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A Duopoly Logit Model with Price Competition and Strategic Compatibility

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ABSTRACT. – This paper provides an analysis of compatibility in a sequential game in which firms first choose whether they supply compatible products and then set the price which they charge. The equilibrium compatibility configuration is the outcome of a trade-off between consumers' valuation of compatibility, and the loss in terms of product differentiation stemming from adhesion to a common standard. Compatibility is achieved provided the compatibility premium is not offset by the intensity of price competition. Further, there tends to be under-provision of standardization.

Concurrence et compatibilité dans un modèle logistique de différentiation horizontale

RÉSUMÉ. – Nous considérons un jeu en deux étapes dans lequel deux firmes concurrentes décident du caractère compatible ou incompatible de leurs produits, avant de fixer le prix auquel ces produits sont commercialisés. La décision de compatibilité affecte le degré de différentiation des produits. L'équilibre reflète le compromis des firmes entre la valeur que les consommateurs associent à la compatibilité, et la perte de différentiation consécutive au choix d'un standard commun. La compatibilité est réalisée à l'équilibre si la prime qui lui est attachée est suffisante pour compenser l'accroissement de la concurrence, mais d'un point de vue collectif le marché ne conduit pas suffisamment souvent à l'émergence d'un standard.

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1 Introduction

As information and communication technologies increasingly permeate the technology system, issues of standardization and product compatibility become central. Technical standards permit agents to communicate, exchange data and use common practices, thereby creating demand-side economies of scale, and compatibility across standards is a way to capture joint benefits. Users are better off with compatible airline customer reservation systems, fax machines, GSMs, cash dispensers (ATMs, Saloner and Shepard [1995]), software packages (Gandall [1994]), game consoles, components of stereo systems, and many other goods and services available today. Compatibility is a way of ensuring interconnection and inter-operability, from which size effects are expected. It therefore stands out as an obvious concern for firms' strategic behavior. Of course this is by no means specific to the "new" or knowledge-based economy: Puffert [1991] discusses compatibility in the context of railway gauge standardization in southern US during the mid-nineteenth century.[1] However, ICTs and the development of the Internet have certainly made the stakes more visible. The use of technical incompatibility by Microsoft, for instance, has played a major role in the emergence and persistence of a dominant position in the market for operating system software (and not only between its browser and Netscape, see Baseman *et al.* [1997]). While compatibility has some social value, the fact that we still see many instances of markets where incompatibilities prevail has been the core motivation for the bulk of research in network economics.

The theoretical literature on compatibility falls within two broad categories. In the first approach there are demand-side scale economies in the form of increasing returns to adoption (Arthur [1989]), that is to say the value a consumer derives from purchasing a good increases with its scope of diffusion. Achieving compatibility then permits users to reap the benefits associated with the group of compatible goods. By contrast, in the "mix-and-match" approach, increasing returns are not the main issue. Product variety and thus demand both change in response to compatibility decisions, as products are systems made up with several distinct parts. We briefly review the two approaches and give some empirical elements.

1.1 Increasing Returns to Adoption

Increasing returns to adoption stem from many sources, among which the major ones probably are *direct* network externalities, the existence of comple-

1. Before standardization, at every break of gauge (*i.e.,* border between regions) goods had to be transshipped to continue the journey. The associated costs led to the conversion of more than 20,000 miles of track in North America alone. Three different gauges have been existing for long in Australia, which has lately engaged in converting its railway system to a common gauge.

mentary goods or services (often referred to in the literature as *indirect* network externalities), and learning-by-using/doing.[2]

When there are network externalities, individual utility directly increases with the number of sold units of compatible products (see the survey by PERROT [1993]). It is often the case that networks externalities almost entirely determine the value of the good: phones, fax machines, more generally communication technologies are of little value in themselves, but they provide network access. SALONER and SHEPARD [1995] study the case of ATMs. They use data on banks' adoptions of ATMs over the period 1972-79 to show that adoption delays decline in the number of branches and the value of deposits (which serves as a proxy for the number of users and hence for production scale economies). The network externality approach is typically that followed since the mid-1980s in a number of theoretical papers, starting with KATZ and SHAPIRO [1985]. In this seminal paper, industry output is shown to be greater under compatibility than at any other (partial compatibility) equilibrium in a fulfilled expectations formulation with output competition. However, private incentives towards compatibility tend to be insufficient when the costs of achieving it must be born unilaterally. In DE PALMA and LERUTH [1996] and ECONOMIDES and FLYER [1998], compatibility is explicitly made the outcome of a sequential game. Firms first commit to a standard and then engage in output competition. In both papers, incompatibility is considered as a means of vertical differentiation. In a duopoly with consumers having variable willingness to pay for the externality, DE PALMA and LERUTH [1996] find that compatibility, though socially preferable, emerges if and only if the duopolists have a close to equal probability of being the largest under incompatibility (*ie,* of being the winner in a standard war). ECONOMIDES and FLYER [1998] examine two different regimes of intellectual property rights: non proprietary (firms can freely coalesce) *vs* proprietary standards (each firm has its own technical standard and a consensus is necessary). Equilibria of the two-stage game are often asymmetric in production levels, prices and output, a tendency which increases with the intensity of network externalities. Full compatibility is the equilibrium in markets in which network externalities play a small role, and is also the industry output maximizing situation. Different conclusions obtain under price competition. Network externalities act as a multiplier on firms' incentives to undercut their rivals (DE PALMA and LERUTH [1993]). Prices are lower under incompatibility than under compatibility, and so are profits (this holds in a discrete-choice model were individual demands are price-inelastic). In DE PALMA, LERUTH and REGIBEAU [1999], converters allow de facto compatibility through double purchase: the possibility of double purchase is shown to increase firms' incentives towards standardization.

2. Learning-by-using refers to user/producer interactions (feedbacks) and indirect effects arising on the consumers' side such as the development and sharing of expertise, the provision of information by user groups, etc. According to ROSENBERG [1982], this is because new technologies often have the property that their true benefits are hard to assess without actually using them. A related stream of literature would be on switching costs (see KLEMPERER 1985), where compatibility contributes to decreasing users' switching costs (*eg,* in the adoption of word processors using the same keystroke commands). By contrast, learning-by-doing refers to the existence of industry learning curves and the associated cost decreases. COWAN [1990] investigates the case of nuclear power plants, where a learning curve with a 5% yearly increase in the rate of operating time (time when power is effectively generated) for each new plant exists.

Dynamic two-period contexts are discussed in FARRELL and SALONER [1985] and KATZ and SHAPIRO [1986], but the focus is on inefficiencies arising from the excess inertia of consumers and the relation between compatibility and innovation, more that on compatibility *per se*.[3]

The approach using complementarity effects is a more subtle one, as benefits are indirect through the provision of complementary goods or services: cars have no value in the absence of parts, gasoline and roads; so are compact disc players without compact discs (see the recent study by GANDAL *et al.* [2000]), and computers without software packages. CUSUMANO *et al.* [1992] argue that the availability of complementary products (prerecorded tapes) drove VHS to dominate over Betamax in the early 1980s though both technologies were of similar quality. COTTRELL and KOPUT [1998] estimate the effect of software provision on the valuation of hardware in the early microcomputer industry (over the period 1980-86), and find a positive relationship between software availability and platform price: variety serves as a signal for platform quality (though this changes over the product life cycle). GANDAL *et al.* [2000] evidence a significant cross-elasticity for the adoption of CD players with respect to CD variety. (They also discuss the possibility of bottlenecks in the diffusion of the system as a whole.) In CHOU and SHY [1990, 1996] and CHURCH and GANDAL [1992], the welfare of consumers is affected by the variety of supporting goods or services that a monopolistically competitive market supplies. Compatible computers can run the same software, whereas incompatible ones cannot. The specifics of consumers' utility functions determines equilibrium compatibility relationships for the hardware industry, and the general result is that profits tend to be higher under compatibility since the demand curves for hardware are generally less elastic compared to the non-standardized case, though welfare suffers from computer firms charging higher prices due to larger software variety.

