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 software packages in a two-stage game by an incumbent and an entrant firm. Consumers enjoy network externality in consumption and maximise expected surplus over the two periods. 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 and depending on the strength of network externalities the incumbent may deter entry. When both firms can build a one-way converter and there are no property rights on the necessary technical specifications, the only fulfilled expectations subgame perfect 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. Entry deterrence will then occur for sufficiently strong network effects. The analysis generalises to any market where network externalities are present.

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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 consumption of the good or service is increasing in the number of people consuming the same good or service. The sources of externalities are different and range 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. The presence of demand externalities raises the important question of compatibility whenever users belonging to one network cannot benefit from the presence of another network of users who adopt an incompatible technology. With incompatibility, absent congestion problems, both sets of consumers cannot benefit from the externalities that would be possible by pooling the two networks. In this paper we analyse the conflicting incentives that an incumbent firm faces when deciding whether or not to make its good compatible with the one produced by an entrant by means of a converter, under a variety of assumptions about the nature of the converter.

We build a model in which there is an incumbent firm which produces a durable software 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 effect 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 by the incumbent;

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, the incumbent may produce, at no cost, a two-way converter which induces perfect compatibility between the two network of users. 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 to possibility to deny the other firm the technical specifications needed to build any converter.

Examples of each of the three scenarios can be easily found for the software market. 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 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.

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 file 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.

In recent years a number of commercial software vendors have introduced so-called *viewers*. 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 accomplish 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[1]. 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

[1]Examples of such viewers are Word Viewer, PDF Viewer, Excel Viewer. Shapiro and Varian (1999, ch.9) discuss examples of how adapters can be used by a firm to interconnect with a rival's network.

on the disclosure of technical specifications by the rivals. For this reason the second scenario analysed in the paper fits the example of the *viewers* while the third better illustrates the case of a converter allowing saving but not reading in the rival format (or viceversa).

The three scenarios described above are analysed under the assumption that *i*) demand in the second period is the residual from demand in period 1 and that *ii*) consumers maximise total net surplus over the two periods.[2]

Compatibility increases the value of the firm's network but increases competition since it makes products homogenous. The incumbent firm has to give up the advantage it enjoys over the entrant thanks to its installed base of users and forecloses the possibility of entry deterrence.

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 either via the construction of an adapter or via the disclosure of technical specification by the operating firms. Farrell and Saloner (1992) discuss the incentive for a dominant firm to refuse the disclosure of its technical information to construct an adapter by a rival firm. In a different context, we find a similar result when the incumbent and the entrant firms play a "disclosure game" such that each firm has to decide, sequentially, on whether to provide its technical specification to the rival. Furthermore we find that at the equilibrium, the dominant firm might be able to deter entry by denying the construction of a one-way adapter to the entrant. The provision of a two-way adapter is also studied in Baake and Boom (2001); in a symmetric setting, they find that in equilibrium the adapter is always provided. Our results show that this finding is sensitive to the symmetric *vs* asymmetric position of the competing firms.

This result has interesting policy implications and suggests that antitrust authorities may have a role in promoting competition via information disclosure obligations.

In the case of a more simple compatibility decision, where each firms is free to build a one-way adapter with the rival technology, the result goes in the opposite direction and entry with full two-way compatibility is the equilibrium outcome. Contrary to the previous case, this result suggests a pro-competitive role of network externalities, a feature that has already been studied in the recent paper by Economides (1996b).

Summing up, the main message of the paper is that (costless) compatibility between incumbent and entrant may or may not be achieved depending

[2]In an extended version of this paper we have also investigated the case of independent demands in the two periods and of myopic behavior of consumers. The qualitative features of the results remain largely unaffected.

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

on *i*) the type of compatibility (one-way vs two-way) and *ii*) the process of information disclosure necessary for the provision of the converter.

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

2 The model

The model is built on a two stage game: in the first period there is a single firm serving the whole market while in the second period entry may occur.

The model focuses on the strategic role of compatibility between the entrant and the incumbent firm. In particular we model three different patterns of compatibility: *i*) full compatibility between the entrant and the incumbent (two-way compatibility), *ii*) full incompatibility (two-way incompatibility), *iii*) partial compatibility (one-way compatibility).

