

Network Externalities, Compatibility and Standards

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Major Paper presented to the
Department of Economics of the University of Ottawa
In partial fulfillment of the requirements of the M.A. Degree
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Ottawa, Ontario

August, 2003

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1. Introduction

Network externalities are defined as the increase in utility that a user derives from consumption of a product as the number of other users who consume the same product increases (Katz and Shapiro, 1985). The theory of network externalities is relevant to many fields of industrial organization, including firms' competitive strategies, standard setting and antitrust policy.

Throughout the research on network externalities, a key issue is compatibility, which has an impact on both firms and consumers. In industries where network externalities are present, there are a number of compatible technologies coexisting with incompatible ones, where firms use the choice of the level of compatibility to support their strategies. For example, a game for Sony's PlayStation cannot be played in Microsoft's Xbox or Nintendo's Game Cube: the three products are not compatible with each other. This is a problem of strategic compatibility. The three big producers of game machines adopt different standard so that they can maintain their market share of the games and the machine. To make a decision to choose among the three, a gamer will consider the games available in the market. The larger the variety of games available for a machine, the higher the value of the game machine will be. In this case, games and the game machine are strongly complementary, and the network externalities will influence the consumer's decision.

This paper reviews the literature on network externalities. I begin with the

definition of network externalities and characterization of network markets in section 2. In section 3 and 4, I discuss the access pricing problem and the credibility problem in network markets. In section 5, I focus on the choice of compatibility, where the firm is trying to solve a trade-off between the benefits and costs of compatibility, then I analyze the incentives for producers to make their products compatible under various market conditions, and the different methods used. In section 6, I discuss the social welfare and policy implications of network externalities. Section 7 concludes.

2. Concepts of network externalities

2.1 Network externalities

Initially, there was a phenomenon known as positive feedback effects or demand externalities in the telecommunications industry. Rohlfs (1974), Katz and Shapiro (1985) and other economists termed such effects “network externalities”. Liebiwutz (1998) describes a network externality as a change in the benefit, or surplus, that an agent derives from a good when the number of other agents consuming the same kind of good changes. More simply, network externalities can be understood as the increase in the willingness to pay for a unit of a good sold in the market when the total number of units sold increases.

Network externalities can be classified into direct and indirect externalities (Katz and Shapiro, 1985; Church and Gandal, 1992; Economides, 1996). When agents

are consuming the same product, direct network externalities are generated. For example, my application for an ICQ account will benefit the existing ICQ users, who now have an additional person to chat with.

In a broader sense, network externalities also arise in many non-network markets where complementary goods are important. Products that are strongly complementary also exhibit positive network effects. For example, camera bodies and lenses provide photographic services (Katz and Shapiro, 1994). DVD and DVD players provide video entertainments. This kind of externality is identified as indirect. Indirect externalities can arise only when the components are purchased at different times.

2.2 The characteristics of markets with network externalities

We will focus on markets where consumers derive little or no benefit from using a single component of the system. Katz and Shapiro (1994) provide a comprehensive and unified analysis of this type of market. There are a number of fundamental properties of network industries that are worth noting:

1 Start up

When the network good has little value when used in isolation, or in other words, no complementary good is available in the market, there arises the problem of start up. For example, if there is no or little software available, the value of a computer will drop dramatically.

2 Critical Mass

In his studies of communication markets, Rohlfs (1974) developed the concept of *critical mass*, which states that a sustainable growth of the network requires a minimal non-zero equilibrium size. Economides and Himmelberg (1995) set up a multiplicative formulation model to further interpret the concept by proving that the expected network size and customer base amount to a “chicken and egg” paradox. That is, with few consumers joining, the expected network size is small; and the smaller the expected network size, the fewer consumers will be attracted to come into the market.

3 Ability to Make Money from Both Sides of a Network

A firm can charge money on either or both sides of the network. This is common in the telecommunications services industry. A cell phone services provider can charge users when they originate calls or when they receive calls or for both. The availability of prices on both sides of the network enables the provider to make full use of complex pricing strategies. When a provider provides both hardware and complementary software in a network, it can apply the prices of the complementary software and hardware to maximize the network effect and therefore maximize its profits (Economides, 2003). This can explain, for example, why Sony is willing to sell its Play Station machine at a price equal to marginal cost and then gain from developing the game.

4 Externalities can be internalized

Firms can apply price discrimination to provide favorable terms to attract large users so that they can maximize their network effect. For example, the firm can compensate a large customer for the positive network effect it brings to the market by providing a very low price (Economides, 2003).

5 Asymmetric market shares

A firm with a larger market share has more complementary goods and its goods are therefore more valuable to consumers. In network markets, there are important asymmetries in market shares and profits. According to Economides and Flyer (2000)'s extreme case of PC operating systems market and specific software applications markets, the entry after the third firm has practically no influence on the output, prices, and profits of the top three firms as well as the consumers' and producers' surplus. From the fourth one on, firms' market shares are too small to bring significant influences to the market.

But the fact that the natural equilibrium market structure in network industries is "Winner take most" with very asymmetric market shares does not imply that competition is weak (Economides, 2003). On the contrary, in network industries, there is usually an intense "war" to be the dominant firm, because a dominant firm will create the top platform and reap most of the benefits.

6 Free entry does not necessarily lead to perfect competition

Because of (5), eliminating barriers to entry can encourage competition, but the market structure remains largely unchanged. This property brings new

challenges to antitrust authorities, since antitrust laws may not be able to change market structure by simply eliminating barriers to entry (Economides, 2003).

7 Market instability

Another important characteristic of network markets is that they are prone to instability (Yang, 1997). The coexistence of incompatible products may be unstable, with a single standard eventually dominating the market. For instance, there are currently several incompatible air-interface standards competing, Time Division Multiple Access (TDMA), Global System for Mobile Communications (GSM), Code Division Multiple Access (CDMA), and many nations have not yet decided which standard to adopt. Because of this instability, the current dominance of one product cannot be guaranteed to continue into the future. Market instability may be caused when there exist multiple equilibria, when there is larger expected sales than current ones and when the size of a disequilibria network is under the critical mass.

