alpha\lambda_0\psi_0^{'}+\alpha\lambda_1\psi_1^{'}+\alpha\lambda_2\psi_2^{'}-c_u-p_{21}$. These customers in the second period will choose to buy q_2 even if all other λ_1 customers either stick to q_0 or buy q_1 if:

$$q_2+\alpha\lambda_0\psi_0^{'}+\alpha\lambda_2\psi_2^{'}-c_u-p_{21}\geq$$

$$\geq\max\{q_1+\alpha\lambda_0x_{0'}+\alpha\lambda_1+\alpha\lambda_2x_2^{'}-c_u-p_{11},\ q_0+\alpha\lambda_0x_0+\alpha\lambda_1+\alpha\lambda_2x_2\}$$

where $x_2^{'}$, x_2 are the new second period fractions that are expected to buy q_1 or q_0 in the second period, respectively. So, these customers expect to buy q_2^e if

$$p_{21}^e-p_{11}^e\leq\Delta q^e+\alpha\lambda_0(\psi_0^{'}-x_0^{'})+\alpha\lambda_2(\psi_2^{'}-x_2^{'}),$$

since we have assumed a relatively important initial innovation.

5.0.11 Regime of no interoperability/ λ_0 customers' potential second period payoffs if they stick to q_0 in the first period/ $\Delta q^e\geq\alpha(\lambda_0+\lambda_1)$

If they expect to upgrade to q_2^e tomorrow after purchasing q_1, their total expected discounted utility is $q_1+\delta q_2^e+\alpha(\lambda_0+\lambda_1)+\delta\alpha\lambda_0x_0^{'}+\delta\alpha\lambda_1x_1^{'}+\delta\alpha\lambda_2x_2^{'}-c_u-\delta c_u-p_{10}-\delta p_{20}^e$, where p_{20}^e is the price they expect to pay tomorrow to upgrade to q_2^e.

5.0.12 Regime of no interoperability/ λ_0 customers' potential second period payoffs if they stick to q_0 in the first period/ $\Delta q^e\geq\alpha(\lambda_0+\lambda_1)$

If these customers expect that they will upgrade to q_1 after choosing to stick to q_0 in the first period, their total discounted expected utility is $q_0+\delta q_1+\alpha\lambda_0x_0^{'''}+\alpha\lambda_1x_1^{'''}+\delta\alpha\lambda_2\zeta_2+\delta\alpha\lambda_1\zeta_1+$

$\delta\alpha\lambda_0\zeta_0 - \delta c_u - \delta p_{10}^e$ while if they expect that they will stick to q_0 for both periods, their total discounted expected utility is $q_0 + \delta q_0 + \alpha\lambda_0 x_0^{'''} + \alpha\lambda_1 x_1^{'''} + \delta\alpha\lambda_2\rho_2 + \delta\alpha\lambda_1\rho_1 + \delta\alpha\lambda_0\rho_0$. If these customers expect to upgrade to q_1 in the second period, their second period expected payoff is $q_1 + \alpha\lambda_2\zeta_2 + \alpha\lambda_1\zeta_1 + \alpha\lambda_0\zeta_0 - c_u - p_{10}^e$, where $\zeta_2, \zeta_1, \zeta_0$ are the new and old second period customers' fractions that stick or buy q_1 in the second period and p_{10}^e is the price they expect to pay tomorrow to upgrade while if they expect to stick to q_0 in the second period, their second period expected payoff is $q_0 + \alpha\lambda_2\rho_2 + \alpha\lambda_1\rho_1 + \alpha\lambda_0\rho_0$. Note that they expect to upgrade to q_2^e if they expect to follow the same coordination rule in the following period (and thus, if $\zeta_0 = \rho_0 = 1$):

$$q_2 + \alpha\lambda_0 x_0^{iv} + \alpha\lambda_1 x_1^{iv} + \alpha\lambda_2 x_2^{iv} - c_u - p_{20}^{'e} \geq$$

$$\geq \max\{q_1 + \alpha\lambda_2\zeta_2 + \alpha\lambda_1\zeta_1 + \alpha\lambda_0\zeta_0 - c_u - p_{10}^e,\ q_0 + \alpha\lambda_2\rho_2 + \alpha\lambda_1\rho_1 + \alpha\lambda_0\rho_0\}$$

or equivalently:

$$p_{20}^{'e} - p_{10}^{'e} \leq \Delta q^e - \alpha\lambda_0 + \alpha\lambda_1(x_1^{iv} - \zeta_1) + \alpha\lambda_2(x_2^{iv} - \zeta_2).$$

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