With full compatibility, users of the two goods communicate perfectly, irrespective of the adopted technology; if incumbent and entrant are fully incompatible then the opposite is true. Finally, with one way-compatibility the users of the compatible technology can communicate with the users of the rival technology but not viceversa. As it will be discussed later on in the paper, one-way compatibility typically occurs between software products when a package can read and save in rival's format but not the other way round. Naturally, the type of compatibility affects consumers' preferences.

2.1 Consumers

There is a population of consumers $\mathcal{P}$ uniformly distributed along the interval $[-\infty, A]$, with $A > 0$, according to the individual *basic* willingness to pay r. r is assumed independent of the size of the users' network. Each consumer buys a single unit of the good.

Following Katz and Shapiro (1985), consumers form expectations about the networks sizes in the two periods and enjoy network externalities: the *total* willingness to pay increases with the expected dimension of the network.

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:[4]

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

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

When the incumbent and the rival technologies are fully compatible then $\mu, \phi = 1$; in this case users network size expectations are equal to the sum of the two firms expected networks. 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.

The impact of the externality on total willingness to pay is given by a function $\mathcal{V}(\cdot)$ of the expected size of the network that a consumer is deciding to join as defined above: for given expectations, the reservation price of consumer type r' is $r' + \mathcal{V}(\cdot)$. We assume that the function $\mathcal{V}(\cdot)$ is monotonically increasing in the expected size of the network; specifically we assume that $\mathcal{V}' > 0 \quad \text{e} \quad \mathcal{V}'' \leq 0$.

The assumption of a population uniformly distributed on $[-\infty, A]$ is equivalent to say that demand is linear and decreasing with a vertical intercept increasing in the level of expected network size. In order to derive the demand functions we need to distinguish between the two periods of the game.

2.1.1 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.

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

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 CS_i^t represents expected gross consumer surplus at time t, $t = 1, 2$ when purchasing from firm i, $i = I, E$. 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 $t = 2$.

If entry occurs, in duopoly equilibrium at time $t = 2$ the consumer must be indifferent between buying from the incumbent or the entrant:

$$CS_I^2 - p_I^2 = CS_E^2 - p_E^2$$

therefore expression (3) can be rewritten as:

$$CS_I^1 - p_I^1 + p_I^2 \geq 0$$

Knowing that the expected gross surpluses of type r consumer buying from the incumbent firm are $CS_I^1 = r + \mathcal{V}(\hat{x}_I^1)$ and $CS_I^2 = r + \mathcal{V}(\hat{y}_I)$ in period 1 and 2 respectively, conditions (2) and (3) become:

$$r \geq \frac{1}{2}\left[p_I^1 - \mathcal{V}(\hat{x}_I^1) - \mathcal{V}(\hat{y}_I)\right] \equiv \varphi \tag{4}$$

$$r \geq -\mathcal{V}(\hat{x}_I^1) + p_I^1 - p_I^2 \equiv \psi \tag{5}$$

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 $p_I^2 - p_I^1/2 - \left[\mathcal{V}(\hat{y}_I) - \mathcal{V}(\hat{x}_I^1)\right]/2$. If this is negative(positive) then the second(first) constraint is binding. Suppose for the moment that $p_I^2 > p_I^1/2 + \left[\mathcal{V}(\hat{y}_I) - \mathcal{V}(\hat{x}_I^1)\right]/2$. 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 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: [5]

$$p_I^1 = A + \mathcal{V}(\hat{x}_I^1) + p_I^2 - x_I^1 \tag{6}$$

[5] It is worth noting that only the expectations about the first period network dimension

2.2 Demand in period 2

Second period demand is derived as a residual of first period demand given the realised first period output. The necessary condition for having two active firms in the second period is the following:

$$p_I^2 - \mathcal{V}(\hat{y}_I) = p_E^2 - \mathcal{V}(\hat{y}_E) \tag{7}$$

where $p_i^2 - \mathcal{V}(\cdot)$ is the network size adjusted price for brand i. Let η be the common level of hedonic prices given in equation (7). 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

$$A - x_I^1 + \mathcal{V}(\hat{y}_I) - p_I^2 = A - x_I^1 + \mathcal{V}(\hat{y}_E) - p_E^2 = x_{tot} \tag{8}$$

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

$$p_I^2 = A - x_I^1 + \mathcal{V}(\hat{y}_I) - x_{tot} \qquad p_E^2 = A - x_I^1 + \mathcal{V}(\hat{y}_E) - x_{tot} \tag{9}$$

2.3 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, the consumers are indifferent between the two.