8 Path dependence / Lock-in

David (1985) developed the concept of path dependence through his positive feedback model. For later adopters, the choice of one technology over another depends on decisions made by earlier adopters. In a competitive network market, the impact can be significant. That is, small differences in initial conditions may lead to outcomes that are costly to change. In this temporal process, time is not a neutral component: irreversibility is one of the characteristics of diffusion trajectories. An already selected technology will persist over a long period of time,

even if it turns out to be an inferior technology, because of the cost of switching to the superior technology. The case of the QWERTY keyboard (David, 1985) is a well-known example of the path-dependence and irreversibility problems. QWERTY keyboard's current dominance is not due to its superiority, but because all users have invested in learning it.

3. The credibility problem in network markets

When there are network externalities, the value of a network good to its owner depends positively on the number of consumers who buy the good. Because of this property, the producer will try to convince consumers that the market will be large. A credibility problem in a network market may exist if a producer has an incentive to misstate his intentions in order to affect the behavior of consumers. Consumers, being aware of this incentive, will ignore or discount the statements of the producer. As a result, a lower than optimal quantity will be produced, which leads to a Pareto inefficient outcome (Economides, 1996).

Until 1985, most studies of this problem considered a multi-period setting with a basic durable good and complementary goods. Katz and Shapiro (1985) were the first to discuss the credibility problem in a market with direct network externalities. They assumed that consumers' expected market size is determined prior to the producer's decision. Once determined, consumers will no longer change their expectations. And the producers make their decisions on how much

to produce according to these expectations. Economides (1993, 1996) furthered the research in a setting in which consumer belief formation and production occurs simultaneously. In this context, there are at least two remedies available to the credibility problem. One is “Invitation to enter” advocated by Katz and Shapiro (1985) and Economides (1996), the other is “Pre-production” introduced by Etziony and Weiss (2001).

3.1 Inviting competition

Katz and Shapiro (1985) and Economides (1996) suggest solving the credibility problem by inviting competitors to share their technology and enter the market. Given consumers’ expected sales, a monopolist will choose a smaller output than total output in oligopoly in order to maximize profit. This implies that for any given expectations, higher expectations of sales can only be realized at equilibrium in a more competitive market than in monopoly market. To create the desired large network effect, the monopolist is required to invite a larger number of participants to the market, thus voluntarily giving up their monopoly position. As a result, consumers believe the market will be large, which enables the innovator-monopolist to sell higher quantities and charge a higher price. It seems paradoxical that the leader benefits from the increase in the network size along with the introduction of competitors and the increase in competition. Actually only if the externality is strong enough, will the network effect prevail over the

competitive effect of new entry.

Economides (1996) set up a model based on consumers' expectations of network-wide sales that are fulfilled at equilibrium. The results are established in quantity leadership and in simultaneous Cournot. When the innovator can charge lump sum licensing fees, he will invite a large number of competitors. But if the innovator-monopolist (quantity leader) is only able to charge marginal licensing fees, when network externalities are weak, he will charge a positive licensing fee for markets. When the externalities are sufficiently strong, the incumbent would subsidize the output of the competitors he invites to enter. The quantity leader will invite entry whether the network externalities are strong or weak, but his profits will be higher than when licensing is free

Considering the incentives to invite entry by a monopolist, Kim (2002) shows that when producing an homogeneous good, a monopolist holder of a technology has no incentive to license to competitors producing no matter how strong network effects are because it is costless for a new entrant to replicate, resulting in oligopoly. While the products are different, the monopolist invites entry when the network externality is weak, since new varieties are costly to introduce.

3.2 Pre-production

The remedy Etziony and Weiss (2001) suggest is pre-producing the good, i.e., creating a large stock of goods that will be supplied to the market when the good

is first introduced. This has the effect of changing the firm's cost structure in a manner that causes consumers to believe that the amount it will optimally sell (and hence the market size) will increase, again leading to higher profitability of the pre-producer.

3.3 Combination of *inviting competition* and *pre-production*

Etziony and Weiss (2001) also combine the two strategies, therefore there are five strategies available: no action, inviting competition, pre-production, pre-production by all firms and inviting competition, pre-production only by the leader and inviting competition.

Comparing the two strategies, inviting competition and pre-producing, Etziony and Weiss (2001) notice that when the marginal cost is high pre-producing becomes more effective than inviting competition; while when the marginal cost is low or equal to zero, to convince the consumer that the marginal cost will be lower is not useful, so inviting competitors is preferred. As for the two combination strategies, in the first the leader produces and then invites competitors who then also pre-produce, the second one is that the leader pre-produces but the invited firms produce in the same period in which they sell. According to Etziony and Weiss (2001)'s result, the two combined strategies will weakly dominate the first three strategies as they increase the range of possibilities facing the producer.

Comparing the two combination strategies, it is shown that the latter dominates the former. Since the price clearly falls with pre-production, it is expected that other firms will lower production when a firm pre-produces. If the invited firms pre-produce, the inviter's profit will be harmed. Etziony and Weiss (2001) show that there is still a range over which the leader does not invite competition when the fringe firms pre-produce so that the leader can keep its quantity (and price) constant. Inviting competitors creates a positive externality that benefits all firms, while pre-producing helps only the firm doing the pre-producing and harms all other firms. Thus, the leader invites the competitors so he can benefit from the positive externality, but he will be better off if the competitors do not pre-produce.