Under both direct and indirect network externalities, firms are confronted with the same dilemma: on the one hand a firm that chooses to make its product compatible increases the value of the product to the consumer; but keeping its output incompatible with other products likely increases monopoly power, though the output is less valuable to consumers.

1.2 Mixing and Matching

The second strand of literature dealing with compatibility is the mix-and-match approach. Products are seen as systems consisting of several distinct parts (in a fixed ratio), and making parts compatible changes the variety of systems available to consumers. Stereo systems consist of a receiver-amplifier, a compact disc player and speakers; PCs embed a central processing unit, a monitor and a keyboard. These components can be bought separately, but a PC can also be sold as a system, as was the original MacIntosh by Apple. Components produced by different manufacturers are compatible if it is feasible for consumers to combine them costlessly into a working system. In

3. GREENSTEIN [1993] finds evidence that government agencies tend to prefer backward compatible hardware technologies in their acquisitions. This positive valuation of compatibility, GREENSTEIN conjectures, is linked to past investment in software applications.

MATUTES and REGIBEAU [1988], consumers are uniformly distributed over the $[0,1] \times [0,1]$ characteristics' space according to their ideal position (combination of characteristics, here the two components), face transportation costs (dis-utility) and purchase at most one unit. In the incompatibility regime, there are two systems at $(0,0)$ and $(1,1)$, whereas under compatibility four systems are available at the corners of the square. Both prices and profits are found to be higher under compatibility than under incompatibility. The same result obtains in ECONOMIDES [1989] for general consumers' demand and transportation costs. The explanation is in terms of the elasticity of the residual demand: under compatibility a price cut for a component triggers a demand response expressed in units of this sole component, while under incompatibility a price cut for a system triggers a response in units of both components. Competition is therefore tougher under incompatibility, a result which also obtains with direct externalities and price competition (see above).

The literature on direct externalities also addresses the issue of product variety. In FARRELL and SALONER [1986], standardization is a constraint on product variety. When consumers have different preferences in their ideal specifications for the good, standardization drives some consumers to purchase their less preferred version of the good in order to attain a larger network benefit; this in turn might yield too much or too little variety compared to social optimality. It should finally be mentioned that compatibility can also be analyzed in terms of converters, which enable ex post compatibility. (Because compatibility no longer requires standardization, one can expect converters to relax the trade-off between standardization and variety.) FARRELL and SALONER [1992] assume that converters make the technology only partly compatible, in the sense that hybrid goods that utilize incompatible components together with an adapter yield lower externalities than systems made up with fully compatible components. It turns out that the availability of converters may actually lead to a decrease in the overall level of compatibility because, when considering the adoption of a converter, consumers do not account for the subsequent social loss in network externalities. Further, the availability of converters can reduce social welfare, as some consumers (there is a continuum of them) combine the "inferior" technology with the adapter, while they would have bought the superior technology in the absence of converters.[4] It should be noted that FARRELL and SALONER do not address the issue of firms' compatibility decisions (*i.e.*, products are assumed to be *ex ante* incompatible), which is precisely the focus of the present paper.

In this paper, we aim at giving further insights into the relationship between compatibility and competition. On the one hand, firms are eager to supply compatible products since consumers make a higher valuation of such products, a contention which a number of well-documented case-studies support (GANDAL [1994]; HARHOFF and MOCH [1997]; see the discussion in section 2.3). On the other hand, we argue that consumers tend to perceive compatible products as closer substitutes and this leads to increased price competition. Indeed, compatible goods must embed characteristics that make compatibility possible. There are internal components, architectural traits, technical features which compatible goods have to share, thereby reducing the amount of differentiation (PCs

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4. DAVID and BUNN [1988] provide a case study of converters – which they call gateway technologies – for power supply systems.

resemble PCs, embed the same operating system, use the Wintel architecture, have similar CPUs, etc.). Goods yielding utility because they enable communication must also achieve some degree of similarity between communication protocols and/or processing architectures in order to get compatibility (interconnection in this case). The same holds for elements of subjective differentiation: though a PC and a MacIntosh are substitutes from the point of view of the task they perform, people perceive different PCs as much closer substitutes than a PC and a MacIntosh. As compatible products share many features, we consider that they are less differentiated than incompatible ones. This we represent by means of a nested Logit demand model: consumers first decide to which standard they will conform, and then choose a single product (or variant) that embodies this standard. We examine the trade-off that firms face between these contradictory incentives, and show that socially sub-optimal outcomes, in particular the under-provision of standardization, are likely to emerge. This we do in a sequential game in which firms first choose whether to sell compatible products and then set the price which they charge. Compatibility occurs when both firms agree to it, and is achieved by affiliation to a common standard. The model is outlined in section 2. In section 3, we characterize the sub-game perfect equilibrium of the sequential game with strategic compatibility choice and then price competition. Finally, section 4 is devoted to an analysis of welfare.

2 A Model of Strategic Compatibility

The industry consists of two mono-product firms $i = 1,2$. Each firm in the industry first determines whether it wants to make its product compatible with the one supplied by its competitor, and then sets its price. Each product embodies a technical standard and full compatibility is achieved when both firms adopt a common standard. Conversely, products embodying distinct standards are assumed to be fully incompatible.

It is assumed that each firm is endowed with a specific standard, which might be proprietary or not. Compatibility can occur through unilateral decisions when standards are not proprietary, whereas it requires a consensus under the proprietary regime (see ECONOMIDES and FLYER [1998] for an analysis of the two regimes of property rights).[5] The distinction is irrelevant in the model presented here because only symmetric equilibria exist: firms' incentives toward standardization therefore always coincide and there will not be a firm willing to be compatible while the other prefers incompatibility. Let the specific standard of firm 1 be labelled A, and that of firm 2 be labelled B. To avoid the potential coordination problem arising from firms' standard choice, it is assumed that when firms want to be compatible they both adhere to standard A (along the same line, see DE PALMA and LERUTH [1996]). Products which embody standard A are referred to as variants of this standard,

5. BESEN and FARRELL [1994] argue that a firm which is willing to be incompatible can prevent access to its standard, but is also able to introduce *ex post* incompatibilities. Building an adapter might seem to be a way of unilaterally forcing compatibility, but it does require knowledge about both standards.

or compatible variants. Obviously incompatibility prevails as soon as one firm is not willing to be compatible (but then so is the other).

We now give a general characterization of demand under the two alternative regimes, before turning to a more precise analysis.

2.1 The Demand Structure

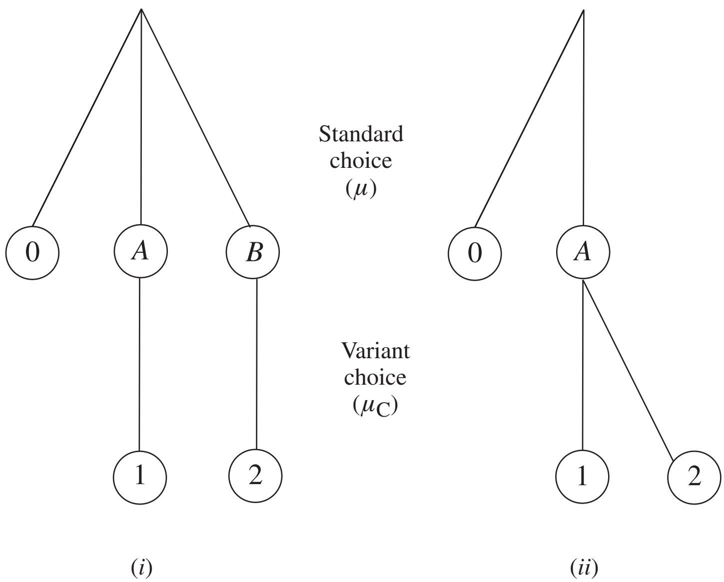
We consider a large population of N heterogeneous consumers. Demand is allocated according to the following discrete choice sequence. In the first stage, each consumer chooses one of the available standards or an outside alternative yielding an exogenously given utility level. The outside alternative can be interpreted as a no-purchase alternative, or a Hicksian composite good, and guarantees that the total volume of demand responds to price changes. In the second stage, the consumers who have decided to buy something choose a good which embodies the technical standard adopted in the first stage. Thus, the first stage of consumers' decision can also be seen as a network choice, while the second one corresponds to a product choice within a specific network.

