The Economics of networks[1]

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Abstract

I analyze the salient features of networks and point out the similarities between the economic structure of networks and the structure of vertically related industries. The analysis focuses on positive consumption and production externalities, commonly called network externalities. I discuss their sources and their effects on pricing and market structure. I distinguish between results that do not depend on the underlying industry microstructure (the 'macro' approach) and those that do (the 'micro' approach). I analyze the issues of compatibility, coordination to technical standards, interconnection and interoperability, and their effects on pricing and quality of services and on the value of network links in various ownership structures. I also briefly discuss the issue of interconnection fees for bottleneck facilities.

1. Introduction[2]

Network industries play a crucial role in modern life. The modern economy would be very much diminished without the transportation, communications, information, and railroad networks. This essay will analyze the major economic features of networks. In the course of the analysis it will become clear that many important non-network industries share many essential economic features with network industries. These non-network industries are characterized by strong complementary relations. Thus, the lessons of networks can be applied to

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[1] Plenary session address, E.A.R.I.E. conference, Chania, Greece, September 1994. I thank Larry White for helpful comments.

[2] The literature on networks is so extensive that it is futile to attempt to cover it. This paper discusses only some issues that arise in networks and attempts to point out areas in which further research is necessary.

industries where vertical relations play a crucial role; conversely, the economic and legal learning developed in the analysis of vertically related industries can be applied to network industries.

2. Classification of networks

Formally, networks are composed of links that connect nodes. It is inherent in the structure of a network that many components of a network are required for the provision of a typical service. Thus, network components are complementary to each other. Fig. 1 represents the emerging *information superhighway* network. Clearly, services demanded by consumers are composed of many complementary components. For example, interactive ordering while browsing in a 'department store' as it appears in successive video frames requires a number of components: a database engine at the service provider, transmission of signals, decoding through an interface, display on a TV or computer monitor, etc. Clearly, there are close substitutes for each of these components; for example, transmission can be done through a cable TV line, a fixed telephone line, a wireless satellite, PCN, etc.; the in-home interface may be a TV-top box or an add-on to a PC, etc. It is likely that the combinations of various components will not result in identical services. Thus, the information superhighway will provide substitutes made of complements; this is a typical feature of networks.

Fig. 2 shows this feature in a simple star telephone network. A phone call from *A* to *B* is composed of *AS* (access to the switch of customer *A*), *BS* (access to the
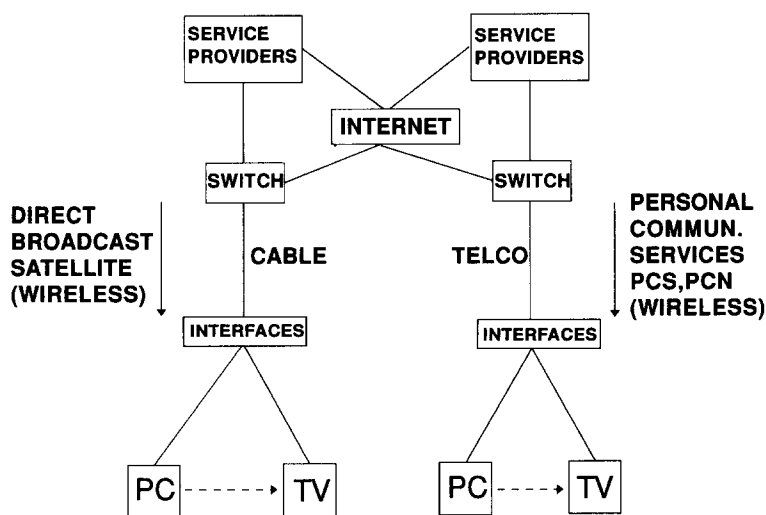

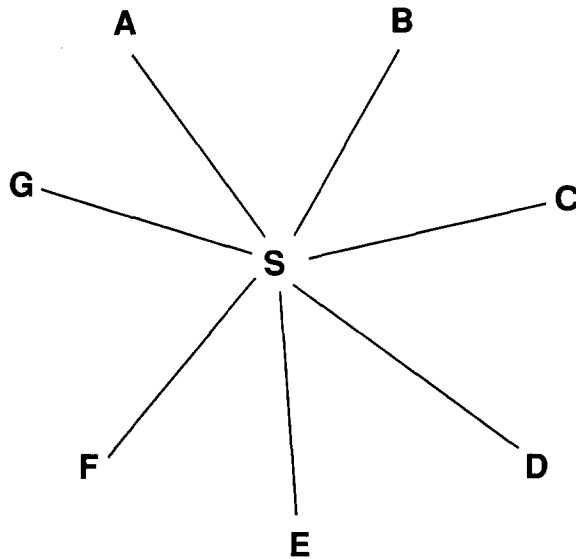
Fig. 1. An information superhighway.

Fig. 2. A simple star network.

switch of customer B), and switching services at S. Despite the fact that goods AS and BS look very similar and have the same industrial classification, they are *complements* and not substitutes.[3]

Networks where services AB and BA are distinct are named 'two-way' networks in Economides and White (1994). Two-way networks include railroad, road, and many telecommunications networks. When one of AB or BA is unfeasible, or does not make economic sense, or when there is no sense of direction in the network so that AB and BA are identical, then the network is called a one-way network. In a typical one-way network, there are two types of components, and composite goods are formed only by combining a component of each type, and customers are often not identified with components but instead demand composite goods. For example, broadcasting and paging are one-way networks.[4]

The classification in network type (one-way or two-way) is not a function of the topological structure of the network. Rather, it depends on the interpretation of the structure to represent a specific service. For example, the network of Fig. 3 can be interpreted as a two-way telephone network where SA represents a local switch in city A, A_i represents a customer in city A, and similarly for SB and B_j.[5] In this network, there are two types of local phone calls $A_i S_A A_k$ and $B_j S_B B_{\ell}$, as well as

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[3] AS and BS can also be components of *substitute* phone calls ASC and BSC.

[4] The 1994 spectrum auction will allow for a large two-way paging network.