Etziony and Weiss (2001) carry out the comparison in different aspects: the number of competitors, the level of production of the leader, the size of the network market, and the price level in each strategy.

ns stands for **No strategy** (no action)

ic stands for **Invite Competition**

pp stands for **Pre-production**

pp_n stands for **Pre-production with n Invited Firms and Invite Competition**

pp_l stands for **Pre-production with only leader firm and Invite Competition**

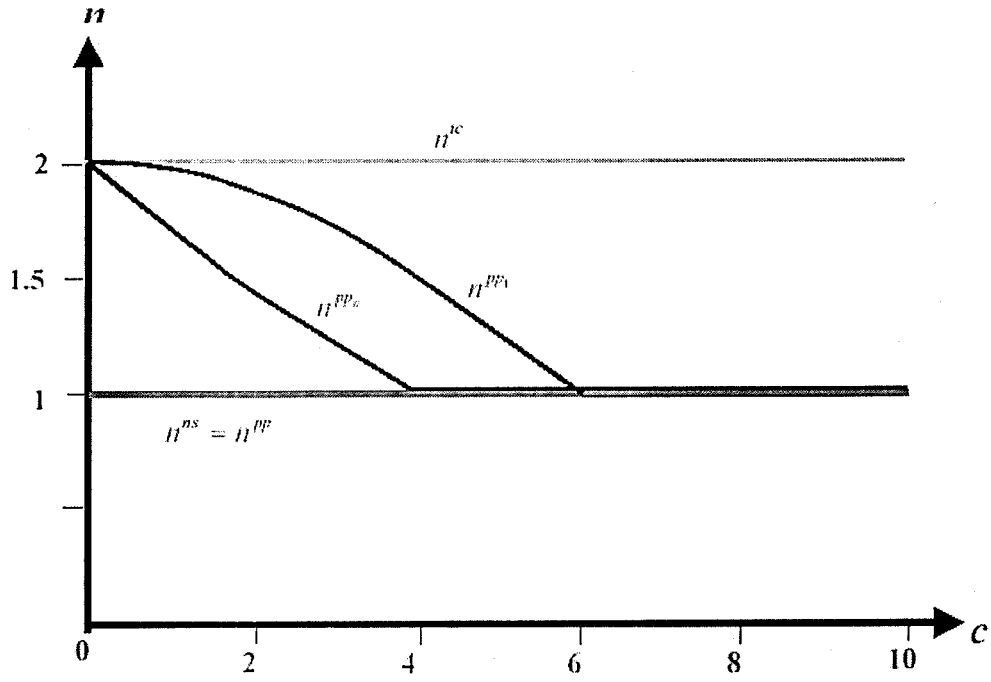


Figure 1 Number of Firms Source: Etziony and Weiss , (2001) Appendix: Figure 8

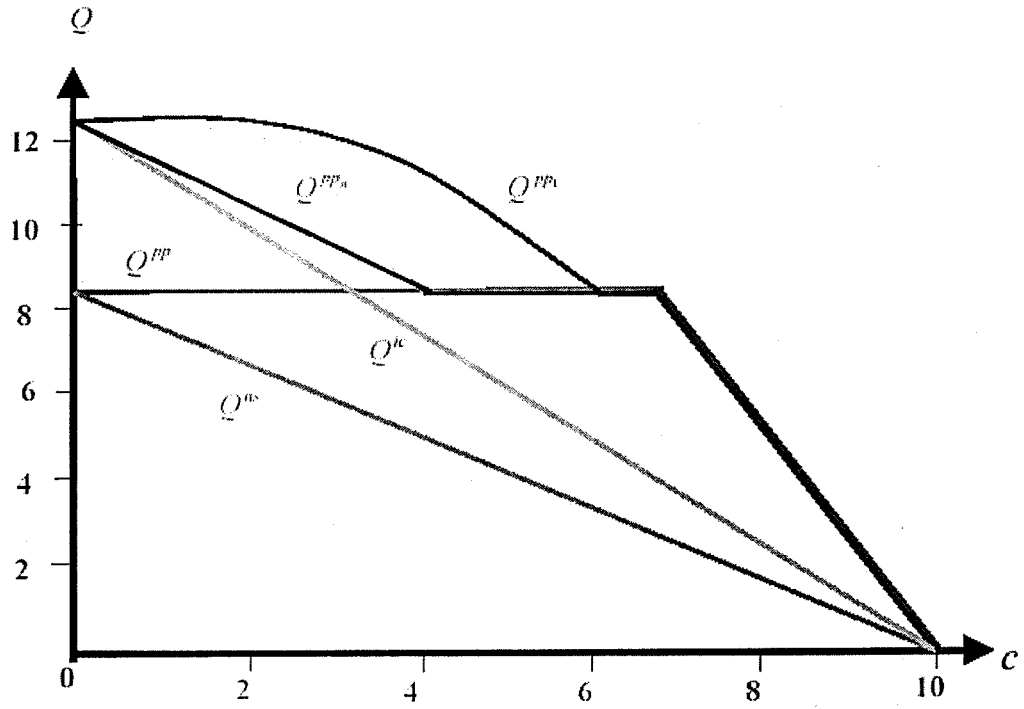


Figure 2 Production by the Leader Source: Etziony and Weiss , (2001) Appendix: Figure 9