Depending on whether the goods are compatible or not, the second stage choice sets differ. When incompatibility prevails, each standard is represented by a single good on the market. Then, the second stage of consumers' choice is trivial as only one good embeds each standard. In this situation there is virtually direct competition between the goods and the outside alternative. By contrast, when firms sell compatible products, they both embody standard A. Conditionally to his decision of purchasing the common standard, each consumer then chooses his most preferred variant in the second stage. So, in this case, there is first competition between the (jointly adopted) standard and the outside alternative, and then competition takes place between the compatible variants. Figure 1 gives a symbolic representation of the demand structure in the two configurations.

Both the competing standards and the variants are assumed to be horizontally differentiated, and how much differentiation there is depends on which stage of the choice sequence is considered. We shall assume that there is less differentiation across variants than across standards. This captures the intuitive idea that compatible variants are closer substitutes than incompatible products, as they have more objective features in common. An equivalent statement is that consumers are heterogenous and the dispersion of consumers' preferences across standards is larger than consumer heterogeneity at the variant level. (Beside objective features, people do perceive compatible goods as closer substitutes than incompatible ones.) We adopt a structure which is widely used in quantitative marketing, empirical industrial economics and the theory of product differentiation: the multinomial Logit (see ANDERSON *et al.* [1992] for an extensive discussion of this and other models of discrete choice, and the Appendix for a more detailed presentation). As we have a two-stage process, overall demand is represented by a nested multinomial Logit. This enables us to explicitly represent the coexistence of different degrees of product differentiation (BEN AKIVA [1973]).[6] The nested

6. The nested Logit is usually utilized to represent a situation in which several differentiated multi-product firms exist in the marketplace and produce a number of differentiated (competing) goods. The goods produced by a firm are often closer substitutes than those produced by distinct firms. A nested Logit captures this feature in a two-stage representation similar to the one we employ.

FIGURE 1
The nested demand structure in the case of incompatible goods (i) ***and in the case of compatible variants*** (ii)



Logit is used by FONCEL and IVALDI [2000], who estimate the demand for PC operating systems in countries of the former G7. The authors view the first stage of the nested Logit as a "form factor" selection (the decision to get a desktop, a laptop or an ultra-portable computer); in the second step, consumers choose the operating system (DOS/Windows or MacOS) which will be running on their computer. Doing so, they implicitly assume that operating systems are closer substitutes than forms.

Having described the decision sequence of consumers, we turn to the formal definition of demand in each configuration.

2.2 The Case of Incompatible Goods

As discussed in the introduction of this section, goods are incompatible if and only if each firm adopts its specific standard. Then, the standard and the corresponding good have the same utility, as each standard is only embedded in one good.

A consumer chosen at random from the population of N consumers has a conditional indirect utility function

(1) $$\widetilde{u}_i = R - p_i + \varepsilon_i, \text{for } i = 1,2.$$

The parameter R stands for consumers' income (which is assumed to be large), p_i is the price of good $i = 1,2$ and ε_i represents consumers' idiosyncratic tastes about good i (horizontal differentiation). The outside, or no-purchase alternative has an associated utility given by

$$\widetilde{u}_0 = R + u_0 + \varepsilon_0. \tag{2}$$

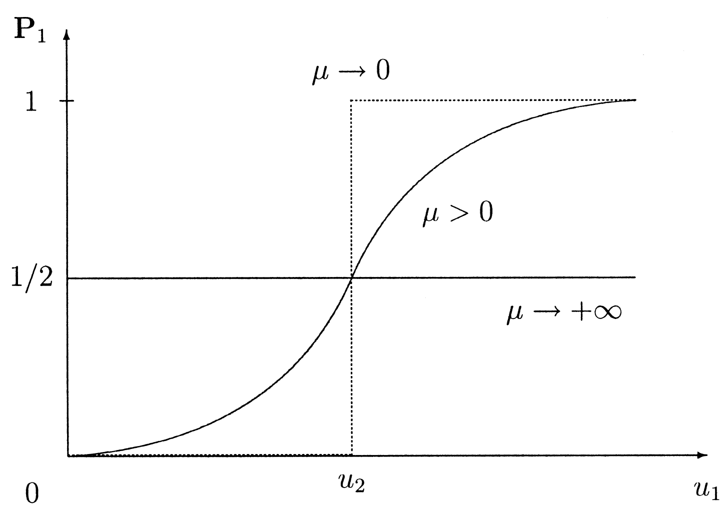
Equations (1) and (2) characterize a standard additive random utility model. If we assume that the ε_is are i.i. double exponentially distributed with parameter $\mu > 0$, the multinomial Logit obtains. The parameter μ measures the dispersion of individual preferences. For small μ the variance of the ε_is approaches zero and choices tend to concentrate on the utility-maximizing alternative(s), whereas large μ-values yield random choice (see the Appendix). As an illustration, Figure 2 represents the purchase probability for good 1 in a Logit formulation with two goods and three different values of the dispersion parameter μ.

The purchase probability for product i is the probability that a randomly selected consumer derives the largest utility from purchasing it.[7] It is written $\mathbf{P}_i = \Pr\{\widetilde{u}_i = \max_{j=0,1,2} \widetilde{u}_j\}$, which in turn yields

$$\mathbf{P}_i = \frac{\exp(-p_i/\mu)}{\sum_{j=1,2} \exp\left(-p_j/\mu\right) + \exp(u_0/\mu)}, \text{for } i = 1,2. \tag{3}$$

FIGURE 2

Logit demand for good 1 with two competing goods and different μ-values: the dotted piecewise linear curve corresponds to $\mu \to 0$; the S-shaped curve corresponds to $\mu > 0$; the horizontal line is for $\mu \to +\infty$



7. In the Appendix, the detailed derivation of the choice probabilities is provided.

Note that the case $u_0 \to -\infty$ corresponds to the standard multinomial Logit in which overall demand is inelastic. Finally, the expected demand addressed to firm i $(i = 1,2)$ is given by $N\mathbf{P}_i$, and the total volume of demand captured by the two goods is $N(\mathbf{P}_1 + \mathbf{P}_2)$, whereas the outside alternative captures $N\mathbf{P}_0$.