[5] In this network, we may identify end-nodes, such as A_i and B_j, end-links, such as $A_i S_A$ and $S_B B_j$, the interface or gateway $S_A S_B$, and switches S_A and S_B.
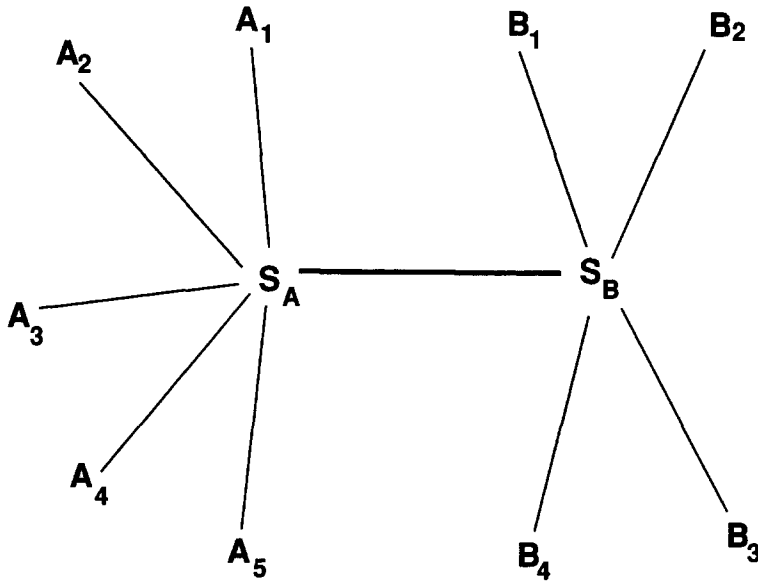
Fig. 3. A simple local and long distance network.

long distance phone call $A_i S_A S_B B_j$. We can also interpret the network of Fig. 3 as an automatic teller machine network (ATM). Then a transaction (say a withdrawal) from bank B_j from ATM A_i is $A_i S_A S_B B_j$. Connections $A_i S_A A_k$ and $B_j S_B B_\ell$ may be feasible but there is no demand for them.

We have pointed out earlier that the crucial relationship in both one-way and two-way networks is the complementarity between the pieces of the network. This crucial economic relationship is also often observed between different classes of goods in non-network industries. In fact, Economides and White (1994) point out that a pair of vertically related industries is formally equivalent to a one-way network. Fig. 4 can represent two industries of complementary goods A and B, where consumers demand combinations $A_i B_j$. Notice that this formulation is formally identical to our long-distance network of Fig. 3 in the ATM interpretation.

The discussion so far was carried under the assumption of *compatibility*, i.e. that various links and nodes on the network are costlessly combinable to produce demanded goods. We have pointed out that links on a network are potentially complementary, but it is *compatibility that makes complementarity actual*. Some network goods and some vertically related goods are immediately combinable because of their inherent properties. However, for many complex products, actual
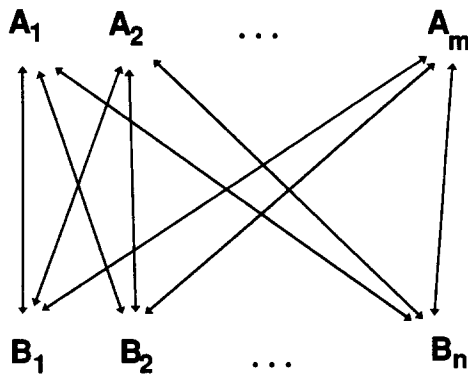
Fig. 4. A pair of vertically related markets.

complementarity can be achieved only through the adherence to specific technical compatibility standards. Thus, many providers of network or vertically related goods have the option of making their products partially or fully incompatible with components produced by other firms. This can be done through the creation of proprietary designs or the outright exclusion or refusal to interconnect with some firms.

Traditionally, networks were analyzed under the assumption that each network was owned by a single firm. Thus, economic research focused on the efficient use of the network structure as well as on the appropriate allocation of costs.[6] In the 70s, partly prompted by the antitrust suit against AT&T, there was a considerable amount of research on economies of scope, i.e. on the efficiency gains from joint operation of complementary components of networks.[7]

Once one of the most important networks (the AT&T telecommunications network in the US) was broken to pieces, economic research focused in the 80s and 90s on issues of interconnection and compatibility. Similar research on issues of compatibility was prompted by the reduced role of IBM in the 80s and 90s in the setting of technical standards in computer hardware and software. Significant reductions in costs also contributed and will contribute to the transformation toward fragmented ownership in the telecommunications sector in both the United States and abroad. Costs of transmission have fallen dramatically with the introduction of fiberoptic lines. Switching costs have followed the fast cost

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[6] See Sharkey (1995) for an excellent survey.
[7] See Baumol et al. (1982).

decreases of microchips and integrated circuits. These cost reductions have transformed the telecommunications industry from a natural monopoly to an oligopoly. The same cost reductions have made many new services, such as interactive video and interactive games, feasible at low cost. Technological change now allows for joint transmission of digital signals of various communications services. Thus, the monopoly of the last link closest to home is in the process of being eliminated,[8] since both telephone lines and cable lines (and in some cases PCS and terrestrial satellites) will provide similar services.[9,10]

In a network where complementary as well as substitute links are owned by different firms, the questions of interconnection, compatibility, interoperability, and coordination of quality of services become of paramount importance. We will examine these issues in detail in the next few sections. We first focus on a fundamental property of networks, i.e. the fact that they exhibit *network externalities*.

3. Network externalities

Networks exhibit positive consumption and production externalities. A positive consumption externality (or network externality) signifies the fact that the value of a unit of the good increases with the number of units sold. To economists, this fact seems quite counterintuitive, since they all know that, except for potatoes in Irish famines, market demand slopes downwards. Thus, the earlier statement, "the value of a unit of a good increases with the number of units sold," should be interpreted as "the value of a unit of the good increases with the *expected* number of units to be sold." Thus, the demand slopes downward but shifts upward with increases in the number of units expected to be sold.

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[8] It is already eliminated in some parts of the United Kingdom, where cable TV operators offer telephone service at significantly lower prices than British Telecom.

[9] These significant changes in costs and the convergence of communications services open an number of policy questions on pricing, unbundling, deregulation, and possibly mandated segmentation in this sector. It is possible that ownership breakup of local and long distance lines is no longer necessary to improve competition. For example, European Union policy mandates open competition by 1998 in any part of the telecommunications network, but does not advocate vertical fragmentation of the existing integrated national monopolies; see European Commission (1994). The reduction in costs and the elimination of natural monopoly in many services may make it possible for this policy to lead the industry to competition.

[10] Another important network, the airline network, faces significant change in Europe. Airlines have not benefited from significant cost reductions and technological change; the present reform is just the abolition by the European Union of the antiquated regime of national airline monopolies, and its replacement by a more competitive environment.

