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One-Way Compatibility, Two-Way Compatibility and Entry in Network Industries

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One-Way Compatibility, Two-Way Compatibility and Entry in Network Industries.*

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Abstract

We study the strategic choice of compatibility between two initially incompatible network goods in a two-stage game played by an incumbent and an entrant firm. Compatibility may be achieved by means of a converter. We derive a number of results under different assumptions about the nature of the converter (one-way *vs* two-way) and the existence of property rights. In the case of a two-way converter, which can only be supplied by the incumbent, incompatibility will result in equilibrium. When both firms can build a one-way converter and there are no property rights on the necessary technical specifications, the unique equilibrium involves full compatibility. Finally, when each firm has property rights on its technical specifications, full incompatibility and preemption are again observed at the equilibrium. With incompatibility, entry deterrence occurs for sufficiently strong network effects. The welfare analysis shows that the equilibrium compatibility regime is socially inefficient for most levels of the network effects.

J.E.L. codes: L13, L15, D43.
Keywords: Network externalities, one-way compatibility, two-way compatibility, entry, invitations to enter.

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1 Introduction

The two related issues of compatibility and network externalities have, recently, drawn large attention in the economic literature. The existence of significant demand externalities is recognised in a number of markets. The essential feature of demand externalities is that the individual benefit from, and consequently individual willingness to pay for, consumption of the good (service) is increasing in the number of people consuming the same good (service) or a compatible one. There are many sources of externalities ranging from the presence of a physical network connecting consumers, as for telecommunications, to the case of a virtual network, as for computers' software and other goods for which a *community of interest* effect arises.

One interesting issue related to the presence of network externalities is that of the incentives of an exclusive holder of a technology to invite entry of competitors through licensing. With network externalities, competition brings two opposite effects: one is the standard competitive effect, which reduces the monopolist's profits, the other is the positive demand effect induced by an increasing network size as output expands. Which of the two prevails depends on a variety of factors, but crucially on the strength of the network effects.

The literature highlights cases of technologies and proprietary standards that failed to achieve a critical mass because the technology/standard was sponsored by a single firm lacking the power to impose it and it is often suggested that these firms should have instead invited entry by open license in the early stages of the market to let the new technology taking off[1].

At the same time, in a significant number of industries (software, media, videogames, hardware, payment systems), largely dominant firms own proprietary technologies and/or standards that are not licensed to competitors. Those niche competitors use their own technology which is incompatible with that of the dominant firm. Such incompatibility, which affects the size of each firm's relevant network, is not necessarily due to technical reasons, but it is rather a consequence of the strategic choices made by firms.

Recent research has shed new light on the incentives to invite entry by a monopolist offering new explanations for this mixed evidence. Kim (2002) shows, in contrast with previous literature, that a monopolist holder of a technology has never the incentive to licence competitors producing an homogeneous good no matter how strong network effects are. Entry is invited when competitors

[1] See Economides (1996a). Licensing is a way to avoid lack of credibility by a monopolist; other reasons for licensing, absent network externalities, are discussed in the literature, see Shepard (1987), Farrell and Gallini (1988) and Ausubel and Denekere (1987) where it is shown that inviting rivals can help the monopolist to solve the problem of the well known Coase's conjecture.

produce differentiated goods and the network externality is weak. The reason behind this result is that in the case of an homogeneous good, the monopolist can always replicate the oligopoly outcome costlessly. With product differentiation this is no longer true since new varieties are costly to introduce. The model used by Kim (2002) is that of Economides (1996a) and assumes standard one-period Stackelberg leadership or Cournot competition.

The interpretation we put forward in this paper rests on the strategic role of the installed base of an incumbent firm. Network effects induce different incentives towards compatibility on established firms and entrants. For an established firm, the network formed by its installed base of consumers conveys an advantage on late comer rivals, therefore, it is a valuable asset to defend and one way of achieving this is by maintaining incompatibility with the entrant. On the other hand, for late comers compatibility with the incumbent's network may be the only way to gain significant market share. Examples of this kind of situation abound. In the videogame industry, Nintendo was dominant in the 32-bit system and denied Atari the permission to include an adapter to play Nintendo cartridges on Atari's machines. In the spreadsheet market, Bordland designed its Quattro Pro spreadsheet so that it could import Lotus files and also copied the menu structure used by Lotus, the then dominant player with its Lotus 1-2-3. In reaction Lotus sued Bordland for copyright infringement.

As illustrated in Shapiro and Varian (1999), one common tactic used by entrant firms facing an incompatible incumbent is to add an adapter/converter or to somehow interconnect with the established technology.

We analyse the conflicting incentives that incumbent and entrant firms face when deciding whether or not to make their good compatible with the one produced by the rival by means of a converter, under a variety of assumptions about the nature of the converter and the existence of property rights.

We build a model in which there is an incumbent firm which produces a durable good subject to network externalities. In period 1 the firm is the only producer and it faces entry in the second period by a potential entrant who supplies an homogeneous good which incorporates a different technology. The assumption of homogeneity of the goods allows us to concentrate on the effects of compatibility choices and of installed bases of users on the pattern of entry and on the feasibility of entry deterrence. Conceptually, the installed base of a network good serves the same purpose of irreversible investment in physical capacity for the incumbent. Whereas, absent switching costs, output decisions have no commitment value, in the presence of network externalities and incompatibility, the incumbent can strategically choose the level of first period output in order to reduce the rival's scale of entry or to preempt it altogether.

We explore different scenarios concerning the way compatibility is achieved.

In particular we consider the following three cases:

1. Compatibility through two-way converters supplied either by the incumbent or the entrant;

2. Compatibility through one-way converters supplied by the incumbent and the entrant;

3. Compatibility through one-way converters supplied by the incumbent and the entrant subject to disclosure of each other technical specifications.

In the first case, one of the two firms may produce, at no cost, a two-way converter which induces perfect compatibility between the two network of users. If the converter is supplied by the incumbent then this scenario is equivalent to the case, widely studied in the literature, of licensing where the incumbents invites entry. In the second case, each firm can freely design a converter which allows its customers to communicate with the customers of the rival firm. Finally, in the third scenario, firms have the possibility to deny to the rival the technical specifications needed to build any converter.

Examples of each of the three scenarios can be easily found. A two-way converter corresponds to the ability, provided by many softwares, to read and save in the rival's format. In text processing, for example, Word allows to read and save in WordPerfect's format. The unilateral provision of this feature allows users of both softwares to communicate and therefore the relevant installed base for each software becomes the entire population of text processing softwares. Adobe Acrobat allows both reading and saving in postscript format. In the streaming media industry both Apple's QuickTime and Microsoft Windows Media Player can playback and save in each other proprietary format (.mov and .wav respectively) and in the other common format MPEG (Moving Picture Experts Group) whose development is supervisioned by the The Internet Streaming Media Alliance (ISMA), a non-profit corporation formed to provide a forum for the creation of specification(s) that define an interoperable implementation for streaming rich media (video, audio and associated data) over Internet Protocol (IP) networks. When the two-way converter is provided by the incumbent, this scenario encompasses as a particular case, that of licensing with the established firm inviting entry of a fully compatible rival.

Examples of one-way converters can take different forms. Software may allow reading but not saving in a different format or viceversa. It is interesting to note the difference between these two cases. If software A allows reading but not saving files produced with software B, then users of the former can read files from the latter but cannot exchange their files with the users of software B. In the opposite case things are reversed. As mentioned above, Bordland Quattro Pro allowed to import files generated with Lotus 1-2-3 but not to save files in Lotus format. In the late 80's, in the hardware industry Apple Computers installed the so called "Hyperdrive" diskette drive which was able to read DOS-formatted diskettes used on Intel-based PCs. Thanks to this device, Mac users were able to read files produced on Intel-based computers but files placed on Macintosh-formatted diskettes were not readable on DOS machines.

Recent examples of one-way converters include the so-called *viewers* introduced by a number of commercial software vendors. These are a downgraded free version of their main software that allows non-users to view and print files prepared with their software. These viewers induce the same result produced by a converter which allows saving in but not reading a different format, the only difference being that the *transaction cost of conversion* rests on the users of the other software[2]. An additional advantage of *viewers* over converters for software vendors is that they do not have to cope with a variety of different formats and to depend on the disclosure of technical specifications by the rivals.

The story of Nintendo *vs* Atari mentioned above better illustrates the third scenario. Atari tried to achieve one-way compatibility but lacked the intellectual property rights to include an adapter in its machines to play Nintendo cartridges.

Quite surprisingly, although the literature about entry, compatibility and standardisation in network industries is well developed,[3] it focuses mainly on the analysis of two-way compatibility, usually introduced via the construction of a two-way adapter, or the disclosure of technical specification by the incumbent firms which invite entry of new competitors through licencing[4]. In the seminal paper by Katz and Shapiro (1985), firms may achieve full (two-way) compatibility through an adapter which can either be built unilaterally by a single firm or be the outcome of a multilateral agreement to define a common standard. Incentives to build the adapter are found to depend strongly on sizes of the firms' networks.

De Palma and Leruth (1996), and Economides and Flyer (1997) analyse compatibility decisions under Cournot competition using the network size as the only vertical dimension of product differentiation. Economides and Flyer (1997) apply the theory of coalition formation to standardization processes

[2]Examples of such viewers are Word Viewer, PDF Viewer, Excel Viewer.