2.3 Compatible Goods

When compatibility prevails, standard A is represented by two products on the market while standard B is not available. We assume that consumers attach a positive value to product compatibility, which is represented by a parameter $\phi > 0$. This is in line with a number of empirical studies. Probably the most relevant contributions for our purpose are those of GANDAL [1994] and HARHOFF and MOCH [1997] about the software industry. Adherence to standards and compatibility is indeed a very important quality feature for software products. GANDAL [1994] studies the market for spreadsheets, and resorts to a hedonic price model to show that a positive value is associated with spreadsheets providing Lotus file compatibility. In a similar vein, HARHOFF and MOCH [1997] apply a hedonic price approach to database software. They find that code compatibility, *ie,* the capability of executing programs written for the dominant database product (dBASE) yields a large and highly significant price premium.[8] The ability to read and write data in the dominant spreadsheet format (file compatibility) is also associated with higher prices, but the difference happens to be much smaller than in the case of code compatibility. The key lesson from these papers is that significant compatibility premiums exist. It is the impact of this premium on strategic compatibility decisions that we examine in the present paper.[9] Note that as we consider compatibility to be valuable *per se* – and therefore do not explicitly model network externalities – the derivation of equilibrium play is substantially simplified (the complications resulting from handling a system of implicit equations as in KATZ and SHAPIRO [1985] or DE PALMA and LERUTH [1993] are avoided). Consider the choice problem of a consumer who has decided to buy standard A in the first stage.

The variants of standard A are horizontally differentiated. The conditional indirect utility of a consumer chosen at random from the population of those consumers who decided (in the first stage) to purchase one of the variants is given by:

$$\widetilde{u}_i = R + \phi - p_i + \varepsilon_i', \text{for } i = 1,2. \tag{4}$$

where the ε_i's again represent consumers' idiosyncratic tastes for the variants, ϕ is the compatibility premium and p_i is the price of good $i = 1,2$. The ε_i's

8. As HARHOFF and MOCH [1997] emphasize it, code compatibility protects past investment in programming, while file compatibility just ensures users that their data can be used with other software packages. Thus we would expect code compatibility to be significantly more valuable than file compatibility for software users. GANDAL [1994] only examines file compatibility.

9. An alternative interpretation is that adopters of compatible goods would not need buying costly converters: ϕ could then represent the amount of money which is saved. We abstract from the precise origin of this premium. If we were to consider $\phi < 0,$ compatibility would be associated to (negative) congestion effects.

are i.i. double-exponentially distributed with parameter μ_C. Letting $\mu_C < \mu$ (*ie,* the ε_i's are less dispersed than the ε_is) captures the assumption that compatible variants are closer substitutes than incompatible products, due to the internal components, architectural traits, technical features which compatible goods have to share, thereby reducing the amount of product differentiation.

The probability of a consumer purchasing good i is obtained by conditioning on the first-stage decision (purchase or no-purchase). It is written $\mathbf{P}_{i,A} = \mathbf{P}_A \mathbf{P}_{i/A}$, where $\mathbf{P}_A = \Pr\{\widetilde{u}_A = \max\{\widetilde{u}_A, \widetilde{u}_0\}\}$ is the probability that standard A as a whole generates more utility than the outside alternative, and $\mathbf{P}_{i/A} = \Pr\{\widetilde{u}_i = \max\{\widetilde{u}_1, \widetilde{u}_2\}\}$ is the probability that purchasing good i yields the highest level of utility given standard A is purchased. From equation (4), the purchase probability for compatible product i, conditional to the decision of purchasing one of the two goods, is

$$\mathbf{P}_{i/A} = \frac{\exp\left(-p_i/\mu_C\right)}{\sum_{j=1,2} \exp\left(-p_j/\mu_C\right)}, \text{for } i = 1,2. \tag{5}$$

Contrasting with the previous situation in which goods where incompatible and thus there was a direct equivalence between a good and a standard, here the two goods do not directly compete with the outside alternative. The two compatible variants are directly competing together and jointly determine the attractiveness of standard A, which in turn competes with the outside alternative. To determine the attractiveness of standard A, we follow BEN-AKIVA and LERMAN [1979] and use the expected value of the maximum utility level within the pool of goods embedding the common standard. Direct computation yields

$$u_A = \mu_C \ln \sum_{j=1,2} \exp\left[\left(R + \phi - p_j\right)/\mu_C\right]. \tag{6}$$

This aggregate index measures the joint attractiveness of the compatible variants. In the first stage of the decision making, a consumer chosen at random from the total population derives a conditional indirect utility from standard A equal to:

$$\widetilde{u}_A = u_A + \varepsilon_A \tag{7}$$

where ε_A is i.i. double exponentially distributed along with ε_0. Standard A is adopted provided it generates more utility than the outside alternative, so the purchase probability for standard A is given by:

$$\mathbf{P}_A = \frac{\exp\left(u_A/\mu\right)}{\exp\left(u_A/\mu\right) + \exp\left(u_0/\mu\right)}. \tag{8}$$

Finally, expected demand addressed to firm i ($i = 1,2$) writes $N\mathbf{P}_{i,A} = N\mathbf{P}_A\mathbf{P}_{i/A}$.

Having defined demand in each configuration, we now seek the sub-game perfect *Nash* equilibrium of the compatibility-then-price game.

3 The Equilibrium

We seek a sub-game perfect *Nash* equilibrium in which firms first choose whether to be compatible and then set prices. The compatibility strategy of firm $i = 1,2$ is defined by $s_i \in \{I,C\}$, where C stands for compatibility (and I stands for incompatibility). Given any compatibility configuration $s \equiv (s_1,s_2)$ determined in the first stage, the equilibrium of the price sub-game is given by $p_1^*(s)$ and $p_2^*(s)$ such that:

(9) $$\pi_i(p_i^*, p_j^*; s) \geqslant \pi_i(p_i, p_j^*; s), \text{for all } p_i \geqslant 0, i = 1,2 \text{ and } j \neq i.$$

Denote the profit functions evaluated at the second stage equilibrium $p^*(s)$ by $\hat{\pi}_i(s) \equiv \pi_i\left[p^*(s); s\right]$. The equilibrium of the compatibility game is then given by s_1^* and s_2^* satisfying

(10) $$\hat{\pi}_i(s_i^*, s_j^*) \geqslant \hat{\pi}_i(s_i, s_j^*), \text{for all } s_i \in \{I,C\}, i = 1,2 \text{ and } j \neq i.$$

A sub-game perfect *Nash* equilibrium for the compatibility-then-price game is defined by s^* and $p^*(s)$ for all compatibility configurations s. The corresponding equilibrium path writes s^* and $p^*\left(s^*\right)$. We proceed by backward induction, defining the price equilibrium and then the equilibrium of the compatibility sub-game. As compatibility prevails if and only if both firms in the industry are willing to be compatible, only the incompatibility and the compatibility regimes need to be examined.

3.1 The Price Equilibrium for Incompatible Goods

Firms are assumed to produce at constant marginal cost c, so that firm i's profit is $\pi_i = (p_i - c)N\mathbf{P}_i$. Differentiating the r.h.s. term in equation (3) and rearranging, we have $\partial\mathbf{P}_i/\partial p_i = -\mathbf{P}_i\left(1 - \mathbf{P}_i\right)/\mu$ for $i = 1,2$. Therefore, the profit derivative for firm i is:

(11) $$\frac{\partial \pi_i}{\partial p_i} = -N(p_i - c)\frac{\mathbf{P}_i\left(1 - \mathbf{P}_i\right)}{\mu} + N\mathbf{P}_i, \text{for } i = 1,2,$$

with second derivative:

(12) $$\frac{\partial^2 \pi_i}{\partial p_i^2} = -N(p_i - c)\frac{\mathbf{P}_i\left(1 - \mathbf{P}_i\right)\left(2\mathbf{P}_i - 1\right)}{\mu^2} - 2N\frac{\mathbf{P}_i\left(1 - \mathbf{P}_i\right)}{\mu}.$$

Evaluating the second derivative of firm i's profit (12) at any point where the first order condition holds gives $-N\mathbf{P}_i/\mu$, indicating that the profit function of each firm is strictly quasi-concave. Therefore firm i's best reply $p_i^{br}\left(p_j\right)$ is uniquely defined. Moreover, uniqueness of the equilibrium is ensured if the best reply functions satisfy $\partial p_i^{br}/\partial p_j < 1$ for $i = 1,2$ and

$j \neq i$ (see *eg,* ANDERSON *et al.* [1992], where it is also checked that no asymmetric equilibrium exists). It is straightforwardly checked that this inequality is satisfied, leading to the following result.