3.1. Sources of network externalities

The key reason for the appearance of network externalities is the complementarity between the components of a network. Depending on the network, the externality may be direct or indirect. When customers are identified with components, the externality is direct. Consider for example a typical two-way network, such as the local telephone network of Fig. 2. In this n-component network, there are $n(n-1)$ potential goods. An additional $(n+1\text{th})$ customer provides direct externalities to all other customers in the network by adding $2n$ potential new goods through the provision of a complementary link (say ES) to the existing links.[11]

In typical one-way networks, the externality is only indirect. When there are m varieties of component A and n varieties of component B as in Fig. 4 (and all A-type goods are compatible with all B-type), there are mn potential composite goods. An extra customer yields indirect externalities to other customers, by increasing the demand for components of types A and B and thereby (because of the presence of economies of scale) potentially increasing the number of varieties of each component that are available in the market.

Financial exchange networks also exhibit indirect network externalities. There are two ways in which these externalities arise. First, externalities arise in the act of exchanging assets or goods. Second, externalities may arise in the array of vertically related services that compose a financial transaction. These include the services of a broker, of bringing the offer to the floor, matching the offer, etc. The second type of externalities are similar to other vertically related markets. The first way in which externalities arise in financial markets is more important.

The act of exchanging goods or assets brings together a trader who is willing to sell with a trader who is willing to buy. The exchange brings together the two complementary goods, 'willingness to sell at price p' (the 'offer') and 'willingness to buy at price p' (the 'counteroffer') and creates a composite good, the 'exchange transaction.' The two original goods were complementary and each had no value without the other one. Clearly, the availability of the counteroffer is critical for the exchange to occur. Put in terms commonly used in finance, minimal liquidity is necessary for the transaction to occur.

Financial markets also exhibit positive size externalities in the sense that the increasing size (or thickness) of an exchange market increases the expected utility of all participants. Higher participation of traders on both sides of the market (drawn from the same distribution) decreases the variance of the expected market price and increases the expected utility of risk-averse traders. Ceteris paribus,

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[11] This property of two-way networks was pointed out in telecommunications networks by Rohlfs (1974) in a very early paper on network externalities. See also Oren and Smith (1981).

higher liquidity increases traders' utility. Thus, financial exchange markets also exhibit network externalities.[12,13]

3.2. The 'macro' approach

There are two approaches and two strands of literature in the analysis of network externalities. The first approach assumes that network externalities exist, and attempts to model their consequences. I call this the 'macro' approach. Conceptually this approach is easier, and it has produced strong results. It was the predominant approach during the 80s. The second approach attempts to find the root cause of the network externalities. I call this the 'micro' approach. In industrial organization, it started with the analysis of mix-and-match models and has evolved to the analysis of various structures of vertically related markets. In finance, it started with the analysis of price dispersion models. The 'micro' approach is harder, and in many ways more constrained, as it has to rely on the underlying microstructure. However, the 'micro' approach has a very significant benefit in defining the market structure. We discuss the 'macro' approach first.

3.2.1. Perfect competition

As we have noted earlier, network externalities arise out of the complementarity of different network pieces. Thus, they arise naturally in both one- and two-way networks, as well as in vertically related markets. The value of good X increases as more of the complementary good Y is sold, and vice versa. Thus, more of Y is sold as more X is sold. It follows that the value of X increases as more of it is sold. This positive feedback loop seems explosive, and indeed it would be, except for the inherent downward slope of the demand curve. To understand this better, consider a fulfilled expectations formulation of network externalities as in Katz and Shapiro (1985), Economides (1993b), Economides (1996a), and Economides and Himmelberg (1995). Let the willingness to pay for the nth unit of the good

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[12] For a more detailed discussion of networks in finance see Economides (1993a). Economides and Schwartz (1995a) discuss how to set up *electronic call markets* that bunch transactions and execute them all at once. Call markets have inherently higher liquidity because they take advantage of network externalities in exchange. Thus, transaction costs are lower in call markets. Economides (1994a) and Economides and Heisler (1994) discuss how to increase liquidity in call markets. The survey of institutional investors reported by Economides and Schwartz (1995b) find that many traders who work in the present continuous market environment would be willing to wait a number of hours for execution of their orders if they can save in transaction costs, including bid-ask spreads. Thus, the time is right for the establishment of call markets in parallel operation with the continuous market.

[13] The increase of utility in expectation due to market thickness was pointed out by Economides and Siow (1988), and earlier and in less formal terms by Garbade and Silber (1976a), Garbade and Silber (1976b), and Garbade and Silber (1979). The effects are similar to those of search models as in Diamond (1982) and Diamond (1984).

when n^e units are expected to be sold be $p(n; n^e)$.[14] This is a decreasing function of its first argument because the demand slopes downward. $p(n; n^e)$ increases in n^e; this captures the network externalities effect. At a market equilibrium of the simple single-period world, expectations are fulfilled, $n = n^e$, thus defining the fulfilled expectations demand $p(n, n)$. Fig. 5 shows the construction of a typical fulfilled expectations demand. Each curve D_i, $i = 1, ..., 4$, shows the willingness to pay for a varying quantity n, given an expectation of sales $n^e = n_i$. At $n = n_i$, expectations are fulfilled and the point belongs to $p(n, n)$ as $p(n_i, n_i)$. Thus $p(n, n)$ is constructed as a collection of points $p(n_i, n_i)$.