[3]See Matutes and Regibeau (1996) and Economides (1996b) for excellent surveys.

[4]The strategic use of one-way compatibility by providers of network goods is briefly mentioned in Shy (2001).

and show that firms belonging the leading coalition (the dominant technology with greatest sales) have less incentive to make their standard available to others as network effects gets stronger. They also show that incompatibility (i.e. each firm adopting its own standard) is the equilibrium structure of the market when externalities are sufficiently relevant. De Palma and Leruth (1996) use a duopoly setting to show that the firms agree on compatibility in a preliminary stage of the game when there is sufficient uncertainty about which of them would become the dominant firm. Farrell and Saloner (1992) discuss the incentive for a dominant firm to refuse the disclosure of its proprietary technical information to a rival firm wishing to build an adapter. The adapter allows one group of users to benefit the network externalities enjoyed by a second group and the paper discusses under which circumstances the dominant firm is willing to raise the rival's cost of building the converter.

Baake and Boom (2001) extend this literature by introducing quality as an additional dimension of vertical differentiation, network size being the other. They analyse a four-stage model where two firms first choose the quality of their products and then they choose whether to install a two-way converter in order to achieve compatibility. Because of property rights on the technical specifications, neither firm can act unilaterally. Finally, firms compete on prices. In equilibrium, firms choose different qualities and full compatibility is always achieved.

While these analyses perfectly apply to networks such as telecommunications where compatibility between firms can only be two-way and where once interconnection between networks is established then customers can freely communicate with each other irrespective of the carrier they belong to, they cannot represent the rich set of situations that frequently occur in many network industries; the scope of the paper is to shed new light on the strategic compatibility choices of an incumbent firm which owns a proprietary technology and which faces potential entry by a rival when the bridge between the two competing technologies is not restricted to full compatibility but, as suggested by the wide set of examples provided above, can also take the different form of one-way compatibility.

We derive the following results. The equilibrium in the compatibility game depends on the type of converter available to the competing firms to make their technologies compatible. When compatibility can only be two-way, incompatibility is always observed in equilibrium. This scenario is equivalent to the case of an incumbent firm deciding whether or not invite entry through licensing; our results closely resemble that of Kim (2001, 2002), with the incumbent that never invites entry of a compatible rival. We get the opposite result when the incumbent and the entrant can freely decide to build a one-way converter. In this case, full compatibility is the equilibrium. Finally, when each firm, in order to design the one-way adapter, needs access to the rival's technical information, then the equilibrium is again full incompatibility. This is exactly what happened in the videogame industry, where Nintendo did not disclose its proprietary technical specification about its technology, thus preventing Atari to construct the adapter.

Under the first and the third scenario, the incumbent firm may actually deter entry if network effects are sufficiently strong. The incumbent's installed base of customers acts as an entry barrier for an incompatible entrant.

This set of results has interesting policy implications that we explore in the last part of the paper where we develop a welfare analysis. We show that depending on the compatibility regime taken into account, market forces may lead to inefficiency. Since Katz and Shapiro (1985) and Katz and Shapiro (1986), the presence of market failures in industries with network externalities is a well known result. The novelty of the paper is that inefficiency also depends on the type of compatibility (one-way vs two-way). The analysis of welfare ends with some useful policy considerations.

The paper is organised as follows: section 2 presents the basic framework, section 3 describes the game and the firms' payoffs; the strategic analysis of compatibility is given in section 4. The welfare analysis is carried out in section 5.

2 The model

The model has two periods: in the first period a single firm serves the market and builds an installed base of customers; in the second period entry by a rival firm may occur and firms compete on quantities. We explore three different scenarios concerning the way compatibility is achieved:

1. Compatibility through two-way converters supplied either by the incumbent or the entrant;

2. Compatibility through one-way converters supplied by the incumbent and the entrant;

3. Compatibility through one-way converters supplied by the incumbent and the entrant subject to disclosure of each other technical specifications.

The possible outcomes for the three scenarios are 4 in total: *i*) full compatibility between the entrant and the incumbent (two-way compatibility), *ii*) full (two-way) incompatibility, *iii*) the incumbent is one-way compatible with the entrant and *iv*) the entrant is one-way compatible with the incumbent.

With full compatibility, users of the two technologies communicate perfectly and the relevant network size is given by the total number of users; if incumbent and entrant are fully incompatible then each technology has its own relevant network equal to the number of users adopting it. Finally, with one-way compatibility the users of the compatible technology can communicate with the users of the rival technology but not viceversa. Therefore, the relevant network for the compatible technology is the total number of users, while the relevant network for the incompatible technology is given by the number of users adopting it.

2.1 Consumers

Each consumer buys at most one unit of the good which is durable. Consumers base their purchase decisions on expected network sizes. The population of consumers P is uniformly distributed along the interval $[-\infty, A]$, with $A > 0$, according to the individual *basic* willingness to pay r[5].

Following Katz and Shapiro (1985), the network externalities are captured by a function V of the expected size of the network that a consumer is deciding to join so that, for given expectations the *total* willingness to pay for a consumer of type r' is given by a $r' + V$. We assume that the function V is monotonically increasing in the expected size of the network; specifically we assume that $V' > 0 \quad \text{e} \quad V'' \leq 0$.

We define $\hat{x}_I^1$ as the expected network size of the incumbent in period 1 (i.e. the total number of expected sales in the first period). In the second period, if entry occurs, consumers, prior to their purchasing decision, observe Firm 1's realised output in period 1 (i.e. Firm 1' installed base) and form expectations about the network size of the two firms. Expectations on firms' network dimension are related to the form of compatibility (two-way vs one-way compatibility) adopted by each firm. We denote with $\hat{y}_i$ the expected network size of firm i, $i = I, E$, in period 2 with:[6]

$$\begin{aligned} \hat{y}_I &= x_I^1 + \hat{x}_I^2 + \mu \hat{x}_E^2 \\ \hat{y}_E &= \hat{x}_E^2 + \phi(\hat{x}_I^2 + x_I^1) \end{aligned} \tag{1}$$

where $\hat{x}_i^2$ represents the expected number of consumers purchasing the good from firm i in period 2.

[5] The support of r has no finite lower limit to avoid corner solutions where all consumers enter the market. The assumption of a uniform distribution yields linear demand functions.

[6] Henceforth E and I are used to denote the entrant and the incumbent respectively.

When the incumbent and the rival technologies are fully compatible then $\mu = \phi = 1$; in this case, users' expectations about network sizes are equal to the sum of the two firms expected sales. When technologies are fully incompatible ($\mu = \phi = 0$) expectations are formed with respect to each firm total expected sales.

One-way compatibility represents the intermediate case, formally when $\mu = 1$, $\phi = 0$ or $\mu = 0$, $\phi = 1$, in which only one firm is compatible with the other and not viceversa: for example if $\mu = 1$ and $\phi = 0$, the incumbent firm, by means of an adapter or an hardware interface, is compatible with the rival technology while the opposite is not true. In this case, since users of the incumbent product can freely communicate with rival's users they form their expectations on the total amount of output sold while the same is not true for those who adopt the entrant's technology. In other words, if the variety produced by the incumbent is compatible with that produced by the entrant, $\hat{y}_I$ contains the installed base of this latter.

2.2 Firms

In period 1 the incumbent is the only active firm; in period 2 entry by a second firm might occur and the two firms compete *à la* Cournot. The two firms incur constant marginal cost (which we normalize to zero) and there is no other fixed cost. The two goods produced are homogeneous, in the sense that for equal expected network sizes and prices, the consumers are indifferent between the two.

We can think of the two goods as performing the same tasks or being equivalent in all characteristics but incorporating different technologies (word processors, spreadsheets and many other software packages share this property). We do not explicitly model why technologies differ; indeed, the focus of our analysis is not on the introduction of new technologies by new entrants, but rather, by assuming exogenously given technological differences, we concentrate on the strategic use of converters/emulators/plug-ins to obtain compatibility.

When firms set their outputs, they take consumers expectations as given. This assumption is common in the literature, and implies that firms cannot affect consumers' expectations because they cannot credibly commit to a certain level of output.[7]

[7] See Katz and Shapiro (1985) and Economides (1996b) among others.

2.3 Demand

2.3.1 Demand in period 1

In the first period, consumers are confronted with a binary decision: buy in $t = 1$ or wait until $t = 2$. They take their first period consumption decisions rationally so as to maximise total expected net surplus over both periods.

Let $CS_I^1 = r + V(\hat{x}_I^1)$ be the expected first period gross surplus of type r consumer who buys from the incumbent, and let $CS_i^2 = r + V(\hat{y}_i)$ be the expected gross surplus from belonging to network $i = I, E$ in period 2. A consumer behaving rationally buys in period 1 if and only if the following two conditions are satisfied:

$$CS_I^1 - p_I^1 + CS_I^2 \geq 0 \tag{2}$$

$$\geq 0 + CS_i^2 - p_i^2 \qquad i = I, E \tag{3}$$

where p_i^t is the price of firm i's good at time t. The first condition ensures that buying in period 1, the consumer enjoys positive total net surplus over the two periods; the second ensures that buying in $t = 1$ is better than buying in $t = 2$.