The two goods perform the same tasks but incorporate different technologies (word processors, spreadsheets and many other software packages share

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.

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.[6] In the following section we derive, by backward induction, the Cournot equilibrium in the second period and the first period monopolistic equilibrium. 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 in the seminal paper 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; in addition, FEE dispenses us from making ad hoc assumptions about how consumers expectations are formed and updated, which is something that would require a fully dynamic model.

The assumption of FEE is also useful in this two stage game; formally, with respect the second period networks, $\hat{x}_i^2$, consumers have expectations at the beginning of both periods: we should have therefore 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 $\mathcal{V}(\cdot)$. In order

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

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:*

$$\mathcal{V}(\cdot) = \theta(\cdot) \qquad \theta \in [0, \bar{\theta}] \quad \textit{and} \quad 0.704 < \bar{\theta} < 1$$

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 of the FEE, that it is unique and stable. [7] The ceiling $\bar{\theta}$ varies according to the kind of compatibility we are considering. The lower bound 0.704 for $\bar{\theta}$ excludes from the analysis the very high levels of the externality, those represented by a value of θ close to 1. Nonetheless this is not a strong restriction mainly because in the reality the impact of the externality rarely plays such a pervasive role. Furthermore, it applies only to a subset of the model solutions. For this reasons we believe these restrictions do not affect the descriptive strength of the predictions of our model.

3.1 Payoffs

In this section we present the FE payoffs in 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 $\mu = 0$, $\phi = 1$). By solving the game by backward induction, we start withe the last stage.

3.1.1 Second period Cournot equilibrium

Conditional on entry and given consumers expectations, in the second period firms compete on outputs. 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 optimal output are respectively:

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

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

These expressions give the optimal 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: $\hat{y}_I = x_I^1 + x_I^2 + \mu x_E^2$ 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

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

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

In Appendix 1 we prove the existence and uniqueness of the FE second period Cournot equilibrium. Depending on the values of the compatibility parameters μ and ϕ, expressions (12) and (13) provide the output produced by the incumbent and by the entrant under the different compatibility regimes that we have briefly mentioned above. More discussion will follow later in the paper when we solve various games which describe the optimal strategies adopted by the two competitors on the choice of their products compatibility.

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 (6) 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 maximisation problem it is easy to derive the first period production given consumers expectations on first period incumbent installed base $\hat{x}_I^1$:[8]

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

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

Appendix 2 shows that the condition $\theta < \bar{\theta}$ is sufficient for having a unique and stable equilibrium with fulfilled expectations. Furthermore, in the appendix we also present the first period equilibrium output; this can be easily obtained from (15) with the FE condition $\hat{x}_I^1 = x_I^1$.

We are now ready to present the FE payoffs in 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 $\mu = 0$, $\phi = 1$). These payoffs are:[9]

$$\pi_{c,c}^I = -\frac{A^2(8\theta^3 + 192\theta - 176 - 69\theta^2)}{(6\theta^2 - 25\theta + 22)^2} \quad \pi_{c,c}^E = \frac{(\theta-4)^2 A^2}{(6\theta^2 - 25\theta + 22)^2}$$

$$\pi_{c,i}^I = -\frac{A^2(60\theta^3 - 176 + 252\theta - 11\theta^4 - 155\theta^2 - 6\theta^5)}{(22 - \theta^3 + 15\theta^2 - 34\theta)^2} \quad \pi_{c,i}^E = \frac{(-\theta^2 + 13\theta - 4)^2 A^2}{(22 - \theta^3 + 15\theta^2 - 34\theta)^2}$$