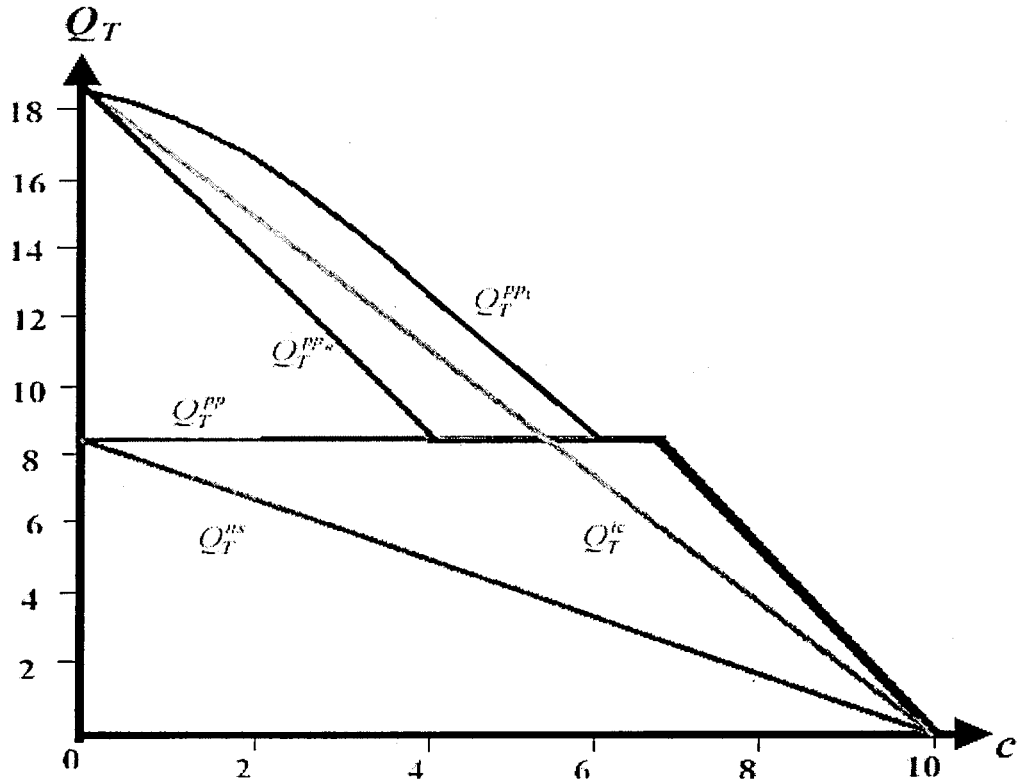


Figure 3 Market Size

Source: Etziony and Weiss , (2001) Appendix: Figure 10

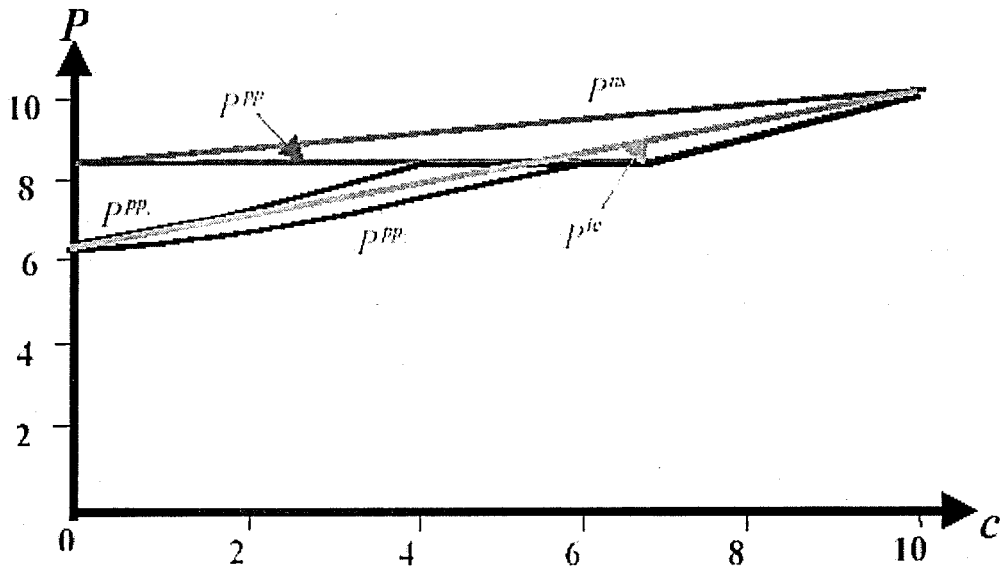


Figure 4 Price

Source: Etziony and Weiss , (2001) Appendix: Figure 11

In Figure 1, comparing the two combination strategies, we notice that more firms are invited when the invited firms do not pre-produce than when they do.

When the cost increases, pre-production is preferred as we discussed before, and the production increases with pre-production. Though the cost increase will also bring down production directly, the increase brought by pre-production will dominate when the costs are low. So in Figure 2 the curve *ppl* stands for the greatest quantity produced. As seen in the other two figures, the market size is highest and the price is lowest with the dominant strategy, pre-production with only leader firm and Invite Competition.

All the results support the dominant strategy of pre-production only by the leader and inviting competition. Since the consumers get a more valuable good for a lower price with greater market size, we can safely conclude that this strategy is optimal not only for the producer; but also for consumers.¹

¹ Here is an application of the combination strategy. A consumer purchases a DVD player because he wants to watch movies in DVD format. If there are only few movies available in DVDs mode, and the consumer believes the DVDs will not be popular in the future, he may refuse to make the purchase. In addition, if he believes the cost of DVDs will rise significantly, he may not purchase the DVD player. So the producer could attempt to convince consumers that DVD movies will be made available and that prices will be kept low. But the consumer may believe that the producer will be more concerned with creating the next generation of machines rather than with the creation of new DVD movies, and that there will be nothing compelling the producer not to increase prices of DVDS once the DVD player have been purchased. The inability of producers to credibly commit to actions in future periods is particularly acute in high-tech industries because of the high rate of technological progress. In this case, to solve the credibility problem, the producer can pre-produce by creating a large stock of DVD movies in the first period, or invite competitors to make DVD movies together (invite competition).

4. Access pricing with network externalities

4.1 The Efficient Component Pricing Rule (ECPR)

Baumol and Sidak (1994) and Willig (1979) proposed the efficient component pricing rule (ECPR) as the proper way to assign access charges to an entrant wishing to join a network which is operated by an incumbent monopoly. When the services offered by the potential entrant are substitutes to the ones offered by the monopoly, the ECPR states that the access price charged by the monopoly must be equal to the average incremental cost incurred by the entrant plus the opportunity cost or profit foregone with the entry of the competitor.

Based on the model of Armstrong, (1996), the ECPR requires that the monopoly provides access to the entrant if its profits remain unchanged after the entry of the competitor. So we get the following equation:

$$PX_0 - C(X_0) = PX(P, p(a), N) + as(p, a) - C(X(P, p(a), N), s(p, a)) \quad (1)$$

Where a is the access charge, s is the entrant's supply of output in the competitive market, $s=(p, a)$, where $s_p > 0$, $s_a < 0$. X is demand that depends on the price P of the incumbent's product, the price p of the entrant's product and the total number N of subscribers of the entrant, $X=X(P, p(a), N)$ with $X_p > 0$ and $p_a > 0$, $X_N > 0$. N depends negatively on the price p and hence the access charge a , $N_{ppa} < 0$. $C(X, s)$ is the cost to monopoly of producing and selling X units and providing the entrant with s units of access. X_0 is the pre-entry output of the monopoly. For simplicity, it is assumed that the entrant requires one unit of access

from the monopoly to supply one unit of its final product s .