Given the homogeneity of the products, if entry occurs, in duopoly equilibrium at time $t = 2$ with both firms active, the consumer must be indifferent between buying from the incumbent or the entrant; this implies that:

$$p_I^2 - V(\hat{y}_I) = p_E^2 - V(\hat{y}_E) \tag{4}$$

Therefore expressions (2) and (3) become[8]:

$$r \geq \frac{1}{2}\left[p_I^1 - V(\hat{x}_I^1) - V(\hat{y}_I)\right] \equiv \varphi \tag{5}$$

$$r \geq -V(\hat{x}_I^1) + p_I^1 - p_I^2 \equiv \psi \tag{6}$$

It turns out that, in equilibrium we need to consider the second constraint only. Which of the two constraints is binding in equilibrium depends on the sign of $p_I^2 - p_I^1/2 - \left[V(\hat{y}_I) - V(\hat{x}_I^1)\right]/2$. If this is negative(positive) then the second(first) constraint is binding. Suppose for the moment that $p_I^2 > p_I^1/2 + \left[V(\hat{y}_I) - V(\hat{x}_I^1)\right]/2$. It is easy to show that second period demand for the incumbent is zero. This result is accomplished by the incumbent fixing the price p_I^2 sufficiently high. This pricing plan, as is well known from the literature around the Coase's Conjecture, is time inconsistent in that chocking second

[8] Expressions (2), (3) and (4), imply that consumers who bought in period 1 do not switch to the entrant's good in period 2.

period market is ex-post suboptimal for the monopolist. Since he has no way of committing himself to such course of action, consumers will not believe that the second period price will be set at a level sufficiently high. Therefore we can concentrate on the second condition.

The total number of consumers meeting this condition is $x_I^1 = A - \psi$; therefore the market clearing condition implies that the first period demand function with optimising agents is simply[9]:

$$p_I^1 = A + V(\hat{x}_I^1) + p_I^2 - x_I^1 \tag{7}$$

2.3.2 Demand in period 2

Second period demand is derived as a residual of first period demand given the realised first period output. From the necessary condition for two active firms in the second period given by (4), let $\eta = p_i^2 - V(\hat{y}_i)$ be the common level of *hedonic* prices. According to the assumption of uniformly distributed population and once recalled that x_I^1 consumers have already purchased the good in the first period, the number of consumers for which $r > \eta$ is equal to $A - x_I^1 - \eta$. Duopoly equilibrium implies the following market clearing condition

$$A - x_I^1 - \eta = x_I^2 + x_E^2 \equiv x_{tot}$$

which can be rewritten as

$$A - x_I^1 + V(\hat{y_I}) - p_I^2 = A - x_I^1 + V(\hat{y_E}) - p_E^2 = x_{tot} \tag{8}$$

where x_{tot} is the total output in the second period. It follows that second period demand functions are:

$$p_I^2 = A - x_I^1 + V(\hat{y_I}) - x_{tot} \qquad p_E^2 = A - x_I^1 + V(\hat{y_E}) - x_{tot} \tag{9}$$

In the following section we derive, by backward induction, the Cournot equilibrium in the second period and the incumbent's optimal output level in

[9]It is worth noting that only the expectations about the first period network dimension enter into the first period demand externality function. Although counterintuitive this has a clear explanation and it does not mean that consumers do not account for $\hat{y}_i$ when purchasing the good in the first period. Consider (2): the expected net surplus from buying in $t = 1$ naturally includes two gross surpluses: CS_I^1 and CS_I^2. Expectations on second period network size are in CS_I^2; when considering the balance between buying today or wait until the next period, which determines the demand in the first period, see (3), CS_I^2 cancels out with the analogous surplus obtained if the good is demanded in the second period. In other words, the additional benefit of the second period network externality on first period consumers valuations is enjoyed also when buying in the second period and it is therefore irrelevant when the first period decision has to be taken.

the first, contingent on the compatibility choices made by the firms. Given the assumption of exogenous expectations, there is a continuum of equilibria in both periods. We restrict the attention to the *fulfilled expectations* equilibria, namely those where the expected network sizes correspond to the actual ones.

3 The fulfilled expectations equilibrium

The equilibrium concept we use is that of *fulfilled expectations* equilibrium (FEE). In each period we restrict our attention to those equilibria which satisfy the condition that expected network sizes equal the actual ones. Ex-post consumers expectations' are correct.

The concept of FEE was first introduced in the literature on networks by Katz and Shapiro (1985) and has been widely adopted by other authors. The main advantage of FEE is that it restricts the number of possible equilibria and it may be interpreted as a long run equilibrium concept.

The assumption of FEE is also useful in this two stage game; consumers form expectations about second period networks, at the beginning of both periods: therefore we should have both first period and second period expectations about x_i^2. By restricting the equilibria to those that match expectations (in both periods), first and second period expectations must be identical at the equilibrium. For the sake of simplicity, we can therefore make no distinction between expectations formed at the beginning of the first and second stage. This clearly does not affect the solution of the game but makes the notation far less cumbersome.

Existence and uniqueness of the equilibrium cannot be generally granted and depend on the exact specification of the externality function $V(\cdot)$. In order to solve the model and to characterise the solutions, we need to specify the functional form of the externality function. We assume the following:

Assumption 1. *The externality function is linear:*

$$V(\hat{x_I}) = \theta \hat{x}_I \quad \textit{and} \quad V(\hat{y}_i^2) = \theta \hat{y}_i^2, \qquad \theta \in [0, \bar{\theta}]$$

The parameter θ measures the strength of network externalities: for given expectations on network dimension, a higher θ implies a higher willingness to pay to belong to that network. θ is bounded above; we will show that this is required to ensure existence, uniqueness and stability of the FEE[10]. The admissible upper bound $\bar{\theta}$ varies according to the kind of compatibility considered and it ranges between 0.704 and 1.

[10]Note that with a strictly concave externality function, the existence of FEE is more easily guaranteed, although additional assumptions are needed to ensure uniqueness.

3.1 FEE Payoffs

We are now ready to derive the FEE payoffs for the four possible outcomes of the game: full compatibility ($\mu = 1$, $\phi = 1$), full incompatibility ($\mu = 0$, $\phi = 0$) and partial compatibility (either $\mu = 1$, $\phi = 0$ or $\mu = 0$, $\phi = 1$).

3.1.1 Second period Cournot equilibrium

Conditional on entry and given consumers expectations, in the second period firms compete on output. Firms face the demand function (9); given the first period incumbent's installed base x_I^1, firm's j maximisation problem is therefore:

$$\max_{x_j^2} \quad \pi_j^2 = (A - x_I^1 + \theta\,\hat{y}_j - x_{tot})\,x_j^2 \tag{10}$$

This is a standard Cournot oligopoly; simple calculations show that incumbent and entrant equilibrium output are respectively:

$$x_I^2 = \frac{A - x_I^1 + 2\theta\,\hat{y}_I - \theta\,\hat{y}_E}{3} \qquad x_E^2 = \frac{A - x_I^1 + 2\theta\,\hat{y}_E - \theta\,\hat{y}_I}{3} \tag{11}$$

These expressions give the quantity produced by each firm in the second period as a function of consumers' expectations about each firm network size and given that x_I^1 customers have already purchased the good in the first period. FEE is derived by setting expected sales equal to the actual ones. Formally: $\hat{y}_I = x_I^1 + x_I^2 + \mu x_E^2$ and $\hat{y}_E = x_E^2 + \phi(x_I^2 + x_I^1)$; solving the system of equations (11) with fulfilled expectations, firms' output in the second period given first period installed base are

$$x_I^2(x_I^1) = \frac{A(\theta(1-\mu) - 1) + (\theta(\theta(\mu\phi - 1) - \phi - \mu + 3) - 1)x_I^1}{3 + \theta(\theta(1 - \mu\phi) + \mu + \phi - 4)} \tag{12}$$

$$x_E^2(x_I^1) = \frac{A(\theta(\phi - 1) + 1) + (\phi\theta - 1)x_I^1}{3 + \theta(\theta(1 - \mu\phi) + \mu + \phi - 4)} \tag{13}$$

Expressions (12) and (13) give, for the different values of the compatibility parameters μ and ϕ, the output produced by the incumbent and by the entrant under the different compatibility regimes. Existence and uniqueness of the FE second period Cournot equilibrium are proved in the Appendix.