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

$$\pi_{i,i}^I = -\frac{A^2(96\theta^3 - 176 + 428\theta - 2\theta^5 - 12\theta^4 - 343\theta^2)}{(22 - \theta^3 + 16\theta^2 - 42\theta)^2} \quad \pi_{i,i}^E = \frac{(-\theta^2 + 13\theta - 4)^2 A^2}{(22 - \theta^3 + 16\theta^2 - 42\theta)^2}$$

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

3.1.3 Entry preemption and full monopolistic profit

So far we have proceeded assuming that in the second period entry occurs. In some circumstances, this may no longer be the case and entry by a rival technology can be discouraged by the incumbent. Hence, before moving on, it is necessary to define the incumbent's profit when in $t = 2$ entry does not occur. As it will become clear later, entry of an incompatible rival is discouraged at the FE equilibrium when θ is sufficiently strong: in this case, by producing a sufficient level of output in the first period, the incumbent is able to preempt the rival thus avoiding entry.

Let us define a trigger value of θ according to the following:

Proposition 1. *Let $\theta^P = 0.315$. If $\theta \geq \theta^P$ then in the market there is no room for an incompatible rival ($\phi = 0$) and entry is preempted.*

[9]These payoffs can be derived by plugging all the equilibrium 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 we omit it.

Proof. Entrant's equilibrium output is given in (13) where x_I^1 is given by (20) in the appendix. When the entrant is incompatible ($\phi = 0$), it is easy to verify that x_E^2 decreases with first period output: from (11):

$$\left.\frac{dx_E^2(x_I^1)}{dx_I^1}\right|_{\phi=0} = -\frac{1}{3 - 4\theta + \theta(\mu + \theta)}$$

For $\theta < 1$ this is always negative; furthermore the above expression becomes more negative the stronger the network effect: for a sufficient level of θ the incumbent, by expanding first period output, has the power to foreclose the market thus preventing entry. With fulfilled expectations, the one-way incompatible entrant's outputs when the incumbent is compatible/incompatible are respectively:

$$x_E^2|_{\mu=1,\phi=0} = \frac{\theta^2 - 13\theta + 4}{15\theta^2 - \theta^3 - 34\theta + 22} \qquad x_E^2|_{\mu=0,\phi=0} = \frac{\theta^2 - 13\theta + 4}{16\theta^2 - \theta^3 - 42\theta + 22}$$

Preemption occurs whenever $x_E^2 \leq 0$. From the above expressions, both these output levels are negative or equal to 0 when $\theta \geq 0.315$. ■

The FEE can be derived following a procedure similar, although much simpler, to the one applied for the duopolistic case. For the sake of brevity we restrict ourself to the presentation of the equilibrium output and profits.[10]

Without entry in the second period, expectations are only on incumbent's network and compatibility is not an issue; demand functions are:

$$p_I^1 = A + \theta\hat{x}_I^1 - x_I^1 + p_I^2 \qquad p_I^2 = A - x_I^1 + \theta(x_I^1 + \hat{x}_I^2) - x_I^2$$

Solving the profit maximisation problem in the second period yields a FE output function of the first period installed base:

$$x_I^2(x_I^1) = \frac{A - (1-\theta)x_I^1}{2 - \theta}$$

Going backward, from the maximisation of the first period profit derives the following FEE:

$$x_I^1 = \frac{4A}{\theta^2 - 9\theta + 10}$$

and the total profit for the monopolist is therefore:

$$\pi^{mon} = 5\,\frac{(\theta - 3)^2\, A^2}{(\theta^2 - 9\,\theta + 10)^2} \tag{16}$$

[10]Again, the complete derivation of the full monopolist case is available on request.

4 The strategic analysis of compatibility

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

1. Compatibility through two-way converters supplied by the incumbent;
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. Allowing for performance disruption is an easy task from which we abstain to avoid cumbersome notation. Many software packages offer the possibility to read and save in rival's formats. We 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.[11] 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.

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:

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

[11] In later sections we show that the case of two-way converter supplied by the entrant yields trivial results. Note also that 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.