In order to solve for the access charge a , it is necessary that there are constant returns to scale in the output of the monopoly and the output of the entrant so that their respective marginal costs are constant and independent of the access charge a . Since the price p depends on a , we still need to assume that p is determined in the competitive market. Solving for a yields,

$$a = \frac{C(X, s)/s}{I} + \frac{(P(X_0 - X) - C(X_0))/s}{II} \quad (2)$$

Equation (2) is the formula for the ECPR. I is the direct incremental cost of providing access and II is the marginal opportunity cost provided to the entrant.

As we know, this formula is derived only when p and s have been determined in the competitive market. If the two goods are homogeneous, $s = X_0 - X$ and (2) reduces to

$$a = \frac{C(X, s)}{s} + P - \frac{C(X_0)}{s} \quad (3)$$

In this case, a is determined in advance since the displacement in the profit of the monopoly by the entry of the competitor is already known. But if the two goods are not perfect substitutes then the opportunity cost is not known in advance. In practice, s depends on a , so a cannot be derived simultaneously with s .

Yannelis (2002) pointed out that the optimality properties of the ECPR may

exist under some restrictive assumptions, but do not hold in the presence of network externalities. The reason is that, when network externalities exist, the ECPR fails to incorporate the social benefit accrued to consumers of the fixed network even though it considers the social opportunity cost of production. Yannelis (2002) has also demonstrated that the opportunity cost may be reduced with the presence of network externalities. However, despite its weaknesses, the ECPR can help us take the terms of the social opportunity cost into account when determining the optimal access price.

5. Compatibility

5.1 The concept of compatibility

Physical networks are compatible if direct interconnection is allowed; virtual networks are said to be compatible if various components of the system can work together (Lemley and O'Brien, 1997). Shy (1995) defines compatibility as one brand being able to be operated or used by other brands, which is a horizontal relationship. When the new hardware can handle old-generation software we call it "backward compatibility"; while "forward compatible" means the old hardware can use new-generation software programs; however, it cannot utilize the software's full range of functions. For example, in 1950, the Federal Communications Commission (FCC) voted to adopt CBS's color system as an industry standard. The system was only backward compatible, i.e., color TV could

receive black-and-white (B/W) signals, while B/W TV could not receive color TV signals. Since a majority of households at that time were using B/W TV sets, broadcasting companies were not willing to broadcast major programs in color. As a result, consumers did not have an incentive to upgrade to color TV, because of the limited number of programs in color. Finally, in 1953, the FCC decided to enable both B/W and color TV customers to receive color TV signals. After this change, Color TV programming increased rapidly, and the demand for color TV boomed. In this case the technology the FCC adopted in 1953 is called “two-way compatible”, which means both side make their machines compatible with the other’s software, while the 1950 technology was “one-way compatible” (Nahm, 1999), where there is only one side providing compatibility.

5.2 The choice of compatibility

Compatibility turns out to be a strategic issue in industries exhibiting network externalities. There are various reasons for firms to choose compatibility. These include reputation, market shares, expected costs in the future and the degree of competition.

5.2.1 Consumers’ expectation and preferences

Katz and Shapiro (1985) develop a model with firms selling a homogeneous product, while consumers have heterogeneous valuations of the basic product, but are indifferent toward firm size. They show that there exists an asymmetric

(fulfilled expectations) equilibrium where firms are not compatible, and that a large firm favors compatibility less than a small firm does. Firms with large or small networks benefit from expansion of networks (through compatibility) asymmetrically, with firms with smaller existing product networks or lack of good reputation benefiting more, and thus more willing to support compatibility. Because when the competing technologies are compatible, consumers don't have to worry about choosing the wrong technology and being stuck on a smaller network anymore, firm's reputation becomes less important to consumers. Katz and Shapiro (1986b) study how compatibility affects price competition when the two systems compete over time. They found that in the early stages of the product life cycle, compatibility relaxes competition by reducing the threat of tipping.² But in the later stages of the product life cycle, compatibility tends to intensify competition because compatibility prevents one firm from dominating the market. The firm who expects that it will have lower costs than its rival in the future may reject compatibility so that it can become the dominant firm.

Economides and Flyer (1997) extend the Katz and Shapiro (1985) model to allow for heterogeneous preferences towards firm size and a varying degree of importance for network effects. They maintain the assumption of a homogeneous product and figure out the equilibrium coalition structures under different

² A technology gets an early advantage as a first mover and benefits from increasing returns to scale. The larger network size leads new users to adopt that technology, reinforcing early successes and aggravating the rivals. Finally, competing technology leaves the market. A market that settles on a single standard is said to have "tipped." (Page, and Lopatka, 1997)

conditions. They discuss firm's choice between a compatible leading standard and a unique standard. A firm adhering to a compatible standard can benefit from accessing a larger network, but loses direct control over the market supply of the good and faces more intra-platform competition. Alternatively, adhering to a unique standard allows the firm to face less or no competition, but it sacrifices the positive network effects. "The tension between these economic forces shapes the coalition formation equilibrium in these markets" (Economides and Flyer, 1997:30). The firm's decision will depend on the extent of the network externality and the number of active firms in the market. Because when the network externalities are weak, most market interactions are close to the market equilibriums in a world of no externalities. When the externalities are strong, the equilibrium market structure brings some new feature reversed to the traditional one. For example, even in presence of free entry and no fixed cost, "there is extreme asymmetry of outputs, prices and profits" (Economides and Flyer, 1997:32).

Nahm (1999) builds a vertically differentiated products model with heterogeneous consumer preferences and allows the interaction of consumers' preferences and network effects. He analyzes the effects of compatibility on software supply and hardware demand in a competitive hardware market and a monopoly hardware market. In the first case, backward compatibility increases the valuation of the hardware market but reduces the valuation of higher

consumer types. In the second case, the effect of backward compatibility on the monopolist's profit depends on how consumers substitute between old and new software programs and how sensitive the number of programs is to consumers' expenditures. Backward and forward compatibility decisions have the direct effect of changing a consumer's software choice set and also have the indirect effect of changing the software prices and variety. While the combined effects influence hardware demand.