To avoid explosions and infinite sales, it is reasonable to impose $\lim_{n \to \infty} p(n, n) = 0$; it then follows that $p(n, n)$ is decreasing for large n. Economides and Himmelberg (1995) show that the fulfilled expectations demand is increasing for small n if either one of three conditions hold: (i) *the utility of every consumer in a network of zero size is zero*, or (ii) *there are immediate and large external benefits to network expansion for very small networks*, or (iii) *there is a significant density*
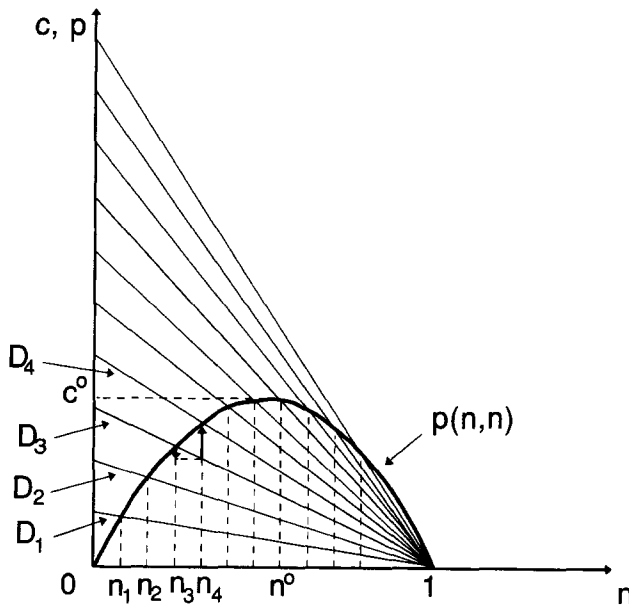

Fig. 5. Construction of the fulfilled expectations demand.

of high-willingness-to-pay consumers who are just indifferent on joining a network of approximately zero size. The first condition is straightforward and applies directly to all two-way networks. The other two conditions are a bit more subtle, but commonly observed in networks and vertically related industries.

When the fulfilled expectations demand increases for small n, we say that *the network exhibits a positive critical mass under perfect competition.* This means that, if we imagine a constant marginal cost c decreasing parametrically, the network will start at a positive and significant size n° (corresponding to marginal cost c°). For each smaller marginal cost, $c < c^\circ$, there are three network sizes consistent with marginal cost pricing: a zero size network; an unstable network size at the first intersection of the horizontal through c with $p(n, n)$; and the Pareto optimal stable network size at the largest intersection of the horizontal with $p(n, n)$. The multiplicity of equilibria is a direct result of the coordination problem that arises naturally in the typical network externalities model. In such a setting, it is natural to assume that the Pareto optimal network size will result.[15]

In the presence of network externalities, it is evident that perfect competition is inefficient: The marginal social benefit of network expansion is larger than the benefit that accrues to a particular firm under perfect competition. Thus, perfect competition will provide a smaller network than is socially optimal, and for some relatively high marginal costs perfect competition will not provide the good while it is socially optimal to provide it.

One interesting question that remains virtually unanswered is how to decentralize the welfare maximizing solution in the presence of network externalities. Clearly, the welfare maximizing solution can be implemented through perfect price discrimination, but typically such discrimination is unfeasible. It remains to be seen to what extent mechanisms that allow for non-linear pricing and self-selection by consumers will come close to the first best.

3.2.2. Monopoly

Economides and Himmelberg (1995) show that a monopolist who is unable to price-discriminate will support a smaller network and charge higher prices than perfectly competitive firms. This is despite the fact that the monopolist has influence over the expectations of the consumers, and he recognizes this influence, while no perfectly competitive firm has such influence.[16] Influence over expectations drives the monopolist to higher production, but the monopolist's profit-maximizing tendency towards restricted production is stronger and leads it to

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[15] It is possible to have other shapes of the fulfilled expectations demand. In general $p(n, n)$ is quasiconcave under weak conditions on the distribution of preferences and the network externality function. Then, if none of the three causes mentioned above are not present, the fulfilled expectations demand is downward sloping.

[16] A monopolist unable to influence expectations will clearly produce less than a monopolist able to influence expectations.

lower production levels than perfect competition. Thus, consumers and total surplus will be lower in monopoly than in perfect competition. Therefore the existence of network externalities does not reverse the standard welfare comparison between monopoly and competition; it follows that *the existence of network externalities cannot be claimed as a reason in favor of a monopoly market structure.*

3.2.3. Oligopoly and monopolistic competition under compatibility

Cournot oligopolists producing compatible components also have some influence over expectations. A natural way to model the influence of oligopolists on output expectations is to assume that every oligopolist takes the output of all others as given and sets the expectation of consumers of his own output. In this setting, M compatible Cournot oligopolists support a network of a size between monopoly ($M = 1$) and perfect competition ($M = \infty$). The analysis can easily be extended to monopolistic competition among compatible oligopolists if firms face downward-sloping average cost curves as shown in Fig. 6. Firms produce on the downward-sloping part of the firm-scaled fulfilled expectations demand. At a symmetric equilibrium, firm j's output is determined at the intersection of marginal cost c and marginal revenue MR_j. Price is read off the fulfilled expectations firm-scaled inverse demand $p(Mq, Mq)$. At a monopolistically competitive equilibrium, the AC curve is tangent to the fulfilled expectations demand at q_j.

Monopolistic Competition with Network Externalities and M Compatible Goods
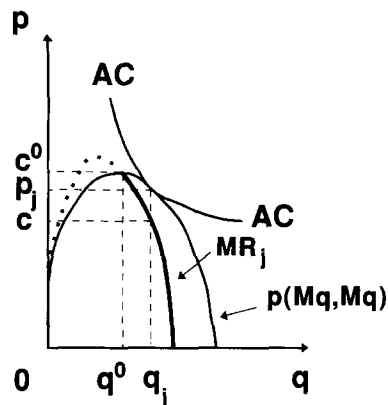

Fig. 6. Monopolistic competition with network externalities and M compatible goods.

3.2.4. Oligopoly under incompatibility

One of the most interesting issues in the economics of networks is the interaction of oligopolists producing incompatible goods. A full analysis of such a market, in conjunction with the analysis of compatible oligopolists, will allow us to determine the incentives of individual firms to choose technologies that are compatible or incompatible with others.

Given any set of firms $S = \{1, ..., N\}$, we can identify a subset of S that adheres to the same technical 'standard' as a coalition. Then the partition of S into subsets defines a coalition structure $C_S = \{C_1, ..., C_k\}$. Compatibility by all firms means that there is a single coalition that includes all firms. Total incompatibility, where every firm adheres to its own unique standard, means that $k = N$.

A number of criteria can be used to define the equilibrium coalition structure. A purely non-cooperative concept without side payments requires that, after a firm joins a coalition, it is better off at the resulting market equilibrium, just from revenues from its own sales.[17] At a non-cooperative equilibrium with side payments, firms divide the profits of a coalition arbitrarily to induce firms to join a coalition. Yet firms do not cooperate in output decisions. Katz and Shapiro (1985) show that the level of industry output is greater under compatibility than at any equilibrium with some incompatible firm(s). This is not sufficient to characterize the incentives of firms to opt for compatibility.