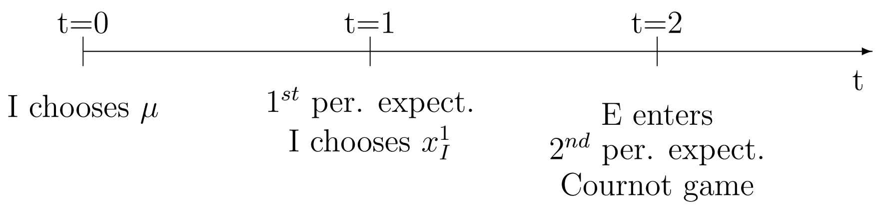

Figure 1: The time line with two-way converter

where $\mu = 0$ implies that no converter is built, and $\mu = 1$ otherwise.[12] The time line is represented in Fig. 1.

4.2 Compatibility through one-way converters

In this scenario each firm has the ability to build a one-way converter, which allows, without altering performance, 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 effect of these decisions on the size of the relevant networks has been already described in the previous subsection. Formally we have:

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

where $\phi = 0$ implies that the entrant builds no converter, and $\phi = 1$ otherwise and μ has the same meaning of the previous case. The timeline is represented in Fig. 2. 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

[12] 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.

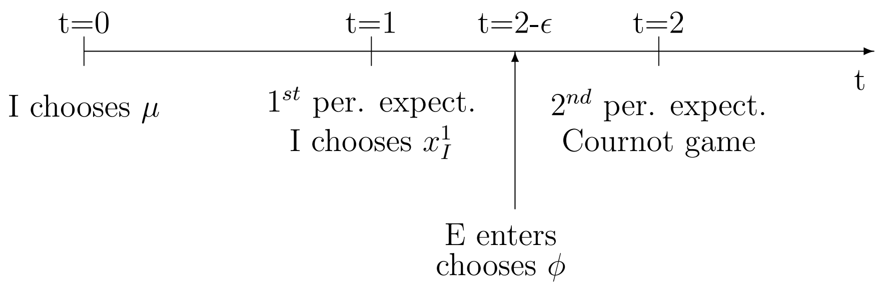

Figure 2: The time line with one-way converters

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.

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 information is disclosed, 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 networks is again the same as previously described. The time line is represented in Fig.(3).

5 Results

In the next three subsections we present the equilibrium for the three games considered.

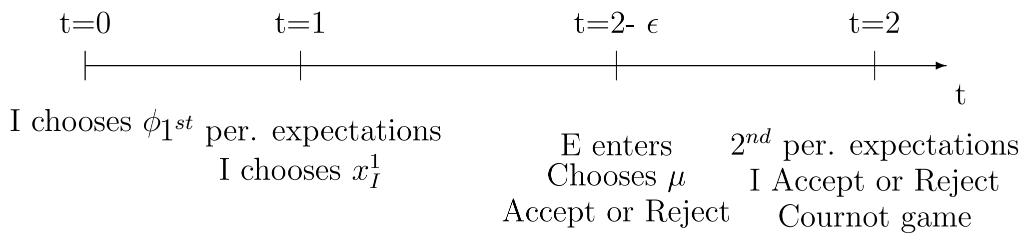

Figure 3: The time line with one-way converters and information disclosure

5.1 Compatibility through two-way converter

In this scenario, the incumbent can unilaterally choose whether the two goods are fully compatible or not.[13] By choosing 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 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 $\theta \geq \theta^P$ entry is deterred.*

Proof. Suppose $\theta < \theta^P$: 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 the incumbent goes for incompatibility. Suppose now that $\theta \geq \theta^P$. In this case we need to compare $\pi^I_{c,c}$ with π_{mon} given in expression 16. Since $\pi_{mon} > \pi^I_{c,c}$ then $\mu = 1$, which induces entry deterrence, is again the optimal incumbent's strategy. ■

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.

It is noteworthy that entry deterrence becomes feasible, under incompatibility, for $\theta \geq \theta^P$. The strategic effect mentioned above is thus reinforced and the incumbent prefers to be incompatible to achieve deterrence.

Consumers maximise their expected surplus across the two periods; high expected prices in period 2 increase demand in period 1, when the incumbent

[13]We do not consider the opposite case where the compatibility decision is up to the entrant. This is trivial since the entrant will always choose full compatibility.