PROPOSITION 1. *[Anderson and de Palma, 1992] When goods are incompatible and demand is defined by relation (3), the unique equilibrium price is implicitly given by*

$$p_i^* = p_I = c + \frac{\mu}{1 - \mathbf{P}_I}, \tag{3}$$

with

$$\mathbf{P}_i = \mathbf{P}_I = \left[2 + \exp\left(\frac{u_0 + p_I}{\mu}\right)\right]^{-1}, i = 1,2. \tag{4}$$

PROOF : From equation (11) the optimal price immediately obtains, and the share of demand addressed to each firm is derived from expression (3).

Individual profit in this configuration is denoted π_I. The equilibrium price and output per firm are decreasing in the relative attractiveness of the outside alternative u_0. Moreover, prices and profits rise with μ (further results on the behavior of equilibrium quantities and welfare can be found in ANDERSON and DE PALMA [1992]).

3.2 Pricing Compatible Goods

When firms sell compatible products, the profit of firm i is written $\pi_i = (p_i - c)N\mathbf{P}_{i,A}$. The first order condition for profit maximization of firm i becomes:

$$\frac{\partial \mathbf{P}_{i,A}}{\partial p_i}(p_i - c) + \mathbf{P}_{i,A} = 0, \text{ for } i = 1,2. \tag{15}$$

Since $\mathbf{P}_{i,A} = \mathbf{P}_A \mathbf{P}_{i/A}$ for $i = 1,2,$ one has:

$$\frac{\partial \mathbf{P}_{i,A}}{\partial p_i} = \frac{\partial \mathbf{P}_A}{\partial p_i}\mathbf{P}_{i/A} + \mathbf{P}_A \frac{\partial \mathbf{P}_{i/A}}{\partial p_i}. \tag{16}$$

The first term reflects the impact of prices on the volume of demand addressed to standard A when it competes with the outside alternative, and the second term stands for inter-firm competition. These two terms are respectively:

$$\frac{\partial \mathbf{P}_A}{\partial p_i} = \frac{\partial \mathbf{P}_A}{\partial u_A}\frac{\partial u_A}{\partial p_i} = -\frac{\mathbf{P}_A\left(1 - \mathbf{P}_A\right)}{\mu}\mathbf{P}_{i/A} \tag{17}$$

and

$$\frac{\partial \mathbf{P}_{i/A}}{\partial p_i} = -\frac{\mathbf{P}_{i/A}\left(1 - \mathbf{P}_{i/A}\right)}{\mu_C}. \tag{18}$$

Evaluating the second derivative of firm i's profit when the first order condition is satisfied yields:

$$(19)\quad \frac{\partial^2 \pi_i}{\partial p_i^2} = -\frac{\mathbf{P}_A \mathbf{P}_{i/A}}{\mu \mu_C} \cdot \frac{\mu^2 \left(1 - \mathbf{P}_{i/A}\right) + \mu_C \left(1 - \mathbf{P}_A\right) \mathbf{P}_{i/A} \left[\mu_C \mathbf{P}_{i/A} + \mu \left(1 - \mathbf{P}_{i/A}\right)\right]}{\mu_C \left(1 - \mathbf{P}_A\right) \mathbf{P}_{i/A} + \mu \left(1 - \mathbf{P}_{i/A}\right)}$$

which is negative. Hence, the profit function π_i is strictly quasi-concave and a symmetric equilibrium exists. Again, it is checked that the equilibrium is unique by showing that the best reply functions satisfy $\partial p_i^{br} / \partial p_j < 1$ for $i = 1,2$ and $j \neq i$. Therefore, the equilibrium with compatible products is characterized by the following proposition.

PROPOSITION 2. *When goods are compatible and demand is defined by relations (5) and (8), the unique equilibrium price is given by:*

$$(20)\quad p_i^* = p_C = c + \frac{\mu}{(\mu_C + \mu)/2\mu_C - \mathbf{P}_C}$$

with,

$$(21)\quad \mathbf{P}_i = \mathbf{P}_C = \left[2 + \exp\left(\frac{u_0 - \phi + (\mu - \mu_C)\ln 2 + p_C}{\mu}\right)\right]^{-1}, i = 1,2.$$

PROOF : Since firms are symmetric at equilibrium, we have $\mathbf{P}_{i/A} = 1/2$. Hence, relation (16) becomes:

$$(22)\quad \frac{\partial \mathbf{P}_{i,A}}{\partial p_i} = -\frac{\mathbf{P}_A}{4}\left[\frac{1 - \mathbf{P}_A}{\mu} + \frac{1}{\mu_C}\right].$$

Substituting in the first order condition (15) and using the fact that $\mathbf{P}_A = 2\mathbf{P}_C$ provides an optimal price of:

$$(23)\quad p_C = c + \frac{2}{\dfrac{1 - 2\mathbf{P}_C}{\mu} + \dfrac{1}{\mu_C}}$$

and a share of demand which is written:

$$(24)\quad \mathbf{P}_C = \left[2 + 2\exp\left(\frac{u_0 - u_A}{\mu}\right)\right]^{-1}.$$

This finally yields:

$$(25)\quad \mathbf{P}_C = \left[2 + \exp\left(\frac{u_0 - \phi + (\mu - \mu_C)\ln 2 + p_C}{\mu}\right)\right]^{-1}$$

as $u_A = \mu_C \ln \sum_{j=1,2} \exp[(\phi - p_j)/\mu_C] = \mu_C \ln 2 + \phi - p_C$. Note that the outside alternative always attracts a non-zero share of demand, which guarantees that $\mathbf{P}_C$ is always strictly lower than 1/2 and, together with the assumption that compatible goods are closer substitutes than incompatible ones ($\mu_C < \mu$), also ensures that the price in equation (20) is well defined. (Indeed $(\mu_C + \mu)/2\mu_C > 1$ and $\mathbf{P}_C < 1/2$).

Let individual profit under compatibility be denoted π_C. The comparison between π_I and π_C is postponed until the next subsection in which the first period compatibility game is discussed. We briefly examine equilibrium prices and quantities in both regimes. When $(\mu - \mu_C)\ln 2 < \phi$ the r.h.s. of equation (21) is larger than the r.h.s. of equation (14). Thus when the loss of product differentiation is small compared to the compatibility premium, the implicitly defined market share is larger under compatibility, *i.e.,* $\mathbf{P}_C > \mathbf{P}_I$. However, from expression (20), the impact of an increase of sales on the price of compatible goods is not easy to evaluate. When $(\mu - \mu_C)\ln 2 \geqslant \phi$ the effect of compatibility on both output and price is ambiguous. Note that when compatibility does not affect differentiation ($\mu_C = \mu$), both the equilibrium output and the equilibrium price are larger under compatibility.

As for the compatibility premium, using the implicit function theorem we see that:

$$(26) \qquad \frac{\partial \mathbf{P}_C}{\partial \phi} = \frac{\mathbf{P}_C (1 - 2\mathbf{P}_C)[\mu + \mu_C (1 - 2\mathbf{P}_C)]^2}{\mu\left[(\mu + \mu_C)^2 - 4\mu_C \mathbf{P}_C (\mu_C \mathbf{P}_C + \mu)\right]} > 0,$$

ie, the output of compatible firms monotonically increases with the compatibility premium. (To see why $\partial \mathbf{P}_C / \partial \phi > 0$, note that as $\mathbf{P}_C < 1/2$, the expression $(\mu + \mu_C)^2 - 4\mu_C \mathbf{P}_C (\mu_C \mathbf{P}_C + \mu)$ takes its smallest value at $\mathbf{P}_C = 1/2$, and this value is $\mu^2 > 0$). Having defined equilibrium prices and outputs, we are able to analyze the first stage of the sequential game.