Intuitively, a firm benefits from a move to compatibility if (i) the marginal externality is strong; (ii) it joins a large coalition; and (iii) it does not thereby increase competition to a significant degree by its action. On the other hand, the coalition benefits from a firm joining its 'standard' if (i) the marginal externality is strong; (ii) the firm that joins the coalition is large; (iii) competition does not increase significantly as a result of the firm joining the coalition. Clearly, in both cases, the second and the third criteria may create incentives that are in conflict; this will help define the equilibrium coalition structure.[18]

Katz and Shapiro (1985) show that if the costs of achieving compatibility are lower for all firms than the increase in profits because of compatibility, then the industry move toward compatibility is socially beneficial. However, it may be true that the (fixed) cost of achieving compatibility is larger than the increase in profits for some firms, while these costs are lower than the increase in total surplus from compatibility. Then profit maximizing firms will not achieve industry-wide compatibility while this regime is socially optimal. Further, if a change leads to less than industry-wide compatibility, the private incentives to standardize may be excessive or inadequate. This is because of the output changes that a change of regime has on all firms. Similarly, the incentive of a firm to produce a one-way adapter, that allows it to achieve compatibility without affecting the compatibility

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[17] See Economides (1984), Yi and Shin (1992a), and Yi and Shin (1992b).

[18] Economides and Flyer (1995) examine the incentives for coalition formation around compatibility standards.

of other firms, may be deficient or excessive because the firm ignores the change it creates on other firms' profits and on consumers surplus.

3.2.5. Coordination to technical standards with asymmetric technologies

So far it was assumed that the cost of standardization was fixed and the same for both firms. If standardization costs are different, firms play a standards coordination game. A 2×2 version of this game is presented in Fig. 7. Entries represent profits. In this game, we will assume that firm i has higher profits when 'its' standard i get adopted, $a > g$, $b < h$. Profits, in case of disagreement, will depend on the particulars of the industry. One standard assumption that captures many industries is that in case of disagreement profits will be lower than those of either standard, e, $c < g$; d, $f < b$. Under these circumstances, the setting of either standard will constitute a non-cooperative equilibrium.[19] There is no guarantee that the highest joint profit standard will be adopted. Since consumers surplus does not appear in the matrix, there is no guarantee of maximization of social welfare at equilibrium. For an analysis with continuous choice of standard specification see Berg (1988).

3.3. The 'micro' approach

The micro approach starts with an analysis of the specific micro-structure of a network. After identifying the physical aspects of a network, such as nodes and links, we identify the goods and services that are demanded on the network. We distinguish between the case where only end-to-end services are demanded and the case when there is also demand for some services that do not reach from end to end. The case when only end-to-end services exist is easier and has been dealt with in much more detail in the literature. However, many important networks, such as the railroad and telephone networks, provide both end-to-end and partial coverage service. We examine this case later.

We start with a simple case where only end-to-end services are demanded. Suppose that there are two complementary types of goods, A and B. Suppose that

		Player 2	
		Standard 1	Standard 2
Player 1	Standard 1	(a, b)	(c, d)
	Standard 2	(e, f)	(g, h)

Fig. 7.

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[19] Standard 1 is an equilibrium if $a > e$, $b > d$. Similarly, Standard 2 is an equilibrium if $g > c$, $h > f$.

each type of good has a number of brands available, A_i, $i = 1, ..., m$, B_j, $j = 1, ...,$ n, as in Fig. 4. Let consumers demand 1:1 combinations $A_k B_j$. We call each of the complementary goods A_i or B_j *components*, while the combined good $A_i B_j$ is called a *composite good* or *system*. Potentially all combinations $A_i B_j$, $i = 1, ..., m$; $j = 1, ..., n$, are possible. Thus complementarity exists in potential. Complementarity is actualized when the components A_i and B_j are combinable and function together without extra cost, i.e. when the components are *compatible*. Often it is an explicit decision of the producers of individual components to make their products compatible with those of other producers. Thus, compatibility is a *strategic* decision and should be analyzed as such.

Modern industrial organization provides a rich collection of environments for the analysis of strategic decisions; because of shortage of time and space, this survey will discuss the decision on compatibility only in few environments.

3.3.1. Mix and match: compatibility vs. incompatibility

The *mix-and-match* literature does not assume a priori network externalities; however, it is clear that demand in mix-and-match models *exhibits* network externalities. The mix-and-match approach was originated by Matutes and Regibeau (1988), and followed by Economides (1988), Economides (1989), Economides (1991a), Economides (1991b), Economides (1993c), Economides and Salop (1992), Economides and Lehr (1995), Matutes and Regibeau (1989), Matutes and Regibeau (1992), and others. To fix ideas, consider the case of Fig. 4 with $m = 2$, $n = 2$, technologies are known, coordination is costless, price discrimination is not allowed, and there are no cost asymmetries created by any particular compatibility standard. Fig. 8 shows the case of compatibility. The incentive for compatibility of a vertically integrated firm (producing A_1 and B_1) depends on the relative sizes of each combination of complementary components. Reciprocal compatibility, (i.e. simultaneous compatibility between A_1 and B_2, as well as between A_2 and B_1) increases demand (by allowing for the sale of $A_1 B_2$ and $A_2 B_1$) but also increases competition for the individual components. There-
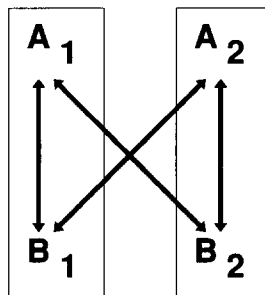

Fig. 8. Mix-and-match compatibility.

fore, when the hybrid demand is large compared with the own-product demand (including the case where the two demands are equal at equal prices), a firm has an incentive to want compatibility.[20] When the demand for hybrids is small, a firm does not want compatibility. Thus, it is possible, with two vertically integrated firms, that one firm wants compatibility (because it has small own-product demand compared with the hybrids demand) while the other one prefers incompatibility (because its own-product demand is large compared with the hybrids demand). Thus, there can be conflict across firms in their incentives for compatibility, even when the technology is well known. The presumption is that opponents will not be able to counteract and correct all incompatibilities introduced by an opponent, and, therefore, in situations of conflict we expect that incompatibility wins.