3.1.2 First period equilibrium

In the first period, the incumbent acts as a monopolist and he recognises that his first period output decision has an impact on second period profits. The incumbent maximisation problem in the first period is the following:

$$\max_{x_I^1} \quad \pi_I = p_I^1\, x_I^1 + p_I^2\, x_I^2(x_I^1) \tag{14}$$

where p_I^1 is the first period demand faced by the incumbent as in (7), while p_I^2 is the incumbent's equilibrium price in the second period given in (9) and $x_I^2(x_I^1)$ is given in (12). Solving the incumbent's maximisation problem we derive the first period production given consumers expectations on first period incumbent installed base $\hat{x}_I^1$[11]:

$$x_I^1(\hat{x}_I^1) = \frac{-((-3+3\mu\phi)\theta^3+(12-3\phi-3\mu)\theta^2-9\theta)\hat{x}_I^1}{(\phi^2\mu-\phi+2-2\mu\phi)\theta^3+(2\mu-9\mu\phi-\phi^2+4+4\phi)\theta^2+(9\phi-33+8\mu)\theta+22} - \frac{((-2\phi+-4\mu+5\phi\mu)\theta^2+(-\phi-4\mu+9)\theta-10)A}{(\phi^2\mu-\phi+2-2\mu\phi)\theta^3+(2\mu-9\mu\phi-\phi^2+4+4\phi)\theta^2+(9\phi-33+8\mu)\theta+22} \tag{15}$$

The fulfilled expectations equilibrium output in the first period is given by:

$$x_I^1 = \frac{-((5\mu\phi+1-2\phi-4\mu)\theta^2+(-4\mu-\phi+9)\theta-10)A}{(-\phi+\mu\phi-1+\phi^2\mu)\theta^3+(-\phi^2+\phi-9\mu\phi-\mu+16)\theta^2+(9\phi-42+8\mu)\theta+22} \tag{16}$$

Uniqueness and stability of the FEE in period 1 is proved in Appendix. The FEE payoffs for the incumbent and the entrant in the four possible outcomes of the game are[12]:

$$\pi^I_{c,c} = -\frac{A^2(8\theta^3+192\theta-176-69\theta^2)}{(6\theta^2-25\theta+22)^2} \qquad \pi^E_{c,c} = \frac{(\theta-4)^2A^2}{(6\theta^2-25\theta+22)^2}$$

$$\pi^I_{c,i} = -\frac{A^2(60\theta^3-176+252\theta-11\theta^4-155\theta^2-6\theta^5)}{(22-\theta^3+15\theta^2-34\theta)^2} \qquad \pi^E_{c,i} = \frac{(-\theta^2+13\theta-4)^2A^2}{(22-\theta^3+15\theta^2-34\theta)^2}$$

$$\pi^c_{i,c} = -\frac{A^2(104\theta^3-17\theta^4+\theta^5+368\theta-176-289\theta^2)}{(22+16\theta^2-2\theta^3-33\theta)^2} \qquad \pi^{i,c}_E = \frac{(\theta-4)^2A^2}{(22+16\theta^2-2\theta^3-33\theta)^2}$$

$$\pi^I_{i,i} = -\frac{A^2(96\theta^3-176+428\theta-2\theta^5-12\theta^4-343\theta^2)}{(22-\theta^3+16\theta^2-42\theta)^2} \qquad \pi^E_{i,i} = \frac{(-\theta^2+13\theta-4)^2A^2}{(22-\theta^3+16\theta^2-42\theta)^2}$$

where $\pi^I_{c,c}$ $\pi^E_{c,c}$ are respectively the incumbent and the entrant total profits when both goods are compatible (full compatibility); $\pi^I_{c,i}$ and $\pi^E_{c,i}$ are total profits when the good produced by the entrant is compatible but not the opposite (one-way compatibility). Similarly, $\pi^I_{i,c}$ and $\pi^E_{i,c}$ are the profits when the entrant's product is compatible but not the incumbent's, and finally $\pi^I_{i,i}$ and $\pi^E_{i,i}$ are the payoffs with full incompatibility.

[11] It is easy to check that the second order condition is satisfied.

[12] These payoffs can be derived by plugging the FEE outputs for x_I^1, x_I^2 and x_E^2 into the firms profit functions. The algebra, available on request, is particularly tedious and for the sake of brevity it is omitted.

3.1.3 The strategic role of the installed base and entry deterrence

So far we have assumed that in the second period entry occurs. In some circumstances, this may no longer be the case and entry can be deterred by the incumbent. The incumbent can use its first period output strategically in order to reduce the scale of entry by the rival in the second period. The output decision in the first period affects second period output for both firms.

Consider expressions (12) and (13); these give the output of the incumbent and the entrant at the FE Cournot equilibrium as a function of the incumbent's first period production and of the compatibility parameters μ and ϕ. Both these expressions are decreasing in x_I^1 but this has a stronger impact on the rival's output which decreases faster. Consequently there exists a level of first period output, denoted with x_I^d, which is sufficient to ensure entry deterrence and a positive second period output for the incumbent. Equating (13) to zero yields:

$$x_I^d = \frac{A(\theta(\phi - 1) + 1)}{(1 - \phi\theta)} \tag{17}$$

Whenever $x_I^1 \geq x_I^d$, entry is deterred.

However, deterrence is not necessarily profitable for the incumbent because the entry deterring level of first period output may be too high. In the next proposition we establish necessary and sufficient conditions for entry deterrence. The proofs of all the mathematical results are in the Appendix.

Proposition 1. *Entry deterrence occurs if and only if:*

1. *the entrant is incompatible* ($\phi = 0$)*;*

2. $\theta \geq \theta^d = 0.315$.

Furthermore, if $\theta \geq 0.394$ *entry is blockaded; pure monopoly output is sufficient to deter entry.*

The idea that the installed base of a network good can play a preemptive role and possibly deter entry has been recently studied by Fudenberg and Tirole (2000) in a different setting. The basic intuition is simple and closely resembles that of the traditional case of irreversible investment. Both irreversible investment and installed base alter irrevocably the conditions under which second period competition occurs. To better grasp how preemption and deterrence come about consider Figure 1 where the second period FE reaction functions are depicted for the case of full incompatibility. These functions should not be confused with standard reaction functions. The two are very different; for each set of expectations we have different reaction functions whereas the FE reaction functions are uniquely determined by imposing fulfilled expectations

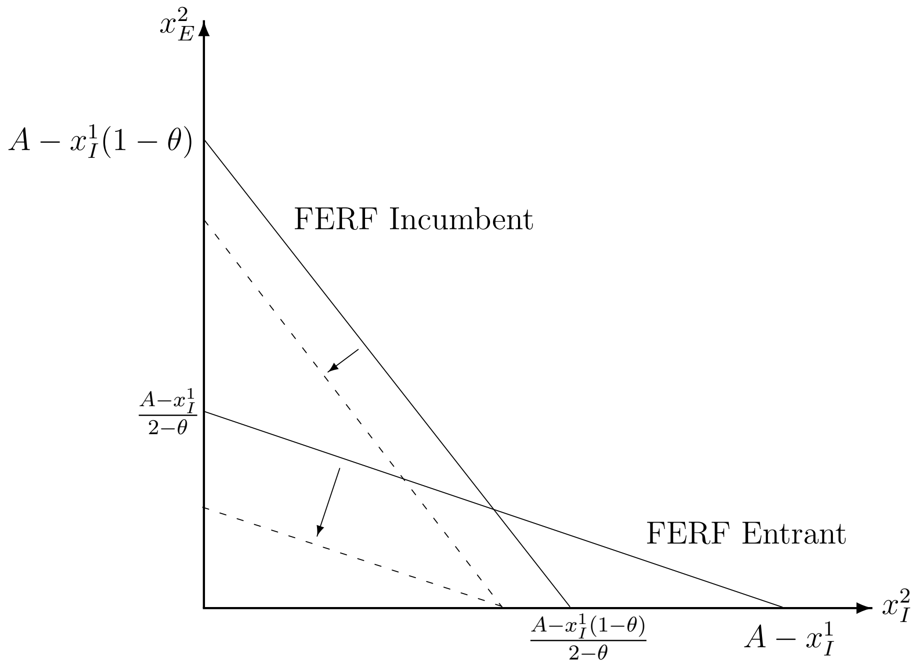

Figure 1: The FE reaction functions

in the standard first order conditions. This means that if one firm plays x_j and consumers expect the other firm to produce x_i, the FE reaction function of firm i gives x_i[13].

Note that an increase in the installed base of the incumbent shifts both reaction functions inwards but the effect on the two is asymmetric. A given increase in x_I^1 shifts the entrant's reaction function more than the incumbent's. For $x_I^1 = A(1-\theta)$ the two functions cross at $(A - x_I^1, 0)$ and entry is deterred. As shown in Proposition 1, in the case depicted in Figure 1 the incumbent chooses to deter entry if $\theta \geq 0.315$, while, in Bain's terminology, entry is blockaded if $\theta \geq 0.394$ since the monopoly output is sufficient to keep the entrant out of the market.

For later use, we define the incumbent's FEE profits in the case entry is

[13]See Katz and Shapiro (1985).

deterred/blockaded[14]:

$$\pi^d = \begin{cases} A^2\theta(\theta^2 - 3\theta + 3) & \text{if} \quad \theta \in [0.315, 0.394] \\ 5\,\dfrac{(\theta-3)^2\,A^2}{(\theta^2 - 9\,\theta + 10)^2} & \text{if} \quad \theta \in (0.394, \bar{\theta}] \end{cases} \tag{18}$$

4 The strategic analysis of compatibility

We explore three different scenarios concerning the way compatibility is achieved:

1. Compatibility through two-way converters supplied either by the incumbent or the entrant;
2. Compatibility through one-way converters supplied by the incumbent and the entrant;
3. Compatibility through one-way converters supplied by the incumbent and the entrant subject to disclosure of each other technical specifications.

Let look at each in detail.

4.1 Compatibility through two-way converter

In this case the bridge between the two, otherwise incompatible, technologies is provided by means of a two-way converter which allows users of both goods to *communicate* perfectly. This amounts to assume that the use of the converter does not downgrade the performance[15]. The unilateral provision of a two-way converter is the case most often considered in the literature since Katz and Shapiro (1985).

Assume that the decision to build a converter is up to the incumbent firm in stage 1 and that the firm incurs no cost in the production of the converter[16]. Also, we assume that the incumbent can credibly commit to such course of action either by making the converter available right at the beginning of $t = 1$ or by including such a clause in the contract signed with its customers.