3.3 Compatibility *vs* Differentiation

We now investigate the outcome of the compatibility game given optimal decisions in the second stage of the game. The structure of the model is such that firms face a tension between product differentiation and consumers' willingness to pay for compatibility.

According to the equilibrium condition (10), firm i ($i = 1,2$) chooses compatibility at the sub-game perfect *Nash* equilibrium if and only if $\hat{\pi}_i(C, s_j^*) \geqslant \hat{\pi}_i(I, s_j^*)$ for $j \neq i$. Moreover, since the game is symmetric, there are no conflicts between firms incentives toward compatibility.[10] Hence, both firms choose compatibility at equilibrium if and only if compatibility yields the highest individual profit, *ie,* $\pi_C \geqslant \pi_I$.

To begin with, assume there is no compatibility premium, *ie,* $\phi = 0$. In this case firms' trade-off is between charging high prices and selling high quanti-

10. Contradictory incentives typically occur when firms are asymmetric, as in the vertical differentiation framework of DE PALMA and LERUTH [1996] and ECONOMIDES and FLYER [1998].

ties, as moving from incompatibility to compatibility increases competition and the overall demand is elastic. We get the following result.

PROPOSITION 3. *When demand is described by a nested multinomial Logit and there is no compatibility premium, the unique equilibrium of the game has both firms supplying incompatible goods.*

PROOF : Equation (21) can be rewritten:

$$\pi_C = (p_C - c)N\mathbf{P}_C = \frac{\mu N \mathbf{P}_C}{(\mu_C + \mu)/2\mu_C - \mathbf{P}_C}. \tag{27}$$

Differentiating the previous expression with respect to μ_C gives:

$$\frac{\partial \pi_C}{\partial \mu_C} = 2\mu N \frac{\mu_C (\partial \mathbf{P}_C/\partial \mu_C)(\mu_C + \mu) + \mu \mathbf{P}_C}{[\mu + \mu_C (1 - 2\mathbf{P}_C)]^2}. \tag{28}$$

Now using the implicit function theorem, we show that:

$$\frac{\partial \mathbf{P}_C}{\partial \mu_C} = -\frac{\mathbf{P}_C (1 - 2\mathbf{P}_C)\left[2\mu^2 - \ln 2 \cdot (\mu_C + \mu - 2\mathbf{P}_C \mu_C)^2\right]}{\mu\left[(\mu + \mu_C)^2 - 4\mu_C \mathbf{P}_C (\mu_C \mathbf{P}_C + \mu)\right]}. \tag{29}$$

The sign of the numerator of (29) is ambiguous, as the amount of differentiation across compatible variants affects both the intensity of price competition between firms and the variety of products embodying the industry standard. However, equations (29) and (28) finally yield:

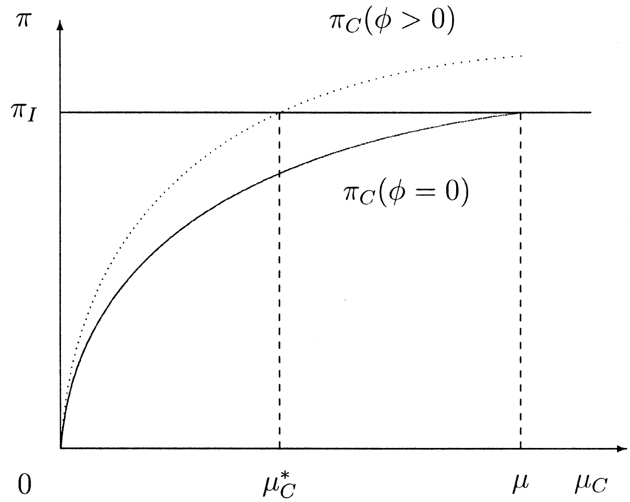
$$\frac{\partial \pi_C}{\partial \mu_C} = 2N\mathbf{P}_C \cdot \frac{\ln 2 \cdot \mu_C (1 - 2\mathbf{P}_C)(\mu + \mu_C)[\mu + \mu_C (1 - 2\mathbf{P}_C)] + \mu^2 [\mu - \mu_C (1 - 2\mathbf{P}_C)]}{[\mu + \mu_C (1 - 2\mathbf{P}_C)] \cdot \left[(\mu + \mu_C)^2 - 4\mu_C \mathbf{P}_C (\mu_C \mathbf{P}_C + \mu)\right]}. \tag{30}$$

Clearly all terms at the numerator are positive since $\mathbf{P}_C < 1/2$ (in the most favorable case $u_0 \to -\infty$, and the two firms attract the whole demand, *ie,* $2\mathbf{P}_C \to 1$). From the previous paragraph we know that $(\mu + \mu_C)^2 - 4\mu_C \mathbf{P}_C (\mu_C \mathbf{P}_C + \mu) > \mu^2$. Hence $\partial \pi_C / \partial \mu_C > 0$ for any μ_C and so profits monotonically rise with μ_C. As $\pi_C = \pi_I$ when $\mu_C = \mu$, we necessarily have $\pi_C < \pi_I$ for $\mu_C < \mu$, thus product incompatibility is the unique equilibrium for the game: the losses from increased competition offset the benefits from larger sales.

The situation is illustrated by the solid curve in Figure 3. The profits of compatible producers rise with the level of product differentiation, starting from zero when goods are perfect substitutes ($\mu_C = 0$) and competition bids prices down to the marginal cost, and rising till the point where $\mu_C = \mu$.

FIGURE 3

Profits for compatible firms as functions of μ_C with (dotted curve) and without (solid curve) compatibility premium



Proposition 3 shares some similarities with traditional differentiation results (*eg,* D'ASPREMONT *et al.* [1979]), according to which firms differentiate their products in order to relax competition. In our model, firms wish to be incompatible (which amounts to differentiating their products) even though overall demand is price-elastic. We now turn to the case in which consumers attach a strictly positive value to product compatibility.

When there is a positive compatibility premium ($\phi > 0$), the compatibility-then-price game has a less immediate outcome. The output $N\mathbf{P}_C$ of compatible firms is larger than in the absence of a compatibility premium, their profit π_C increases with the level of differentiation μ_C and when $\mu = \mu_C$, one has $\pi_C > \pi_I$ as both the equilibrium output and the equilibrium price are larger under compatibility (see previous subsection). The dotted curve in Figure 3 depicts firms profits as μ_C is varied, for non-zero ϕ. Compatibility now has a positive influence on consumers' willingness to pay for the goods, leading to the following result.

PROPOSITION 4. *For any positive value of the compatibility premium ϕ, there exists a cutoff value of μ_C, denoted μ_C^*, such that the sub-game perfect Nash equilibrium of the compatibility-then-price game entails incompatibility when $\mu_C < \mu_C^*$ and compatibility when $\mu_C > \mu_C^*$. Formally, $s_1^* = s_2^* = I$ when $\mu_C < \mu_C^*$ and $s_1^* = s_2^* = C$ when $\mu_C > \mu_C^*$.*

PROOF : It suffices to note that for any positive ϕ, we know from the previous proposition that the profit π_C of compatible firms monotonically increase with μ_C, up to a value that strictly exceeds π_I when $\mu_C = \mu$. Hence, there is a unique value of μ_C, denoted μ_C^* (with $\mu_C^* < \mu$), such that $\pi_I = \pi_C$. Above μ_C^* compatibility is the equilibrium strategy, whereas incompatibility prevails when $\mu_C < \mu_C^*$.