These results hold both for zero-one decisions (i.e. compatibility vs. incompatibility) and for decisions of partial (or variable) incompatibility. The intuition of the pro-compatibility result for the zero-one decision in the equal hybrid- and own-demand is simple. Starting from the same level of prices and demand in both the compatibility and incompatibility regimes, consider a price increase in one component that produces the same decrease in demand in both regimes. Under incompatibility, the loss of profits is higher since *systems* sales are lost rather than sales of *one component*. Therefore, profits are more responsive to price under incompatibility; it follows that the residual demand facing firms is more elastic under incompatibility, and therefore firms will choose lower prices in that regime.[21] This is reminiscent of Cournot's (1838) celebrated result (see Cournot, 1927) that a vertically integrated monopolist faces a more elastic demand and will choose a lower price than the sum of the prices of two vertically disintegrated monopolists.[22]

So far we have assumed that compatibility is reciprocal – i.e. that the same adapter is required to make both A_1B_2 and A_2B_1 functional. If compatibility is not reciprocal (i.e. if different adapters are required for A_1B_2 and A_2B_1) the incentive of firms to achieve compatibility depends on the cross substitution between own-products and hybrids. Roughly, if the substitutability among A-type components is equal to the substitutability among B-type components, the earlier results of the reciprocal setup still hold.[23] Nevertheless, if the degree of substitutability among the As is different than among the Bs, one firm may create an

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[20] Matutes and Regibeau (1988) and Economides (1989) find that compatibility is always the firms' choice because they assume a locational setting with uniform distribution of consumers in space that results in equal own-product and hybrid demands at equal prices. The exposition here follows the more general framework of Economides (1988) and Economides (1991a).

[21] These results also hold when firms can price discriminate between buyers who buy the pure combination A_iB_i and buyers who buy only one component from firm i. Thus, firms practice mixed bundling. See Matutes and Regibeau (1992) and Economides (1993c).

[22] See Economides (1988) for a discussion of Cournot's result, and Economides and Salop (1992) for an extension of the result to (parallel) vertical integration among two pairs of vertically related firms.

[23] Economides (1991a, p. 52).

advantage for itself by introducing some incompatibilities. However, it is *never* to the advantage of *both* vertically integrated firms to create incompatibilities.

The issue of compatibility and coordination is much more complicated if there are more than two firms. A number of coalitions can each be formed around a specific technical standard, and standards may allow for partial compatibility, or may be mutually incompatible. Not enough research has been done on this issue. Research in this area is made particularly difficult by the lack of established models of coalition formation in non-cooperative settings. The analysis based on coalition structures is more complicated in the 'micro' approach because of the specifics of the ownership structure.

The studies we referred to this far take the ownership structure as given (i.e. as parallel vertical integration), and proceed to discuss the choice of the degree of compatibility. In many cases, vertical integration is a decision that is more flexible (and less irreversible) than a decision on compatibility. Thus, it makes sense to think of a game structure where the choice of technology (which implies the degree of compatibility) *precedes* the choice of the degree of vertical integration. Economides (1996b) analyzes the choice of asset ownership as a consequence of the choice of technology (and of the implied degree of compatibility). It posits a three-stage game of compatibility choice in the first stage, vertical integration in the second stage, and price choice in the third stage. Incentives for vertical mergers in industries with varying degrees of compatibility are compared. In analyzing the stage of compatibility choice, the influence of the anticipation of decisions on (vertical) industry structure on compatibility decisions is evaluated. (Fig. 9.)

3.3.2. Changes in the number of varieties as a result of compatibility decisions

Economides (1991b) considers the interplay of compatibility and the number of varieties of complementary goods. There are two types of goods, A and B, consumed in 1:1 ratio. There are two brands of good A, A_1 and A_2, each produced by an independent firm. The number of B-type brands, each also produced by an independent firm, is determined by a free-entry condition, so that industry B is in monopolistic competition. In a regime of compatibility, each B-type component is immediately compatible with either A_1 or A_2. In a regime of incompatibility, each

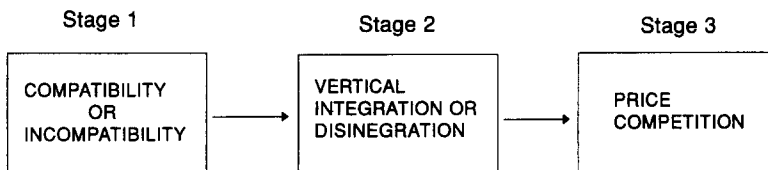| Stage 1	Stage 2	Stage 3
COMPATIBILITY OR INCOMPATIBILITY	VERTICAL INTEGRATION OR DISINEGRATION	PRICE COMPETITION

Fig. 9. Compatibility decisions are less flexible than vertical integration decisions.
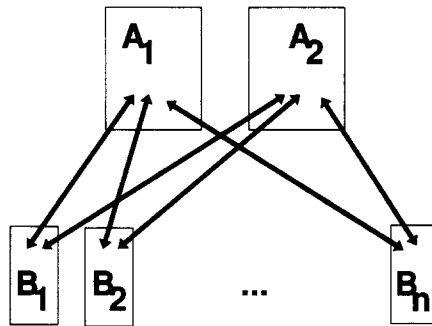
Compatibility

Fig. 10. Compatibility.

brand B_i produces two versions, one compatible with A_1 and one compatible with A_2. The two cases are shown in Fig. 10 and Fig. 11.

Under incompatibility, each B-type firm incurs higher fixed costs; it follows that ceteris paribus the number of B-type brands will be smaller under incompatibility. An A-type firm prefers incompatibility or compatibility according to the equilibrium profits it realizes in each regime. These profits, and the decision on compatibility, depends on the specifics of the utility function of consumers, and in particular on the impact of an increase of the number of varieties on utility. If
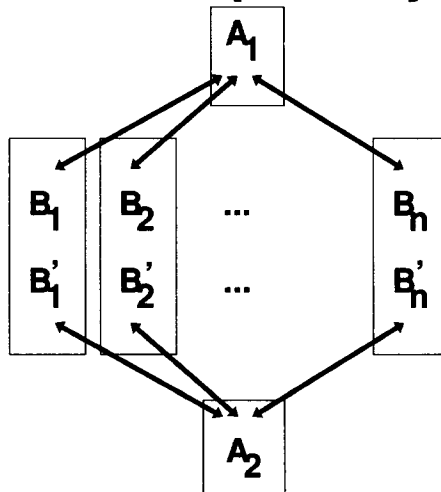
Incompatibility

Fig. 11. Incompatibilty.

industry demand is not sensitive to increases in the number of varieties of composite goods n (and does not increase much as n increases), then equilibrium profits of an A-type firm decrease in the number of firms; therefore profits of an A-type firm are higher at the smaller number of firms implied by incompatibility, and an A-type firm prefers incompatibility. Conversely, when consumers have a strong preference for variety and demand for composite goods increases significantly in n, equilibrium profits of an A-type firm increase in the number of firms; therefore its profits are higher at the larger number of firms implied by compatibility, and an A-type firm prefers compatibility.