Mason (2001) develops a model in which consumers have different preferences for firm size and location; moreover, firms are differentiated both vertically and horizontally. In this setting there exist two effects that determine firms' incentives toward compatibility. Firstly, compatibility decreases vertical differentiation between firms of different sizes. If it were assumed that compatibility is perfect and costless, consumers would be indifferent about which firm they buy from. As a result, compatibility increases competition between firms, and profits may fall. Secondly, compatibility decreases competition. As we know, when firms' products are not compatible, it is firm's size that determines the 'quality' of a firm, and competition for market share is intense. Compatibility, by decreasing the importance of market share for horizontally differentiated firms, also weakens competition. Which effect dominates depends on the relative importance of horizontal and vertical aspects in consumers' utilities. For example, when firm size is a relatively important factor for consumers, neither the large nor

the small firm wishes to be compatible in the unique asymmetric equilibrium. For intermediate cases, the larger firm does not wish to be compatible, while the smaller firm prefers compatibility.

5.2.2 Innovation

Katz and Shapiro (1986) also deal with firms' compatibility choice in a market of cost-reducing technological progress. They conclude that the technologically superior firm may not prefer compatibility so that it can attract consumers who are afraid of getting stuck with the obsolete technology, while the technologically inferior firm always prefers compatibility in order to eliminate the consumers' worry of being locked in the outdated technology after the innovation takes place.

It is generically accepted that the consumers' expectations are of great importance. In contrast to Katz and Shapiro (1985)'s opinion, Kim (2000) regards the choice of compatibility of the products as the result of firms' unilateral or bilateral decisions instead of an exogenous characteristic of the market. And in contrast to Katz and Shapiro (1986), Kim assumes that technological progress is a quality improving process, rather than cost-reducing. He explores the relationship between the firms' compatibility choice and quality improving technological progress. Firms' compatibility choice critically depends on how users' expectations of the network size are formed. Kim discussed the compatibility choice in two cases, static expectations and rational expectations. In each case he

solved the model with and without technological innovation. He draws the conclusion that if users have rational expectations, the firm with the small or no innovation prefers full compatibility, while the firm with the large innovation prefers complete incompatibility. These results are similar to those of Katz and Shapiro (1986), but are obtained through a different mechanism. Katz and Shapiro found that the firm with the large (cost-reducing) innovation makes its technology incompatible in order to attract consumers who are afraid of getting stuck with the obsolete technology after the innovation. But in Kim's model, perfect incompatibility is chosen by the firm with the large innovation in order to prevent consumers from switching away after the innovation. Concerning a technologically inferior firm, it prefers compatibility because it wants to recover the lost market share induced by the rival's innovation. But in Katz and Shapiro (1986), the firm with inferior technology prefers compatibility in order to eliminate the consumers' worry of being locked in the outdated technology after the innovation takes place.

Farrell and Saloner (1992) discuss the incentive for a dominant firm to refuse the disclosure of its proprietary technical information to prevent a rival firm from building an adapter. An adapter allows one group of users to benefit from the network externalities, which benefit another group. Farrell and Saloner also found that when a technology was supplied only by a single firm, that firm is willing to raise the rival's cost of building the converter.

De Palma and Leruth (1996) use a duopoly model to show that when the uncertainty about which firm would become the dominant firm is sufficient, firms choose compatibility in an early stage of the game. Palma (1999) extends this analysis by allowing consumers to buy from both firms. He considers how such “double purchasing” affects firms' decisions towards compatibility, showing that there tends to be more standardization than is socially optimal.

Manenti and Somma (2002) further the study of the strategic choice of compatibility between an incumbent and an entrant firm in a two-stage game, where compatibility may be achieved by means of a converter. The equilibrium in the compatibility game depends on the type of converter available to the competing firms to make their technologies compatible. In the first stage the firm is the only producer and in the second stage the incumbent faces a potential entrant who supplies a homogeneous good endowed with a different technology. Then they explore three different scenarios concerning compatibility. When compatibility is achieved through two-way converters supplied either by the incumbent or the entrant, incompatibilities will prevail in equilibrium, which is similar to Kim (2002)'s result. When compatibility is achieved through one-way converters supplied by the incumbent and the entrant, the equilibrium will be full compatibility, in contrast to Kim (2002)'s result. Finally, when each firm has property rights on its technical specifications, the equilibrium will be full incompatibility. With incompatibility, the incumbent can deter entry when

network effects are strong. An incompatible entrant will always prefer to build an adapter, which will allow it to enjoy the benefits of the incumbent's installed base.

5.2.3 Product differentiation

In Katz and Shapiro (1994), product differentiation was discussed. It may have similar effects on compatibility incentives as price competition. With the positive feedback of network effects, a firm will have an advantage over its rivals in establishing an installed base when consumers have a preference for its components. Therefore the firm may prefer incompatibility. Under incompatibility, the entrant will suffer an installed base disadvantage. They also note that firms may support compatibility when it maximizes total industry profit.

Baake and Boom (1997) allow the consumers' evaluations of firms' goods to depend on the inherent qualities of the goods as well as on the market shares of the firms. In the equilibrium that they identify, the larger firm would prefer not to be compatible, but the smaller firm prefers compatibility and is able to induce agreement by the larger firm through the choice of the inherent quality of its good. The model in this paper nests some or all parts of these analyses, while including other cases not considered by the earlier papers.

Jonard and Schenk (1999) set up a horizontal differentiation model with network externalities to study firms' compatibility decisions. When the goods are compatible, which allows the consumers to access a larger network, consumers

make a higher valuation of goods and are more willing to buy them. On the other hand, compatibility increases substitutability between products, leading to a higher degree of competition. They used a one shot game in which firms choose whether to remain incompatible or not. There exists a trade-off between product differentiation and network externalities; the outcome depends on the functional form of the externalities function. When network externalities are very concave, compatibility is the equilibrium; if however the externalities are less concave, both overall incompatibility and full compatibility can be equilibria.