[14] To compute this profit function, we use the outputs produced by the incumbent in the two periods when deterring entry are $x_I^d = A(1-\theta)$ and $x_I^2 = A\theta$. If entry is blockaded, outputs are x_{mon}^1 and x_{mon}^2.

[15] Allowing for performance disruption is an easy task from which we abstain to avoid cumbersome notation.

[16] The assumption of zero costs for the converter is broadly consistent with the observation that converters are often a simple *add-on* to much more complex software whose development costs are much more relevant.

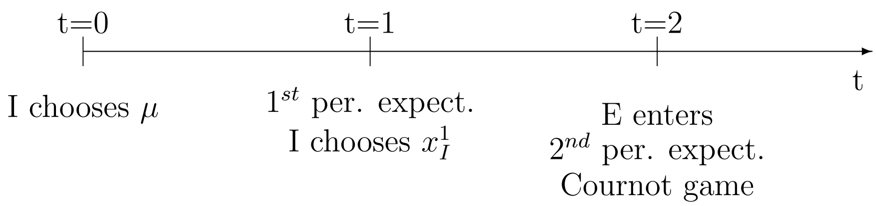

Figure 2: The time line with two-way converter

Compatibility implies that the size of the relevant network for customers of both goods is the same and equal to total amount of output sold. Consumers in period 1 contemplating the purchase of the good incorporate this information in their expectations. Formally, this is equivalent to saying that we have only one compatibility parameter, or $\mu = \phi$; therefore consumers expectations are:

$$\hat{y}_I = \hat{x}_I^2 + \mu\hat{x}_E^2 + x_I^1$$
$$\hat{y}_E = \hat{x}_E^2 + \mu(\hat{x}_I^2 + x_I^1)$$

where $\mu = 0$ implies that no converter is built, and $\mu = 1$ otherwise.[17] The time line is represented in Figure 2. With compatibility the incumbent accrues to the value of its network in both periods through consumers expectations but, at the same time, increases rival's competitiveness because, with compatibility, the incumbent shares the first period installed base with the entrant, thus making its product perfectly homogeneous, in terms of network size, with the rival's. Furthermore, compatibility makes entry deterrence unfeasible due to the sharing of the installed base.

Proposition 2. *The incumbent always chooses incompatibility ($\mu = 0$); for $\theta \geq \theta^d$ entry is deterred.*

The advantage from increasing the size of the incumbent network through compatibility is small, and the strategic effect of a dominant position in the market prevails.

Consumers maximise their expected surplus across the two periods; high expected prices in period 2 increase demand in period 1, when the incumbent is a monopolist. Incompatibility, then has the additional benefit of allowing

[17] Compatibility levels however may take intermediate values between 0 and 1. We do not consider this possibility. This does not result in a severe loss because, given the assumption that the cost of compatibility, through converters, is zero, one can easily show that the entrant will always choose full compatibility, and that the incumbent will prefer extreme to intermediate values.

the incumbent to charge in period 2 a price which is higher than that charged by the rival and this increases first periods sales. Incompatibility is chosen whatever θ and deterrence occurs for $\theta \geq \theta^d$.

This confirms in a two stage setting the result of the recent literature on monopolist's incentive to invite entry of a compatible rival: as in Kim (2001) and Kim (2002), in our model the incumbent monopolist has never the incentive to invite entry of an homogeneous and compatible technology, regardless the degree of network effects.

The case where the entrant builds the two-way converter is trivial. Provision of the converter is a dominant strategy for the entrant because with full compatibility, the installed base of the incumbent looses all its preemptive value and $\pi^E_{c,c} > \pi^E_{i,i}$ always holds.

4.2 Compatibility through one-way converters

Under this scenario each firm has the ability to build a one-way converter, which allows one-way compatibility to the users of its product. As an example think of a software package that can read files created by other packages but cannot save in their format. More generally, *one-way compatibility happens when a component from one system works in the other, but the reverse is not true* (Katz and Shapiro, 1994). One-way converters allow one of the technologies to obtain the network externalities accruing from the installed base of the other but not viceversa (David and Buun, 1988).

Again, the incumbent chooses μ at the beginning of the game and can credibly commit to this decision. The rival chooses whether to build or not to build the converter at time $t = 2$ having observed the incumbent's choices. The relevant expected networks are:

$$\hat{y}_I = \hat{x}^2_I + \mu \hat{x}^2_E + x^1_I$$
$$\hat{y}_E = \hat{x}^2_E + \phi(\hat{x}^2_I + x^1_I)$$

where $\phi = 0$ ($\mu = 0$) implies that the entrant (incumbent) builds no converter, and $\phi = 1$ ($\mu = 1$) otherwise. The timeline is represented in Figure 3. It should be noted that we have implicitly assumed that one-way compatibility allows the firm providing it to reap the full benefits of enlarged network size. This amounts to assume that the network externality enjoyed by consumers of the one-way compatible good are independent of the provision of the converter by the firm producing the other good.

The game tree is represented in Figure 4. The incumbent's decision to build a converter is taken before production in the first period takes place, at the beginning of the second period; the entrant, having observed the incumbent's

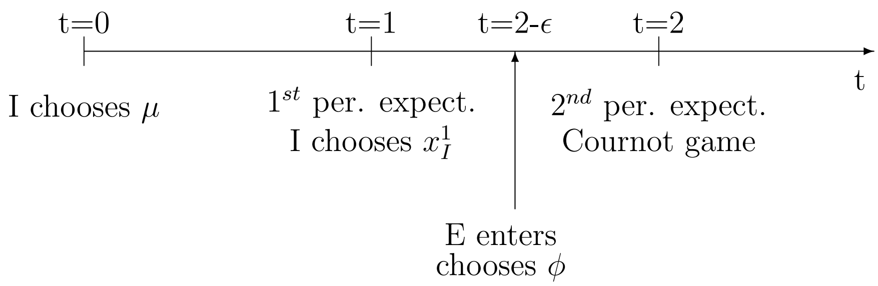

Figure 3: The time line with one-way converters

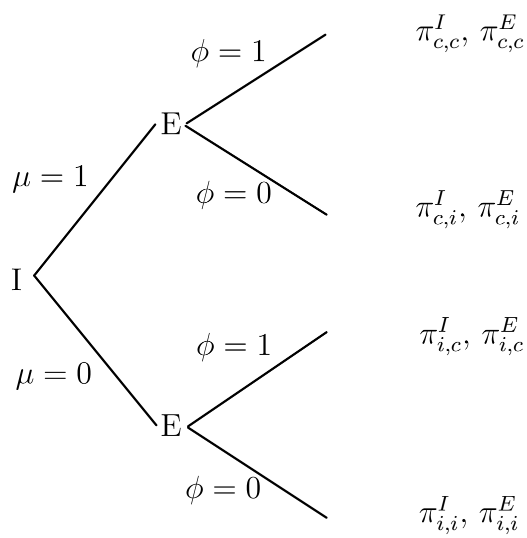

Figure 4: The game tree with one-way converters

choice, decides whether to build a converter itself. In FE equilibrium the decision by the entrant is correctly anticipated by consumers in period 1.

Proposition 3. *For any possible value of θ, the only subgame perfect FE equilibrium involves both players building a converter (full compatibility: $\mu = 1$, $\phi = 1$).*

This result is driven by the behavior of the entrant whose dominant strategy is to build the converter. By doing so, the entrant enlarges its relevant network with the installed base of the incumbent, which in turn prefers to to be compatible itself with a one-way compatible rival. Under this scenario, entry cannot be prevented by the incumbent and the entrant is on an equal footing with the incumbent which loses its first mover advantage.

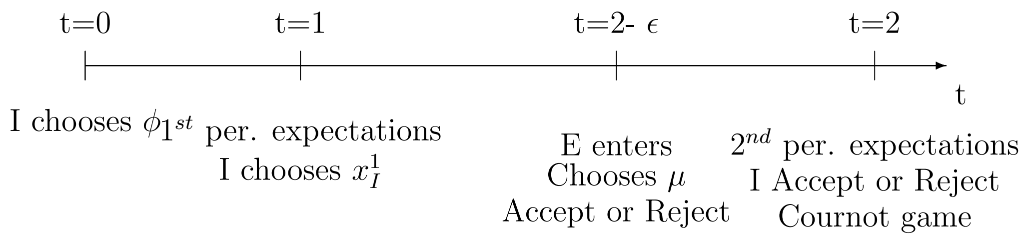

Figure 5: The time line with one-way converters and information disclosure

Corollary 1. *Entry of a one-way compatible entrant cannot be discouraged.*

4.3 Compatibility through one-way converters and disclosure of technical specifications

In this last case, the two firms have property rights on the technical specifications that are needed to build a one-way converter. Alternatively we can think of the case in which in order to build a converter access is required to information that is privately owned by firms.

This implies that each firm has to decide whether or not to disclose such information to the rival, which in turn has to decide what to do with this information. Using the same notation, this time the incumbent firm chooses $\phi = 1$ if he discloses the information, or $\phi = 0$ otherwise. Similarly, the entrant chooses μ. Once offered the information each firm decides about the building of the converter; we call this decision *accept* or *reject*. The effect on the size of the relevant expected networks is the same described in the previous section. The time line is represented in Figure 5.