Church and Gandal (1992b), Chou and Shy (1990a), Chou and Shy (1990b), and Chou and Shy (1990c) also examine the impact of the number of varieties of complementary (B-type) goods on the decisions of consumers to buy one of the A-type goods under conditions of incompatibility.

3.3.3. Quality coordination in mix-and-match

The framework of mix and match models applies to both variety and quality features that are combinable additively in the utility function. That is, in the standard mix-and-match model, the utility accruing to a consumer from component A_i is added to the utility from component B_j. However, in some networks, including telecommunications,[24] the utility of the composite good A_iB_j is not the sum of the respective qualities. In particular, the quality of voice in a long distance call is the minimum of the qualities of the component parts of the network, i.e. the local and the long distance transmission. Thus, significant quality coordination problems arise in a network with fragmented ownership. Economides (1994b) and Economides and Lehr (1995) examine this coordination problem.

Let A and B be components that are combinable in a 1:1 ratio. Suppose that the quality levels of the components are q_A and q_B, while the quality level of the composite good is $q_{AB} = \min(q_A, q_B)$. Consumers have varying willingness to pay for quality improvements as in Gabszewicz and Thisse (1979) and Shaked and Sutton (1982), and firms play a two-stage game of quality choice in the first stage, followed by price choice in the second stage. As mentioned earlier, Cournot (1927) has shown that an integrated monopolist producing both A and B will charge less than two vertically related monopolists, each producing one component only. This is because of the elimination of double marginalization by the integrated monopolist. Economides (1994b) and Economides and Lehr (1995) show that an integrated monopolist also provides a higher quality than the two independent monopolists. In bilateral monopoly, marginal increases in quality have a bigger impact on price. Being able to sell the same quality at a higher price than under integrated monopoly, the bilateral monopolists choose lower quality levels, which are less costly. Despite that, because of double marginalization, prices are

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[24] See also Encaoua et al. (1992) for a discussion of the coordination of the timing of different legs of airport transportation.

higher than in integrated monopoly, a lower portion of the market is served, and firms realize lower profits.[25] Thus, *lack of vertical integration leads to a reduction in quality*. Note that this is not because of lack of coordination between the bilateral monopolists in the choice of quality, since they both choose the same quality level.[26]

In this setting, Economides and Lehr (1995) examine various ownership structures where, for at least one of the types of components there is more than one quality level available. Clearly, a situation where all components have the same quality is not viable, since competition would then drive prices to marginal cost. Further, for a 'high' quality composite good to be available, both an A- and a B-type goods must be of 'high' quality. They find that a third (and fourth) 'low' quality goods have a hard time surviving if they are produced by independent firms. In contrast, in parallel vertical integration (with firm i, $i = 1$, 2, producing A_i and B_i), firms prefer not to interconnect – i.e. to produce components that are incompatible with those of the opponent.

4. Network externalities and industry structure

4.1. Invitations to enter

In the presence of strong network externalities, a monopolist exclusive holder of a technology may have an incentive to invite competitors and even subsidize them. The realization of network externalities requires high output. A monopolist may be unable credibly to commit to a high output as long as he is operating by himself. However, if he licenses the technology to a number of firms and invites them to enter and compete with him, market output will be higher; and since the level of market output depends mainly upon other firms, the commitment to high output is credible.

The invitation to enter and the consequent increase in market output has two effects; a *competitive effect* and a *network effect*. The competitive effect is an expected increase in competition because of the increase of the number of firms. The network effect tends to increase the willingness to pay and the market price because of the high expected sales. Economides (1993b) and Economides (1996a) show that, if the network externality is strong enough, the network effect is larger than the competitive effect, and therefore an innovator-monopolist invites competitors and even subsidizes them on the margin to induce them to increase production.

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[25] Consumers also receive lower surplus in comparison to vertically integrated monopoly.

[26] The *reliability* of the network, measured by the percentage of time that the network is in operation, or by the probability of a successful connection, is measured by the product of the respective reliabilities of the components (another non-linear function).
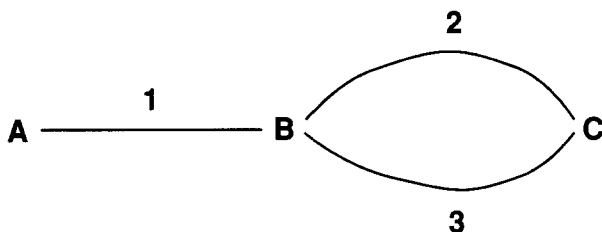
Fig. 12. *AB* is a bottleneck facility.

4.2. Interconnection or foreclosure by a local monopolist?

Many telecommunications, airline networks and railroad networks have the structure of Fig. 12. In a railroad network, there may be direct consumer demand for links *AB*, *BC*, as well as *AC*. This figure can also represent a telephone network with demand for local telephone services (*AB*) and for long distance services (*ABC*); in that case, there is no direct demand for *BC*, but only the indirect demand arising from long distance calls *ABC*. In many cases, one firm has a monopoly of a link that is necessary for a number of services (here *AB*), and this link is a natural monopoly. This bottleneck link is often called an essential facility. The monopolist can foreclose any firm by denying access to the bottleneck facility. What are his incentives do so?