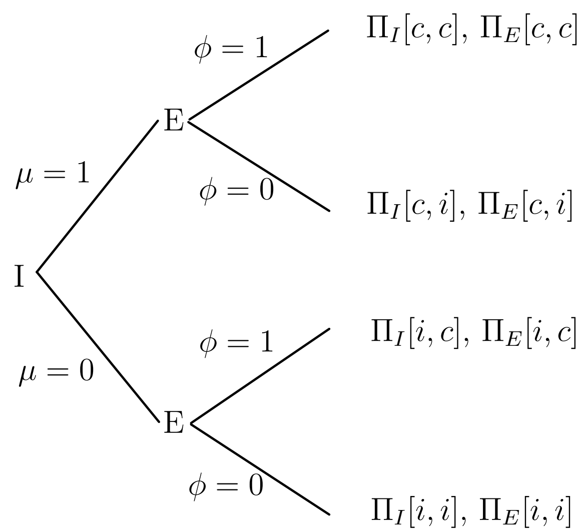

Figure 4: The game tree with one-way converters

is a monopolist. Incompatibility, then has the additional benefit of allowing 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 $\theta \geq \theta^P$.

5.2 Compatibility through one-way converters

The time line is depicted in Fig.2 above and the extended game tree is represented in Fig. 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 choice, decides whether to build a converter itself.

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

Proof. 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 $\theta \geq \theta^P$ 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. ■

This result is driven by the behavior of the entrant whose dominant strategy is to build the converter. By doing so, the entrant enlarge 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.

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

5.3 Compatibility through one-way converters and information disclosure

Under this scenario, 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 Fig. 5.

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

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

Proof. We determine the equilibrium by backward induction. Consider first the case with $\theta < \theta^P$; 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 ($t = 4$) has to decide whether to accept the offer on not. There are three nodes where the incumbent is asked to decide; these are represented by the following paths of actions:

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 $\mu = 1$.

Looking at Fig. 5, it is easy to see that if the incumbent is asked to accept/reject $\mu = 1$, then it is always optimal to accept since from the payoff functions:

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

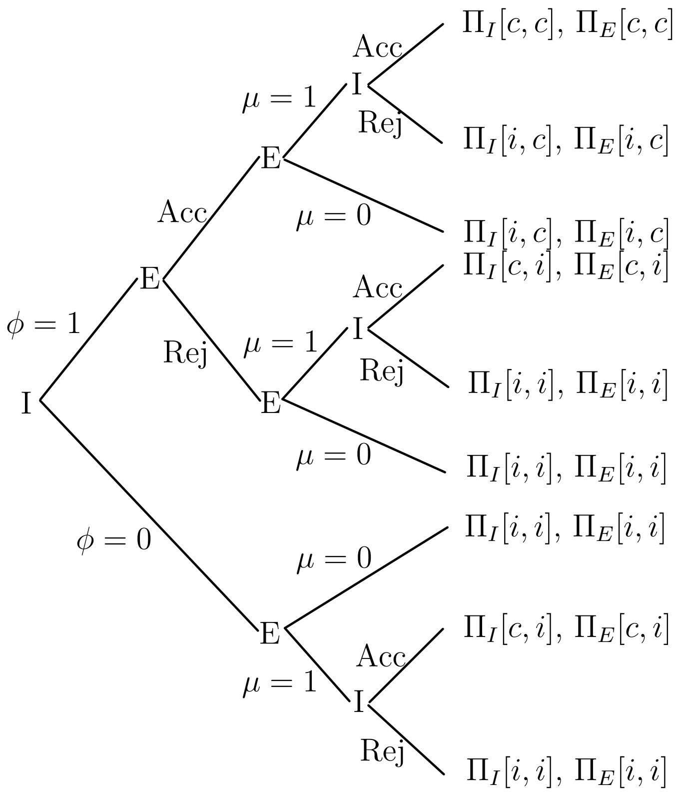

Figure 5: The game tree with one-way converters and information disclosure

At $t = 3$, the rival has to decide on whether to disclose its information by knowing that if information is disclosed, the incumbent will use it in order to provide a compatible product and to obtain a higher payoff. As clearly represented by the game tree, the rival is called to make such decision at three different nodes of the tree:

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, $\phi = 0$.