The incumbent firm makes a commitment at the beginning of period 1 about disclosure of the technical info required for the building of the converter by the entrant. The same decision is taken by the entrant at the beginning of period 2 when the two firms decide, if given the opportunity by the rival, to build the converter before competing in quantities. The game tree is given in Figure 6.

Proposition 4. *The FE subgame perfect equilibrium involves:*

1. *full incompatibility if $\theta < \theta^d$;*
2. *entry deterrence if $\theta \geq \theta^d$.*

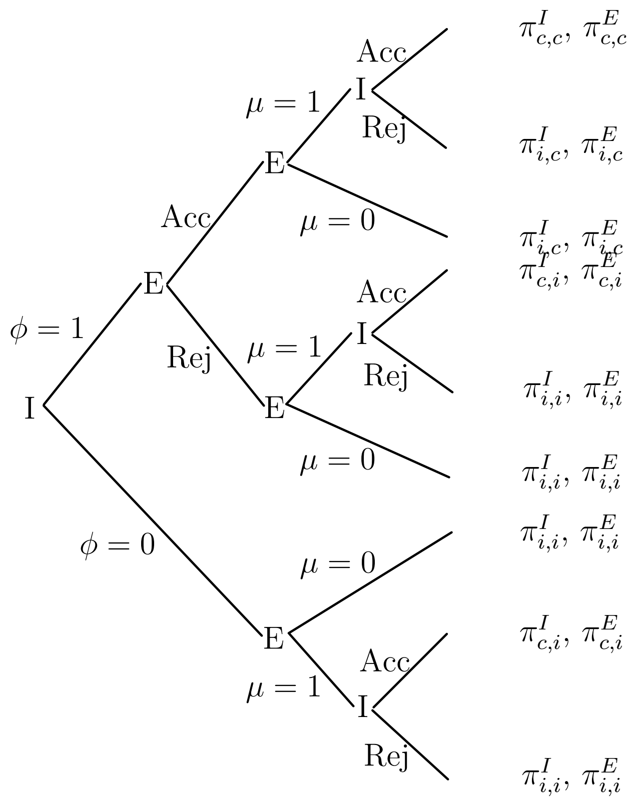

Figure 6: The game tree with one-way converters and information disclosure

This result is interesting: both firms strictly prefer not to disclose their private information to the rival. By doing so, with strong network externalities ($\theta \geq \theta^d$), the incumbent is also able to deter entry.

The existence of property rights on private information, alters the equilibrium dramatically compared with the scenario analysed in the previous section. The entrant likes compatibility with the incumbent but information disclosure is a dominated action. Moreover, provision of a one-way adapter by the entrant is possible only if the incumbent discloses its own private information and it is never optimal for it to do so. Even allowing the entrant the possibility of a credible commitment about the revelation of its information, the equilibrium outcome does not change since for the incumbent it is still dominant not to disclose.

This result closely replicates what has been observed in the videogame industry when Nintendo denied Atari the permission to include an adapter to allow Atari's users to play games written for Nintendo. In this case, the existence of property rights has allowed an established technology to maintain its dominant position preventing rivals to interconnect with its installed base.

5 Welfare analysis and policy implications

We conclude the paper by studying the choice of compatibility from the point of view of a welfare maximising regulator or authority; we do so by contrasting the above compatibility choices obtained as equilibrium of the different games, with the compatibility regime that would be selected by a social welfare optimising agent, provided that firms are free to compete in quantities. The comparison between the solutions of the different games with the socially optimal compatibility regime will provide some useful policy implications.

Social welfare is defined as the sum of consumer's and producer's surplus in the two periods. Social welfare depends on the compatibility parameters ϕ and μ and on the strength of network externalities θ:

$$W(\phi, \mu; \theta) = CS^1(\phi, \mu; \theta) + CS^2(\phi, \mu; \theta) + \sum_i \pi^i(\phi, \mu; \theta) \qquad i = I, E \quad (19)$$

where CS^i denotes the surplus enjoyed by period i consumers.

Consider first period consumers. The total surplus that each first period consumer enjoys is the sum of the surplus derived over both periods. According to expression (2), the total surplus for the individual of type r is

$$CS^1(r) = r + V(\hat{x}_I^1) - p_I^1 + r + V(\hat{y}_I) \quad (20)$$

where p_I^1 is the price paid in the first period which, according to (7), depends on the price in the second period, p_I^2. Replacing (7) and (9) into (20) and rearranging we finally derive the total surplus for type r individual when he joins the incumbent network in the first period:

$$CS^1(r) = 2(r - A + x_I^1) + (x_I^2 + x_E^2) \tag{21}$$

At the fulfilled expectations equilibrium, only those consumers with r bigger than $A - x_I$ purchase the good in the first period. Integrating over all consumers who do join the network in the first period we derive the consumers' surplus:

$$CS^1 = \int_{A-x_I}^{A} [2(\gamma - A + x_I^1) + (x_I^2 + x_E^2)]d\gamma = (x_I^1)^2 + x_I^1(x_I^2 + x_E^2) \tag{22}$$

where the x's represent the fulfilled expectations firms' output. Note that the surplus in the first period depends also on the size of the network in the second period.

Consider second period consumers; the surplus enjoyed by type r individual when purchasing from firm i in the second period is simply given by:

$$CS_i^2(r) = r + V(\hat{y}_i) - p_i^2 = r - A + x_I^1 + x_I^2 + x_E^2 \qquad i = I, E$$

where the last expression has been obtained using (9). In the second period, only those consumers with r bigger than $A - x_I - x_I^2 - x_E^2$ purchase the good, provided that those with $r > A - x_I$ have already joined the network in the first period; therefore, total second period consumers' surplus is:

$$CS^2 = \int_{A-x_I-x_I^2-x_E^2}^{A-x_I} [\gamma - A + x_I^1 + x_I^2 + x_E^2]d\gamma = \frac{(x_I^2 + x_E^2)^2}{2} \tag{23}$$

Similarly, we can compute the surpluses when entry is deterred/blockaded by the incumbent; these are simply given by[18]:

$$CS_{mon}^1 = (x_I^1)^2 + x_I^1 x_I^2 \qquad\qquad CS_{mon}^2 = \frac{(x_I^2)^2}{2}$$

The FE equilibrium quantities sold in both periods are known. By substituting them into the above expressions, we compute the expressions of the welfare function (19) for all the scenarios considered: full compatibility, full incompatibility, one-way compatibility and entry deterrence/blockaded; formally:

$$\mathrm{W}_{c,\,c} = \frac{1}{2}\,\frac{A^2\,(808 - 16\,\theta^3 + 192\,\theta^2 - 696\,\theta)}{(-25\,\theta + 6\,\theta^2 + 22)^2}$$

[18] We omit the computation, which is available on request.

$$W_{c,i} = \frac{1}{2}\,\frac{A^2\,(808 + 34\,\theta^4 + 12\,\theta^5 + 1074\,\theta^2 - 1424\,\theta - 236\,\theta^3)}{(22 + 15\,\theta^2 - 34\,\theta - \theta^3)^2}$$

$$W_{i,c} = \frac{1}{2}\,\frac{A^2\,(808 - 2\,\theta^5 + 932\,\theta^2 + 39\,\theta^4 - 1416\,\theta - 280\,\theta^3)}{(22 + 16\,\theta^2 - 33\,\theta - 2\,\theta^3)^2}$$

$$W_{i,i} = \frac{1}{2}\,\frac{A^2\,(808 + 1798\,\theta^2 - 326\,\theta^3 + 4\,\theta^5 - 2144\,\theta + 31\,\theta^4)}{(22 + 16\,\theta^2 - 42\,\theta - \theta^3)^2}$$

$$W^d = \begin{cases} A^2\left(1 + \theta - \frac{3}{2}\,\theta^2 + \theta^3\right) & \text{if} \quad \theta \in [0.315, 0.394] \\ \dfrac{1}{2}\,\dfrac{(11\,\theta^2 - 66\,\theta + 131)\,A^2}{(\theta^2 - 9\,\theta + 10)^2} & \text{if} \quad \theta \in (0.394, \bar{\theta}] \end{cases}$$

where W^d represents welfare when the incumbent deters entry or when entry is blockaded[19].

Although the algebra is a bit tedious, it is relatively easy to compare the welfare levels in the different scenarios; these comparisons yield the following proposition[20]:

Proposition 5 (Socially optimal compatibility regimes). *a) When entry cannot be deterred or blockaded ($\theta < \theta^d$), welfare is maximised with full compatibility if $\theta < 0.27$ and with a one-way compatible incumbent ($\phi = 1$, $\mu = 0$) for $\theta > 0.27$; b) when $\theta \geq \theta^d$, deterrence is never socially optimal and welfare is maximised with full compatibility.*

This result is interesting and it can be explained by analysing the conflicting balance between first and second period consumers surplus.

Consider the case with $\theta < \theta^d$; in this case entry always occurs in equilibrium whatever the compatibility choice made by the incumbent. First period and second period consumers have different and somehow diverging interests regarding compatibility. Since first period sales (i.e. the incumbent installed base in the first period) are greater if the rival is incompatible than otherwise, first period consumers prefer entry of an incompatible technology which allows them to enjoy stronger network effects in the first period. On the other hand, second period consumers strictly prefers full compatibility since it increases the second period relevant network. If the strength of network externalities is not too strong, then the effect on second period consumers prevails and full compatibility is socially optimal. If $\theta > 0.27$, then the reverse is true and it is socially optimal to have an incompatible entrant in the second period.