5.2.4 Compatibility with indirect network externalities and between networks

Chou and Shy (1989, 1990) investigate the incentives of firms to produce compatible products in a market where there are no direct network externalities, but only indirect ones. They analyze a computer industry with the assumption that specific software is a complementary product. Their conclusion is that despite the fact that a computer firm increases the variety of its supporting software by making its machine compatible with other machines' software, it may end up losing part of its market share and profit by investing in compatibility. Chou and Shy investigate the computer industry equilibria under three hardware designs: two-way compatibility, one-way compatibility, and incompatibility. Here two-way compatibility means both computer firms make their machines compatible with the other's software, incompatibility means no firm invests in compatibility, while one-way compatibility means only one firm makes its

machine compatible with the other's software. One-way compatibility may result in two types of equilibria; in one equilibrium, machine specific software coexists with common software, which is called economically one-way compatible; in the other equilibrium, only common software is produced, where the machines are called economically compatible. This framework is useful to explain why in some industries firms do not invest in making their products compatible. Because if one firm has an incentive to make its product compatible with the other firm's software, then one-way compatibility may result in a situation where the machines are economically compatible, thereby eliminating the incentive for the second firm to invest in compatibility.

Economides (1991) develops an economic model to explore the incentives of private networks to be compatible by forming shared networks. He concludes that the choice of compatibility is decided by the relative scale of the demand for transactions within and across private networks. In other words, when the demand for transactions across private networks is the same as the demand for transactions within the private networks, each private network prefers compatibility with other private networks. In contrast, when demand for transactions across networks is low, each private network prefers incompatibility and blocks access from outside. As a result, two private networks maximize the incompatibility. When the demand for transactions within only one of the two private networks is high, one network chooses to maximize incompatibilities, while the other private network

desires compatibility, which leads to partial incompatibility between the two networks.

5.3 How to access compatibility

Farrell and Saloner (1987) sort compatibility by the means of achieving it:

5.3.1 Physical compatibility

Physical objects are designed to fit together physically or electro-magnetically. The availability of converters, translators, adapter, and other “gateway technologies” achieves compatibility. Shapiro and Varian (1999) illustrate that entrant firms who face an incompatible incumbent often add an adapter/converter to somehow interconnect with the established technology.

5.3.2 A de facto standard

One of a number of competing standards wins and followers begin to imitate the successful products. However, a standard war may lead to a single, proprietary product. To avoid this, firms can team up together to promote a new standard. For instance, in order to avoid another Beta/VHS format war, hardware manufacturers led by Sony, Toshiba, and Panasonic, together with movie studios led by Warner and Columbia (a division of Sony), cooperated to establish a single standard. As a result of their efforts, the Digital Video Disc or Digital Versatile Disc (DVD) came out. DVDs can store ten times as much information as compact discs (CD), providing a five channel surround soundtrack (Dranove and Gandaly, 2000). But even so, firms that have not been invited to take part in the setting of standards

may suffer from their exclusion.

5.3.3 Giving up proprietary control

Instead of severe competition, a vendor may choose to give up proprietary control of a technology, or license it cheaply in order to make it more credible as a market standard. For example, Adobe issues Adobe Acrobat Reader freely. Acrobat Reader enables users to view and print Adobe Portable Document Format (PDF) files on all major hardware and operating system platforms. With a ten-year proven track record, PDF became a universal file format that covers the fonts, images, graphics, and layout of any source document. More than 500 million copies of the Adobe Acrobat Reader have been distributed. Even the governments of the United Kingdom and Germany use PDF for electronic document exchange. Finally, PDF became the de facto standard for the secure and reliable distribution and exchange of electronic documents and forms around the world (Adobe Official Website).

5.3.4 International compatibility achieved by the International Standardization Commissions' work

Industry standards bodies arise to try to solve coordination problems. Now there are hundreds of official and unofficial standard setting bodies, like the International Organization for Standardization (ISO), which covers all areas except electrical and electronic engineering; and the International Electrotechnical Commission (IEC) which covers the fields of electrical and electronic engineering. Formal standard setting is designed to be open to all participants

without any firm controlling the standard (Shapiro, 2000). However, these standards bodies are often criticized that the proceedings to set a formal standard are too slow, too political and the chosen standard is not always the best choice.

6. Social welfare and policy implication

6.1 The costs and benefits of compatibility and standards

Compatibility has many benefits. First, there will be greater realization of network externalities. In a market with network externalities, products must be linked to physical or conceptual “networks” in order to create value. When all users are in a single network, the size of the network is maximized and positive network effects come into being. For example, a telephone user benefits from the fact that any given user can communicate with any other user by phone. Similarly, in hardware-software networks, PC users benefit from access to a larger software market than Mac users. This is likely to lead to increased entry, variety, and greater price and innovation competition in the supply of software components for PC (Shapiro, 2000).

Second, compatibility reduces production costs. Farrell and Saloner (1987) state that with greater scale economies and allowing the use of interchangeable parts, standardization reduces costs associated with production and assembly. The more people have the original product, the more readily and cheaply available complementary products will be. Furthermore, standardization also saves on the costs of training how to use the product. For instance, most of the software in the

market is Windows-based, which simplifies the application of the software greatly.

Third, compatibility protects buyers from being locked in. In the TV game case mentioned in the introduction, consumers lack the protection of compatibility. Once they choose one of the game machines, they are locked in and can only play the games issued by the same producer of the game machine. The Federal Communications Commission (FCC) sets standards that all television receivers must meet with the signals sent out by local broadcasters, so the buyers are protected and don't have to worry about losing a channel because of technology compatibility problems (Nahm, 1999).

However, compatibility may constrain product variety and innovation. The need to meet a standard imposes limits on firms' product design choices, which leads to a reduction in variety. An industry may get stuck on an old and inferior technology even when a new technology is available. This happens when firms lack complete information. Even if everyone prefers the new technology, as a result of limit switching, one might switch, but others will not follow. The standard also restricts to the innovation, because it will take more time to create a new product adhering existing standard. When it is possible to introduce a new generation, firms must consider whether to preserve intergenerational compatibility, and sometimes they refuse to. They may not choose the new standard because the incompatibility costs are borne by them, leaving a larger

installed base of the old standard. On the other hand, systems compatibility can increase available variety by allowing "mix and match" purchase (Farrell and Saloner, 1987). For example, when buying a PC, consumers can combine different hardware settings to meet their needs.