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

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

Furthermore, the stage before, the entrant has to accept/reject $\phi = 1$ conditional on the offer being made by the incumbent. According to the payoff function, the rival accepts the offer since $\pi^E_{i,i} < \pi^E_{i,c}$.
Finally, by knowing these sequence of decisions, the first period monopolist decides about the disclosure of its technical specifications at the beginning of the game; according to what has been discussed above, the incumbent opts not to reveal its information given that $\pi^I_{i,i} < \pi^I_{i,c}$. This is enough to show that the only subgame perfect FE equilibrium when $\theta < \theta^P$ is the full incompatibility regime where both the firms do not disclose their specifications.
If $\theta \geq \theta^P$ there is no room for entry of an incompatible rival (when $\phi = 0$): by choosing not to reveal its specifications, the monopolist can prevent entry. From $\pi^I_{c,c}$) and $\pi^I_{i,c}$ it is easy to verify that monopolist's profits are always bigger than the profits that the incumbent would obtain if entry occurs: $\pi_m > \max[\pi^I_{c,c}, \pi^I_{i,c}]$.
This implies that the incumbent will always deter entry by not disclosing the information. ■

This result is interesting: when the impact of network externalities is small enough, both firms decide not to disclose information to the rival. With stronger network externalities, the incumbent by denying its technical specifications is also able to deter entry. This result contradicts the predictions of existing literature on the effects network externalities. For example in Economides (1996b) it is shown that network effects move pro-competitively and an incumbent technology may have incentive to invite entry of a compatible entrant provided that network effects are sufficiently strong.

Our result is driven mainly by the timing of the events that we have modelled here. While the incumbent would like to accept the rival's offer of compatibility at the last stage of the game, the entrant is worsen off by revealing its technical information to the incumbent and therefore it will never launch the offer. The incumbent anticipates the entrant's strategy and goes for incompatibility.

6 Conclusion

This paper focuses on the strategic choice of compatibility between two initially incompatible goods in a two-stage game by an incumbent and an entrant firm. Consumers enjoy network externality in consumption and maximise expected surplus over the two periods. Compatibility may be achieved by means of a converter.

We derive a number of results under different assumptions about the nature of the converter: two-way compatibility, one-way compatibility and one-way compatibility with information disclosure 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 and depending on the strength of network externalities the incumbent may deter entry. When both firms can build a one-way converter and there are no property rights on the necessary technical specifications, the only fulfilled expectations subgame perfect 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. Entry deterrence will then occur for sufficiently strong network effects.

For expositional convenience we have referred our analysis to software goods, but it should be clear that the analysis applies more generally to any market exhibiting network effects in which interfaces can be built to bridge two otherwise technically incompatible networks.

Appendix 1: Existence and uniqueness of second period FE Cournot equilibrium.

Solving the maximisation problem (10) gives firms standard reaction curves:

$$x_I^2 = \frac{A - x_I^1 + \theta\, \hat{y}_I - x_E^2}{2} \tag{17}$$

$$x_E^2 = \frac{A - x_I^1 + \theta\, \hat{y}_E - x_I^2}{2} \tag{18}$$

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 sufficient for having both the reactions curves with fulfilled expectations 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(17) and (18), 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 also 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 (17) and (18):

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

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.

■

Appendix 2: Existence and uniqueness of first period FE equilibrium.

From expression (15), with FE the equilibrium level of expected (and realised) first period sales is the solution of $x_I^1 = x_I^1(\hat{x}_I^1)$ 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

$$\frac{dx_I^1(\hat{x}_I^1)}{d\hat{x}_I^1} < 1 \tag{19}$$

Deriving 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 (19) is verified for $\theta < 1$ for all the combinations of the compatibility parameters except that the full incompatibility case ($\mu = 0, \phi = 0$). In this case, condition (19) 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:

$$x_I^1 = \frac{-((5\mu\phi + 1 - 2\phi - 4\mu)\theta^2 + (-4\mu - \phi + 9)\theta - 10)A}{(-\phi + \mu\phi - 1 + \phi^2\mu)\theta^3 + (-\phi^2 + \phi - 9\mu\phi - \mu + 16)\theta^2 + (9\phi - 42 + 8\mu)\theta + 22} \quad (20)$$

■

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