Things are much simpler if $\theta \geq \theta^d$. In this case, the incumbent uses its installed base to deter entry but this strategy is never socially optimal. Entry,

[19]Recall Proposition 1 for details of when this happens.

[20]The details of the proof are omitted as it is just a matter of comparing welfare levels under the different regimes as a function of θ.

which is only possible via a compatible technology, is socially desirable and welfare is maximised with full compatibility.

This result, which clearly holds if compatibility can be achieved at no cost, confirms the widespread idea that compatibility is good for consumers since it makes the network larger and it increases individuals utility[21]. The novelty of our framework which contemplates also intermediate forms of compatibility, is that when network effects are sufficiently strong consumers may be better off when only the incumbent is compatible with the entrant and not viceversa.

From Proposition 5, two others useful observations derive.

Corollary 2 (Market failure). *Games 1 and 3 always induce inefficient compatibility choices. Game 2 yields the socially desirable outcome for* $\theta < 0.27$ *and* $\theta \geq \theta^d$.

This corollary states the social inefficiency of the compatibility regimes that result in equilibrium. The presence of market failures in markets characterised by network externalities is a well known result since Katz and Shapiro (1985, 1986). A related interesting issue to address is whether this inefficiency can be avoided in some way by a regulator or by an antitrust authority. The social optimum can be obtained when network effects are not too strong or, when they are bigger then θ^d, by imposing compatibility between different technologies.

Consider the last game (the disclosure game); here the social welfare could be maximised simply by mandating each firm to reveal to the rival the specifications needed to build the adapter. But, clearly, this is not always possible: the regulator would prefer to avoid such a direct intervention in the market or simply she might not be allowed to implement such policy. The alternative would be to impose a rule on firms' conducts that we can define as *reciprocity rule*: whenever a firm accepts the offer made by the rival, it too has to offer its technical specifications.

This kind of rules in which, rather than intervening directly on firms' strategies, regulators tends to create a "level playing field" are quite popular among policymakers, especially in IT sectors and network industries in general. In our game, this is equivalent to say that if the incumbent offers compatibility ($\phi = 1$), then, by accepting the offer, the entrant is automatically required to provide its technical specifications to the incumbent. It is possible to show the following:

Corollary 3 (Neutrality of the "Reciprocity Rule"). *The equilibrium of the game with information disclosure is not affected by the imposition of the "reciprocity rule".*

[21]See Katz and Shapiro (1985).

In other words each firm's commitment to reveal its information if the rival's offer is accepted, something implied by the reciprocity rule, is not enough to avoid inefficient compatibility; to achieve social efficiency a direct intervention is needed.

6 Conclusion

We have developed a simple model to study what we believe is an important aspect of competition in network industries which can account for the observed coexistence in a number of markets of different and incompatible technologies. Maintaining incompatibility with entrants is a strategic choice for an incumbent firm to protect its dominant position. With incompatibility, the installed base of consumers serves the same preemptive purpose of irreversible investment. In our model compatibility can be achieved via a converter and we study three different scenarios (two-way converter, one-way converters, one-way converters with property rights). Whenever an incumbent firm can prevent the entrant to be compatible, as in our first and third scenario, it will choose to do so. In the resulting equilibria entry can be deterred for sufficiently strong network effects. Conversely an incompatible entrant will always prefer to build an adapter (both one and two-way) because this will allow it to enjoy the benefits of the incumbent's installed base. These results further qualify those found in previous literature that highlight the possibility of an incumbent inviting entry of a compatible rival in order to increase network size. We show that this never occurs in our model. We finally discuss the welfare properties of the equilibria and we show that unless the regulatory authority intervenes to mandate the appropriate compatibility regime, strategic forces tend to lead to a socially inefficient compatibility outcome.

Appendix

Existence and uniqueness of second period FE Cournot equilibrium. Solving the maximisation problem (10) gives firms standard reaction curves:

$$x_I^2 = \frac{A - x_I^1 + \theta\,\hat{y}_I - x_E^2}{2} \tag{24}$$

$$x_E^2 = \frac{A - x_I^1 + \theta\,\hat{y}_E - x_I^2}{2} \tag{25}$$

To prove that the second period cournot equilibrium with fulfilled expectations is unique and stable, we proceed in two stages.
First let us show that Assumption 1 is a sufficient condition for both the fulfilled expectations reactions curves to be negatively sloped and single valued. Imposing FE, namely $\hat{y}_I = x_I^1 + x_I^2 + \mu x_E^2$ and $\hat{y}_E = x_E^2 + \phi(x_I^1 + x_I^2)$, into (24) and (25), the slopes of the reaction functions are simply:

$$\frac{dx_I^2}{dx_E^2} = \frac{\theta\mu - 1}{2-\theta} \qquad \frac{dx_E^2}{dx_I^2} = \frac{\theta\phi - 1}{2-\theta}$$

which are both negative for $\theta < 1$. This is enough to verify that the reactions curves are also single valued.
To guarantee existence and uniqueness of the second period equilibrium, we can invoke Szidarowsky and Yakowitz (1977) and show that the reaction functions are decreasing in the total industry output. From the reaction functions (24) and (25):

$$x_I^2 = A - x_I^1 - x_{tot} + \theta(\hat{y}_I) \qquad x_E^2 = A - x_I^1 - x_{tot} + \theta(\hat{y}_E)$$

where $x_{tot} = x_I^2 + x_E^2$. For any $\theta < 1$, both these expressions define a continuous function $x_i^2(x_{tot})$ which is decreasing in x_{tot}. Therefore also the sum $x_I^2 + x_E^2$ is continuous and decreasing. The FEE is given by the level of output such that $x_{tot} = \sum_i x_i^2(x_{tot})$. The Brower's fixed point theorem guarantees the existence of the equilibrium while the condition $x_i^2(x_{tot})' < 0$ is sufficient for establishing uniqueness.

■

Existence and uniqueness of first period FE equilibrium. From expression (15), with FE the equilibrium level of first period sales is the solution to $x_I^1 = x_I^1(\hat{x}_I^1)$ where (15) can be thought of as a mapping of sales expectations into actual ones. FE then define a fixed point of the function $x_I^1(\hat{x}_I^1)$.
Since $x_I^1(\hat{x}_I^1)$ is a linear function of $\hat{x}_I^1$, then to prove the existence, uniqueness and stability of the equilibrium is sufficient to verify that

$$\frac{dx_I^1(\hat{x}_I^1)}{d\hat{x}_I^1} < 1 \tag{26}$$

Differentiating expression (15):

$$\frac{dx_I^1}{d\hat{x}_I^1} = \frac{-3((-1+\mu\phi)\theta^2 + (4-\phi-\mu)\theta - 3)\theta}{(\phi^2\mu - \phi + 2 - 2\,\mu\phi)\theta^3 + (2\mu - 9\mu\phi - \phi^2 + 4 + 4\phi)\theta^2 + (9\phi - 33 + 8\mu)\theta + 22}$$

This expression provides the slope of the mapping $x_I^1 = x_I^1(\hat{x}_I^1)$ as a function of θ, given the compatibility parameters $\phi = 0, 1$ and $\mu = 0, 1$. It is easy to verify that condition (26) is met for $\theta < 1$ for all the combinations of the compatibility parameters except in the full incompatibility case ($\mu = 0, \phi = 0$). In this case, condition (26) is satisfied for $\theta < 0.704$ which is the lower level of the upper bound $\bar{\theta}$.
Finally, by setting $x_I^1 = \hat{x}_I^1$, the first period FEE is simply given by:

$$x_I^1 = \frac{-((5\mu\phi + 1 - 2\phi - 4\mu)\theta^2 + (-4\mu - \phi + 9)\theta - 10)A}{(-\phi + \mu\phi - 1 + \phi^2\mu)\theta^3 + (-\phi^2 + \phi - 9\mu\phi - \mu + 16)\theta^2 + (9\phi - 42 + 8\mu)\theta + 22}$$

■

Proof. of Proposition 1 In order to establish when the incumbent deters entry, we need to study under which conditions the optimal level of first period output x_I^1 is greater than x_I^d. Use expressions (15) and (17) to compute the differences $\Delta\left|_{\phi=1}\right. = x_I^1 - x_I^d$ and $\Delta\left|_{\phi=0}\right. = x_I^1 - x_I^d$; with simple manipulations we obtain:

$$\Delta\left|_{\phi=1}\right. = \frac{A\,(\theta-4)\left((\mu-1)\,\theta^2 + (3-\mu)\,\theta - 3\right)}{(\theta-1)\left((2\,\mu-2)\,\theta^3 + (16-10\,\mu)\,\theta^2 + (8\,\mu-33)\,\theta + 22\right)} \tag{27}$$

$$\Delta\left|_{\phi=0}\right. = \frac{A\left(\theta^2 - 13\,\theta + 4\right)\left(3 + \theta^2 + \theta\,\mu - 4\,\theta\right)}{-22 - 16\,\theta^2 + 42\,\theta - 8\,\theta\,\mu + \theta^2\mu + \theta^3} \tag{28}$$