Lastly, compatibility will have positive and negative impacts on competition. When competing products are compatible, companies tend to compete on price, product features, and post-sales service. At the same time, some aspects of compatibility encourage entry, allowing any firm to enter a market with a homogenous product. However, if competing standards are proprietary, companies will compete fiercely to become a dominant standard. This may be good competition at first, however once a standard is reached, it can lead to monopoly power. Compatibility increases competition at all points in time if the entire product category would fail to take off without standardization, because consumers are too worried about being stranded to make initial purchases (Shapiro, 2000).

6.2 Policy implications

6.2.1 Government intervention

Katz and Shapiro (1985) point out that public policy can have an important impact on the features which private decisions will depend on, such as the possibility for firms to act unilaterally and the feasibility of side payments. Furthermore, public policy can affect the cost of compatibility. When firms are

permitted to get together, they may reduce the cost of compatibility by cooperation.

Katz and Shapiro (1994) conclude that the equilibrium in systems markets may diverge from the social optimum: (1) economies of scale and product differentiation will lead the market to oligopoly or monopolistic competition, instead of perfect competition; (2) due to the importance of R&D and innovation, together with the risk of tipping, these markets are often monopolized by one firm. Naturally, government intervention may be called upon to improve market performance. However Katz and Shapiro question public policy toward systems markets by acknowledging that governments may not have the proper incentives to achieve better standards or may lack information for proper policy.

Shy (2001) uses the FCC colour TV standard setting case and Japanese MITI (Ministry of International Trade and Industry) high-definition TV standard setting case to demonstrate why government intervention in standard setting is undesirable. In the first case, the market rejected the government chosen standard. In the second case, the official standard was considered to be outdated. In Shy's view, even though market failures may occur where an industry standardizes on a inferior technology, government's intervention is still not advocated, because there is no guarantee that the government will choose the best standard. Moreover, because politicians are financed partly by firms, their independence is doubted.

2.2 Antitrust

The concepts of network externalities and compatibility attract the interests of more and more policy makers and begin to be taken into consideration in antitrust lawsuits. Significant changes in technology have enhanced the needs of reshaping antitrust to meet the new conditions. “Traditional antitrust intervention cannot accomplish anything because the conditions that such intervention seeks to establish already exist in this market. Unfortunately, the desired competitive outcome is not.” (Economides, 2003:15) Antitrust has made an effort to introduce free entry to stimulate competition. But as I mentioned as a characteristic of network market, free entry could bring more participants into the market, but it does not necessarily eliminate the profits of the high production firms, and therefore fails to change the market structure significantly. Firms do not reach their high output and market domination by exclusion, coercion, tying, erecting barriers to entry, or any other anti-competitive behavior. The extreme inequality in market shares is a natural feature of the market equilibrium, “No anti-competitive acts are necessary to create market inequality” (Economides, 2003:14). Network markets bring new challenge to antitrust authorities, because if there is no anti-competitive behavior, the antitrust authorities can hardly intervene.

Shapiro (2000) asserts that when antitrust enforcers are deciding whether to allow cooperative standard setting, they should consider the following points. First, if the firms in the proposed standards coalition have market power, antitrust should

be concerned. In contrast, if the firms lack market power collectively and there are firms that could put forth competing standards, then cooperation will not harm competition.

Second, it is important to make sure that the coalition has closed membership. On the one hand, open membership can prevent member firms involved from excluding non-member firms the market. But on the other hand, open membership will increase the probability of firm's possessing market power and decrease the degree of competition.

Third, if two or more companies each has patents that are essential to production, this will increase the incentives to cooperate. However, the firms could license to each other and to third parties separately, which leads to higher royalty rates than collective licensing. So in this case, cooperative standard setting should not be allowed.

Fourth, since royalties have cartel-like effects, we need to make sure royalties are not required for adhering to the standard.

Fifth, as discussed in section 2.2, Rohlfs (1974) developed the concept of *critical mass*, which states that a sustainable growth of the network requires a minimal non-zero equilibrium size. In this condition, cooperation is desirable. When either the buyers or suppliers of complementary components are strongly preferred standards to launch the products, cooperative standard setting should be permitted.

Lastly, whether there are sufficient restraints placed on members of the standards coalition. The restraints must be strong enough to limit members' ability to produce non-standard products.

Concerning antitrust policy and compatibility, Economides and White (1994b) point out that compatibility is equivalent to the more general concept of complementarity. So there is a strong parallel relationship between the concepts of "network and compatibility" and "vertical relationships and complementarity". When the usefulness of the products depends on the technical compatibility between the components, complementarity is feasible. Thus firms have the option of making their products not complementary with other components, i.e. "compatibility makes complementarity feasible" (Economides and White, 1994b: 7), but not inevitable. Firms are able to reduce or eliminate the complementarity of their products with other products by introducing various degrees of incompatibility. Therefore the decision to produce and sell a component that is incompatible with potentially complementary components amounts to exclusion. Economides and White (1994b) provide a framework based on this linking of compatibility with complementarity to examine vertical mergers, compatibility oriented joint ventures, and vertical restraints. They identify beneficial effects of most compatibility and network arrangements, but under some situations, anti-competitive effects will arise. The policy prescription can be summarized as one of general tolerance and encouragement of these arrangements but with

enforcement powers available to curb anti-competitive practices and arrangements.

7. Conclusions

This paper is a partial review of the literature on network externalities. It began with the definition of network externalities and the characterization of network markets. Then I discussed the credibility problem, access pricing and compatibility with network externalities. Network externalities can change many standard predictions of economic theory. For instance, a monopolist may have an incentive to invite competitors to solve credibility problems, and the ECPR loses its optimality. As for compatibility, firms decide to make their products compatible for different purposes, such as reputation and market share. The effect of compatibility on effective competition is ambiguous.

From the point of view of social welfare, inefficiencies identified in the equilibrium levels of compatibility lead to government intervention. However, most economists have opposed the abuses of public intervention and even question the effect of intervention. Network externalities also complicate the analysis of antitrust and bring new challenges to the antitrust authorities.

There are many potential areas for future research. As for the choice of compatibility, a more general model could be introduced, so that we can research the interaction between vertical and horizontal compatibility. Another question is

the maximization of social welfare using compatibility. Since it is widely accepted that there are large inefficiencies identified in the equilibrium of compatibility, what should the government do to improve on the market outcome? Governments need clearer directions from theory to guide their interventions.

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