An immediate corollary of this proposition is that for any pair (μ,μ_C) satisfying $\mu_C < \mu$, there exists a cutoff value of ϕ above which compatibility is observed at the unique sub-game perfect *Nash* equilibrium. Standardization in this model is achieved provided the valuation of compatibility by consumers dominates the increase in competition stemming from weaker product differentiation. Conversely, incompatibility occurs when the loss in horizontal differentiation is too high with regard to consumers' valuation of compatibility. Whether the market provides enough or too much standardization with regard to the social optimum is investigated in the next section.

4 Welfare Analysis

The multinomial Logit offers a convenient framework for welfare analysis. According to Ben-Akiva and Lerman [1979], the surplus of an individual consumer is the expected value of the maximum utility level over the set of alternatives (see also equation (6)). As this expected value is the same for any consumer, net consumers' surplus (we abstract form consumers' income) is written:

$$S = N\mu \ln \sum_{k\in K} \exp\left(\frac{u_k}{\mu}\right), \tag{31}$$

where,

$$K = \begin{cases} \{0, A, B\} \text{ if goods are incompatible,} \\ \{0, A\} \text{ if goods are compatible.} \end{cases} \tag{32}$$

Evaluating welfare at the symmetric equilibrium when incompatibility prevails yields:

$$W_I = N\mu \ln\left[\exp\left(\frac{\mu \ln 2 - p_I}{\mu}\right) + \exp\left(\frac{u_0}{\mu}\right)\right] + 2\,(p_I - c)\,N\mathbf{P}_I, \tag{33}$$

where the first term stands for net consumers' surplus and the second one for firms profits. Similarly, welfare at the symmetric equilibrium when compatibility prevails is written as:

$$W_C = N\mu \ln\left[\exp\left(\frac{\mu_C \ln 2 + \phi - p_C}{\mu}\right) + \exp\left(\frac{u_0}{\mu}\right)\right] + 2\,(p_C - c)N\mathbf{P}_C. \tag{34}$$

Product compatibility has a indirect influence on consumers' surplus, via the price which is charged, and two contrary direct effects: the compatibility premium increases surplus, but reduced product variety ($\mu_C < \mu$) affects consumers' surplus negatively.

The price equilibrium is only implicitly defined, which makes the analytical comparison of W_I and W_C difficult. Yet, the following numerical experiment

TABLE 1
Social welfare and private incentives in three different configurations

μ_C	Compatibility valuation					
	$\phi = 0$		$\phi = 1$		$\phi = 5$	
	W_C/W_I	π_C/π_I	W_C/W_I	π_C/π_I	W_C/W_I	π_C/π_I
10	**1.00**	**1.00**	1.07	1.07	1.37	1.36
9	0.97	0.94	1.04	**1.00**	1.34	1.28
8	0.95	0.88	**1.01**	0.94	1.31	1.20
7	0.93	0.82	0.99	0.87	1.28	1.11
6	0.90	0.75	0.97	0.80	1.26	**1.01**
5	0.88	0.67	0.95	0.72	1.23	0.90
4	0.86	0.58	0.93	0.62	1.20	0.78
3	0.84	0.48	0.90	0.51	1.17	0.63
2	0.82	0.35	0.88	0.37	1.14	0.46
1	0.79	0.20	0.85	0.21	1.11	0.25

illustrates the potential inefficiency of the equilibrium outcome. Setting $c = 0$, $u_0 = 0$, $\mu = 10$ and $N = 100$, we vary the parameters defining the private incentives toward compatibility, namely μ_C and ϕ. Table 1 summarizes the equilibrium profit and social welfare under both regimes, when $\phi = 0,1,5$ and $\mu_C = 1,\ldots,10$.

For each ϕ-value, the first column of Table 1 depicts the ratio W_C/W_I of the welfare when compatibility is achieved over the welfare associated with incompatibility, whereas the second column depicts the ratio π_C/π_I of firms' profits under both regimes. The reference values are $W_I \simeq 915.03$ and $\pi_I \simeq 226.76$. It is easily seen that ϕ exerts a positive influence upon firms' profit and consumers' surplus. Increasing product substitutability (diminishing μ_C) decreases firms' profit down to the point where incompatibility is the optimal choice. Decreasing μ_C further even makes incompatibility socially preferable. This yields the following result.

PROPOSITION 5. *As soon as consumers have a non-zero valuation of compatibility, the equilibrium outcome might be socially suboptimal. The market then provides an insufficient amount of standardization.*

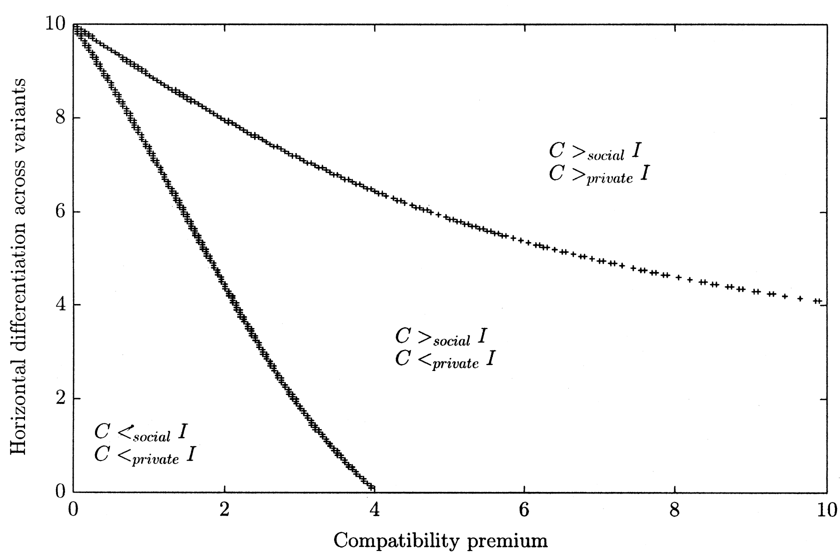
When consumers do not valuate compatibility ($\phi = 0$), the equilibrium and the social optimum coincide and they entail incompatibility. By contrast, as soon as the value attached to compatibility is non-zero, private and public incentives toward compatibility might not coincide as evidenced by Table 1. In this case there is not enough standardization with regard to the social optimum. While under-provision of compatibility is a rather traditional result (*eg,* KATZ and SHAPIRO [1985]) the underlying argument here is different: increased product substitutability stemming from compatibility prevents firms from reaping the associated consumers surplus.

In Figure 4 we give a more complete picture of the tension between private and social incentives toward compatibility.[11] We plot the (ϕ, μ_C)-pairs such that either W_C / W_I or π_C / π_I is equal to 1 (or both are). The same parameter values as in Table 1 were used, and we considered increments of 0.05 for the compatibility premium, which was varied from 0 to 10. For each of these values we computed the amount of product differentiation corresponding to identical private incentives ($\pi_C / \pi_I = 1$) under both regimes (this value we denoted μ_C^* in Proposition 4), and identical social benefits ($W_C / W_I = 1$). The upper curve in Figure 4 separates the (ϕ, μ_C)-space in term of private incentives while the lower curve concerns social optimality.