We want to determine the sign of each of the two expressions. Let us start from (27). The numerator is always positive; the sign of denominator is negative for $\theta = 0$, still negative for θ approaching 1 and since it is strictly convex in θ the sign remains negative over the interval $[0, 1)$. Therefore the sign of (27) is negative. This shows that with a compatible entrant ($\phi = 1$) entry is never deterred in the FE equilibrium.
Now consider (28); to determine the sign of this expression it is useful to consider the two cases of $\mu = 1$ and $\mu = 0$ separately. With $\mu = 1$ (28) becomes:

$$\frac{A\left(\theta^2 - 13\,\theta + 4\right)\left(3 + \theta^2 - 3\,\theta\right)}{-22 - 15\,\theta^2 + 34\,\theta + \theta^3} \tag{29}$$

The denominator is negative both for $\theta = 0$ and $\theta = 1$ and the first derivative is strictly positive in θ thus implying that the denominator is always negative. The numerator is positive for $\theta = 0$ and negative for $\theta = 1$, the second derivative is always positive in $\theta \in [0, 1)$. This is sufficient to prove that there is only one value

of θ such that the numerator is zero. This happens for $\theta = 0.315 \equiv \theta^d$. Therefore the sign of (28) when $\mu = 1$ is negative for $\theta < \theta^d$ and positive thereafter.
With $\mu = 0$ (28) becomes:

$$\frac{A\left(\theta^2 - 13\,\theta + 4\right)\left(3 + \theta^2 - 3\,\theta\right)}{-22 - 16\,\theta^2 + 42\,\theta + \theta^3} \tag{30}$$

The numerator is the same as in the previous case. As for the denominator, it is easy to check that it is always negative in the relevant range of θ. Therefore the result is the same as before. We can finally conclude that $\Delta\,|_{\phi=0} \geq 0$ only if $\theta \geq \theta^d$, which ends the proof of the first part of the proposition.
To prove the second part we need to show that the output the incumbent will produce acting as a pure monopoly x^1_{mon} in the first period is not sufficient to deter entry for $\theta < 0.394$. To do this we compute the optimal production plan for the two periods under the assumption that the incumbent is the only active firm. Second period monopoly output contingent on x^1_I is the same as in the duopoly case[22], the first period output is different and given by:

$$x^1_{mon} = \frac{4A}{\theta^2 - 9\theta + 10} \tag{31}$$

Comparing x^1_{mon} with x^d_I it is straightforward to verify that $x^1_{mon} \geq x^d_I \iff \theta \geq 0.394$.

■

Proof. of Proposition 2 Suppose $\theta < \theta^d$: from the previous section, we know that entry occurs. From the expressions $\pi^I_{c,c}$ and $\pi^I_{i,i}$ it can be verified that for any value of θ, $\pi^I_{i,i} > \pi^I_{c,c}$: the incumbent always gain from incompatibility. Therefore at $t = 1$, the incumbent chooses incompatibility.
Suppose now that $\theta \geq \theta^d$. In this case we need to compare $\pi^I_{c,c}$ with π_d given in expression (18). Since $\pi_d > \pi^I_{c,c}$ then $\mu = 0$, which induces entry deterrence, is again the optimal incumbent's strategy.

■

Proof. of Proposition 3 In the second stage of the game the entrant decides whether to build the converter. Observing the payoff functions it is immediate to verify that irrespective of the choice of the incumbent in the first period, $\phi = 1$ is the dominant strategy for the entrant:

$$\pi^E_{c,c} > \pi^E_{c,i} \qquad \pi^E_{i,c} > \pi^E_{i,i}$$

Naturally, this holds also for $\theta \geq \theta^d$ since in this case entry of an incompatible rival cannot occur and $\pi^E_{c,i} = \pi^E_{i,i} = 0$.
Moving backward, since $\pi^I_{c,c} > \pi^I_{i,c}$ then also for the incumbent is optimal to be compatible with the entrant.

[22] And equal to $x^2_{mon} = \frac{A-(1-\theta)x^1_{mon}}{2-\theta}$.

■

Proof. of Proposition 4 We determine the equilibrium by backward induction. Consider first the case with $\theta < \theta^d$; in this situation, entry cannot be prevented by the incumbent who, conditional on information being disclosed by the entrant ($\mu = 1$), at the last stage of the game, has to decide whether to accept the offer or not. There are three nodes where the incumbent is asked to decide; these are reached along the following paths:

1. Incumbent offers its technical specifications, $\phi = 1$, Entrant accepts and offers $\mu = 1$;
2. Incumbent offers its technical specifications, $\phi = 1$, Entrant rejects and offers $\mu = 1$;
3. Incumbent refuses information disclosure, $\phi = 0$, Entrant offers $\mu = 1$.

In Figure 6, we can see that if the incumbent is asked to accept/reject $\mu = 1$, then it is always optimal to accept since:

$$\pi^I_{c,c} > \pi^I_{i,c} \qquad \pi^I_{c,i} > \pi^I_{i,i} \qquad \pi^I_{c,i} > \pi^I_{i,i}$$

The entrant has to decide whether to disclose its information knowing that if information is disclosed, the incumbent will use it in order to build the converter. The entrant has to take such decision at three different nodes reached along the following paths:

1. Incumbent offers its technical specifications, $\phi = 1$, Entrant accepts;
2. Incumbent offers its technical specifications, $\phi = 1$, Entrant rejects;
3. Incumbent denies information disclosure, $\phi = 0$.

It is simple to check that for the entrant is optimal to deny its technical specifications to the incumbent ($\mu = 0$) since

$$\pi^E_{i,c} > \pi^E_{c,c} \qquad \pi^E_{i,i} > \pi^E_{c,i} \qquad \pi^E_{i,i} > \pi^E_{c,i}$$

Moving backwards, the entrant has now to accept/reject $\phi = 1$ conditional on the offer being made by the incumbent. The entrant accepts the offer since $\pi^E_{i,i} < \pi^E_{i,c}$. Finally, anticipating these sequences of decisions, the incumbent at the initial node decides not to reveal its information given that $\pi^I_{i,i} > \pi^I_{i,c}$. This shows that the only subgame perfect FE equilibrium when $\theta < \theta^d$ is the full incompatibility regime where both firms do not disclose their specifications.
If $\theta \geq \theta^d$, we know from Proposition 1 that entry of an incompatible rival is deterred; choosing not to reveal its specifications, the monopolist prevents entry. This simplifies the game tree; if ϕ is set to zero at the initial node, the game ends with the incumbent enjoying profits π_d. If the incumbent chooses $\phi = 1$ and the entrant rejects, the game ends with entry deterrence and the same profits for the incumbent. If the incumbent chooses $\phi = 1$ and the entrant accepts, the remaining nodes and branches are the same depicted in Figure 6. The observation that $\pi_d > \max[\pi^I_{c,c}, \pi^I_{i,c}]$ concludes the proof.

■

Proof of Corollary 3. Let us start with $\theta < \bar{\theta}$. From the previous analysis, we know that at the last stage of the game the incumbent always accepts the offer $\mu = 1$ since:

$$\pi^I_{c,c} > \pi^I_{i,c} \qquad \pi^I_{c,i} > \pi^I_{i,i} \qquad \pi^I_{c,i} > \pi^I_{i,i}$$

Suppose that the incumbent offers ϕ =1. Given the reciprocity rule, if the entrant accepts, it must also offer its information to the incumbent which will accepts the offer. The entrant ends up with $\pi^E_{c,c}$. On the other hand, if the incumbent's offer is rejected, the entrant is free to deny its technical specifications; in this case, if it offers $\mu = 1$, the incumbent will accept and entrant's payoff is $\pi^E_{c,i}$, while if it does not offer compatibility, the final outcome of the game is full incompatibility and entrant's payoff is $\pi^E_{i,i}$. Since

$$\pi^E_{c,i} < \pi^E_{i,i}$$

the entrant prefers not to disclose its technical specifications to the incumbent, given that it did not accept incumbent's offer. Summing up, under reciprocity, if $\phi = 1$ has been offered by the incumbent, then the entrant obtains $\pi^E_{c,c}$ if it accepts the offer and $\pi^E_{i,i}$ otherwise; since $\pi^E_{c,c} > \pi^E_{i,i}$, then the entrant always accepts the offer.
Going backward, let's consider incumbent's choice. If it does not reveal its technical information, reciprocity does not apply and the entrant can either offer $\mu = 1$ or $\mu = 0$; in the first case, since the incumbent accepts the offer, entrant's payoff is $\pi^E_{c,i}$ and $\pi^E_{i,i}$ otherwise. Again, since $\pi^E_{c,i} < \pi^E_{i,i}$ the entrant will never launch the offer.
Therefore the incumbent decides $\phi = 0$ or $\phi = 1$ by anticipating that, if the offer is launched then full compatibility is the equilibrium and if it denies its technical specifications then the game ends with full incompatibility. Since $\pi^I_{c,c} < \pi^I_{i,i}$, the incumbent will never disclose its information: $\phi = 0$ and $\mu = 0$ is the compatibility equilibrium.
Suppose now that $\theta > \bar{\theta}$. In this case when the incumbent does not disclose its information ($\phi = 0$), preemption occurs and the firm obtains π^d. If, on the contrary, information is disclosed, then entry occurs and the entrant accepts and builds the adapter. For the reciprocity, the entrant must make the same offer to the incumbent who accepts: full compatibility is the outcome in this case.
Consider the incumbent's problem: since $\pi^d > \pi^I_{c,c}$ then it will never disclose its specifications.
This shows that the equilibrium of the game is unaffected by the imposition of the reciprocity rule.

■

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