As can be seen from this illustrative example, the cutoff value μ_C^* is a decreasing function of the compatibility premium. The lower curve is the value of μ_C such that social welfare is identical in both regimes. It is always below the cutoff value μ_C^*, except when $\phi = 0$ and compatibility does not generate any loss in terms of product differentiation. The equilibrium compatibility configuration is socially optimal if and only if π_C / π_I and W_C / W_I are both either larger or smaller than one. Above the upper curve, compatibility is preferred to incompatibility from both the social ($C >_{social} I$) and private standpoint ($C >_{private} I$). By contrast, below the lower curve, incompatibility is preferred to compatibility from both the social ($C <_{social} I$) and private ($C <_{private} I$) standpoints. In the area between the two curves both types of incentives do not coincide: $C >_{social} I$ but $C <_{private} I$. So we see that there can be less standardization than socially desirable, but no excess standardization. When the compatibility premium is large enough (larger

FIGURE 4

Private and social incentives in the (ϕ, μ_C)-space; conflicting incentives exist between the two curves



11. This exercice was suggested by one of the referees.

than 4 in our example), compatibility is always socially desirable but excessively large losses in terms of product differentiation still drive firms to prefer incompatibility.

So far, we have restricted attention to a symmetric compatibility premium. A natural extension is to let goods benefit from compatibility in an asymmetric manner. The conditional indirect utilities from purchasing compatible variant i then is $\widetilde{u}_i = R + \phi_i - p_i + \varepsilon'_i$, with $\phi_1 \neq \phi_2$. Assume for instance consumers of good 1 value compatibility more than consumers of good 2, *ie,* $\phi_1 > \phi_2$. This is equivalent to saying that variant 1 is of higher quality than variant 2. This we know to produce asymmetric equilibria with a higher price, output and profit for firm 1 (see ANDERSON *et al.* [1992, chapter 7]). In turn this implies that firm 1 is more eager to supply a compatible product than firm 2. Hence there will be situations in which firm 1 wants compatibility, but firm 2 does not. Compatibility then does not take place – unless no consensus is required to achieve compatibility. Only when both firms gain by adhering to a common standard will standardization occur, *ie,* only when the compatibility premium exceeds the loss in differentiation for firm 2.

5 Conclusion

Several well-documented case-studies have shown the existence of a significant compatibility premium in consumers' valuation of network goods. Everything else equal, firms therefore should produce compatible goods in order to charge higher price. But compatibility also decreases product differentiation, as compatible variants are perceived by consumers as (and present a number of common features that in effect makes them) closer substitutes. Hence, for firms the trade-off is between increasing the value of the good supplied (therefore benefitting from the elasticity of residual demand) and renouncing part of their monopoly power. Several forms of this trade-off have received attention in the literature, but in the present paper we have given an explicit account of both the existence of distinct levels of product differentiation across the product hierarchy and the compatibility premium.

This we have modelled in a two-stage game in which firms first choose to make their product compatible with that of the other firm, and then compete in price. Resorting to a two-stage game endogenizes the compatibility decision as in DE PALMA and LERUTH [1996], CHOU and SHY [1990, 1996], ECONOMIDES and FLYER [1998] or CHURCH and GANDAL [1992]. However we depart from the framework of these authors (*Cournot* competition *à la* KATZ and SHAPIRO [1985]) by considering a discrete choice model and price competition. The demand structure we employ is a nested multinomial Logit, a functional form which is often used in empirical micro-economics and lends itself pretty well to the study of contexts in which people have different tastes and preferences. We have modelled how compatibility simultaneously increases consumers' valuation of compatible goods and changes product substitutability, so that two nested levels of differentiation coexist. It was shown that when consumers do attach a value to product compatibility, firms' compatibility decisions are the outcome of a trade-off between higher product quality and accrued price competition. In turns out that compatibility is achieved at equilibrium provided the amount of product differentiation among compatible goods remains above a cutoff value.

Even though the model does not yield explicit solutions to the price subgame, some insights into the welfare implications of compatibility decisions could be given. Especially, we have shown that the equilibrium outcome can be socially suboptimal when consumers valuate compatibility and compatibility entails a high loss in product differentiation. While welfare maximization would call for product compatibility, firms prefer to make their products incompatible in order to prevent price competition from being too tough. Under-provision of compatibility is a fairly standard result in the literature (see the discussion in the introduction), though here we neither rely on asymmetries between firms (De Palma and Leruth [1996]; Economides and Flyer [1998]) nor on compatibility costs (Katz and Shapiro [1985]), but rather on the interplay between compatibility and product variety.

Compatibility in our framework was either total or absent. It would probably be worth considering intermediate cases in which firms would set the degree of compatibility of the product they sell before competing. This would require a careful definition of partial compatibility, and the compatibility relationship itself, a direction which has not been very much investigated so far. ▼

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APPENDIX

The Multinomial Logit

In this Appendix, we give a brief presentation of the multinomial Logit which follows that of ANDERSON, DE PALMA and THISSE [1992, chapter 2]. The multinomial Logit is a discrete choice model. We consider a population of heterogenous individuals choosing among the same set of mutually exclusive alternatives indexed with $i = 1,\ldots,n$. Each individual has a deterministic utility function U defined on the set of alternatives, which is decomposed into two parts: a function u defined over observable or measurable characteristics, and the difference e between U and u. The utility derived from alternative i is written $U_i = u_i + e_i$. It is assumed that each individual differs from the others with respect to the unobservable characteristics and factors influencing his choice. Therefore, the valuation e_i can be represented by a random variable ε_i with zero mean (otherwise the mean of ε_i can be added to u_i) and the utility of individual i is modeled by the random variable $\widetilde{u}_i = u_i + \varepsilon_i$. The observable utility u_i reflects the preference of the population for the ith alternative while ε_i accounts for idiosyncratic taste differences across members of the population. The probability that a randomly selected individual chooses alternative i is then given by:

(35) $$\mathbf{P}_i = \Pr\{\widetilde{u}_i = \max_{j=1,\ldots,n} \widetilde{u}_j\}, i = 1,\ldots,n,$$

therefore satisfying the principle of maximization of individual utilities. The Logit model obtains when the ε_is are identically independently distributed according to the double exponential distribution:

(36) $$F(x) = \Pr\{\varepsilon_i \leqslant x\} = \exp\{-\exp[-(x/\mu + \gamma)]\},$$

where γ is *Euler*'s constant ($\gamma \simeq 0.5772$) and $\mu > 0$. Let $f(x) = F'(x)$ for all x. From equation (35), the probability $\mathbf{P}_i$ that alternative i is chosen is written $\Pr\{\varepsilon_1 - \varepsilon_i \leqslant u_i - u_1,\ldots,\varepsilon_n - \varepsilon_i \leqslant u_i - u_n\}$, which, due to independency, is also equal to:

(37) $$\mathbf{P}_i = \int_{-\infty}^{+\infty} f(x) \prod_{j\neq i} F\left(u_i - u_j + x\right) dx$$
$$= \int_0^{+\infty} \exp(-y) \prod_{j\neq i} \exp\left[-y\frac{\exp\left(u_j/\mu\right)}{\exp(u_i/\mu)}\right] dy$$

with the change of variables $y = \exp[-(x/\mu + \gamma)]$. Integrating, the choice probabilities directly obtain in an exponential form similar to (3), (5) and (8), namely:

(38) $$\mathbf{P}_i = \frac{\exp(u_i/\mu)}{\sum_{j=1}^{n} \exp\left(u_j/\mu\right)}, i = 1,\ldots,n.$$

The double exponential distribution has mean zero and variance $\mu^2\pi^2/6$. For $\mu \to 0$, the variance of the ε_is tends to zero. All the information about preferences is contained in the u_is and the characteristics of the different alternatives are perfectly known so the utility-maximizing alternative(s) attract(s) the whole demand. By contrast, when $\mu \to \infty$ the u_is contain almost no information and choice is purely random, *ie,* $\lim_{\mu\to\infty} \mathbf{P}_i = 1/n$ for $i = 1,\ldots,n$. In a population of N statistically identical and independent individuals the distribution of choices is multinomial with expectation $N\mathbf{P}_i$ for $i = 1,\ldots,n$, which is a good approximation of the aggregate demand for sufficiently large N.