Economides and Woroch (1992) examine intermodal competition in the context of a simple network pictured in Fig. 13. *S* and *R* are local switches; *AS* and *BR* is local service (in different cities); *SR* and *STR* are alternative long distance services. The diagram is simplified by eliminating *R* without any essential loss. Suppose that an integrated firm offers end-to-end service (*ASB*), while a second firm offers

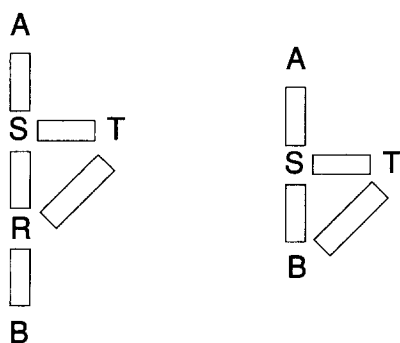## Network in Extensive and Collapsed Form

Fig. 13. Intermodal competition.

service of partial coverage only (*STB*). They find that, although the integrated firm has the opportunity to foreclose the opponent, it prefers not to. In fact, *the integrated firm is better off by implementing a vertical price squeeze on the opponent*, and charging a significantly higher price to the opponent for the use of the monopolized link than it 'charges' itself.[27] Thus, foreclosure, although feasible, is not optimal for the integrated firm.[28]

Economides and Woroch (1992) also find that vertical disintegration is not desirable for the firm that offers end-to-end service. Once disintegrated, its constituent parts realize lower total profits. This is because, besides appropriating monopoly rents for its *AS* monopoly, the integrated firm (*ASB*) was creating a significant restriction of competition in *SB–STB* market by its de facto price discriminating strategy. After disintegration, the *SB–STB* market becomes much more competitive, even if *AS* price discriminates between *SB* and *STB*. Thus, even if network *ASB* were to receive the full rent earned by the new owner of *SB*, its after-divestiture profits would be lower than before divestiture.[29]

Even in simple networks, there may be relations among firms that are neither purely vertical nor purely horizontal. Thus, the conventional wisdom about vertical and horizontal integration fails. Economides and Salop (1992) discuss pricing in various ownership structures in the model of Fig. 8. They call the ownership structure of this figure, where each firm produces a component of each type, *parallel vertical integration*. They also consider the *independent ownership* structure, where each of the four components is owned by a different firm. In both of these structures, no firm is purely vertically or purely horizontally related to another firm. Thus, starting from independent ownership, or starting from parallel vertical integration, a merger to *joint ownership*, where all components are produced by the same firm, can either increase or decrease prices. Thus, simple prescriptions against mergers may easily fail.

In the model of Fig. 13, Economides and Woroch (1992) consider the case where link *ST* is owned by a firm that owns a vertically related link (either *AS* or *BT*), or is owned by an independent firm. Clearly, the strategic structure of the game remains unaffected when link *ST* changes hands between two firms that also own a link that is vertically related to *ST*. Therefore, if *ST* has a fixed cost, it is a liability to such a firm; each firm would like the opponent to own it. However, if the link is owned by a third party, it is has a positive value because of its monopoly position in the chain. Thus, each original owner has an incentive to sell *ST* to a third party. The direct implication is that the value of links depends on

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[27] This result is dependent on the linear structure of the demand system, and may not hold for any demand structure.

[28] Church and Gandal (1992a) find that sometimes firms prefer foreclosure, but their model does not allow for a vertical price squeeze.

[29] This result is in contrast to Bonanno and Vickers (1988) because of the absence of two-part contracts in Economides and Woroch (1992).

what other links a firm owns. Thus, general prescriptions on the desirability of unbundling of ownership are suspect.

Often parts of the network are regulated, while other parts are not. This is the typical arrangement in telephony in the US, where only local telephone companies are tightly regulated, since their market is traditionally considered a natural monopoly.[30] Baumol and Sidak (1994a) and Baumol and Sidak (1994b) propose that, to attract efficient entrants in the long distance market and to discourage inefficient entrants, a local telephone company should charge them an *interconnection (or access) fee* equal to the marginal cost of provision of service plus any opportunity cost that the local telephone company incurs.[31] This is correct under a set of strict assumptions: first that the end-to-end good is sold originally at the competitive price; second that the entrant produces the same complementary good (long distance service) as the incumbent;[32] third, that there are no economies of scale in either one of the complements. Economides and White (1995) and Economides and White (1996) discuss how the relaxation of these assumptions leads to different interconnection charges. For example, if competition between an entrant and the incumbent reduces the market power of the incumbent, entry may increase social welfare even when the entrant produces at higher cost than the incumbent.

5. Sequential games

In network markets, and more generally in markets with network externalities, when firms and consumers interact in more than period, *history matters*. Both consumers and firms make production and consumption decisions based on sizes of installed base and on expectations of its increases over time. The same underlying technology and consumers preferences and distribution can lead to different industrial structures depending on the way things start. Thus, strategic advantages, such as first mover advantages, can have long run effects.[33]

Network externalities and historical events are particularly important in the speed of adoption of an innovation that creates services on a network. Cabral (1990) discusses the adoption of innovations under perfect competition in the presence of network externalities. His main conclusion is that, when network externalities are strong, the equilibrium adoption path may be discontinuous. This

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[30] This is changing for some customers through the existence of competitive access providers, who directly compete with the local telephone company for large customers, and the potential for competition by cable companies.

[31] Kahn and Taylor (1994) have very similar views.

[32] Armstrong and Doyle (1994) relax this assumption.

[33] See Arthur (1988), Arthur (1989), David (1985). David argues that the QWERTY keyboard was adopted mainly because it appeared first while the DVORAK keyboard was superior. This is disputed by Liebowitz and Margolis (1990).

is another way of saying that there are two network sizes supported as equilibria at the same time instant. This may occur at the start of the network, and then it is called positive critical mass by Economides and Himmelberg (1995). It may also occur at other points in the network evolution. In practice, discontinuities in the size of the network over time do not occur since that would imply an infinite size of sales at some points in time. Continuity and smoothness of the network path is restored if instantaneous marginal production costs are increasing. Under this assumption, Economides and Himmelberg (1995) find that the adoption path is much steeper in the presence of externalities. Further, driven by the externality, in early stages the network can expand so quickly as to exhibit increasing retail prices even when marginal costs are falling over time. Their analysis is applied to the fax market in the US and Japan.

The analysis is more complex when we depart from the assumption of perfect competition. Accordingly, this analysis tends to be in the form of simple two-period models. We analyze it with reference to the standard simultaneous choice coordination game of Section 3.2.5, where we now interpret the first strategy as sticking to the old technology, and the second as the adoption of a new one (Fig. 14). Network externalities for both technologies mean that $a > c$, e; $b > d$, f; $g > c$, e; $h > d$, f. If both firms are worse off when they are not coordinated, both the 'new technology' (i.e. (N, N)) and the 'old technology' (i.e. (O, O)) will arise as equilibria. Clearly, one of the equilibria can be inefficient. If the (O, O) equilibrium is inefficient and is adopted, Farrell and Saloner (1985) call the situation *excess inertia*.[34] Similarly, if the (N, N) equilibrium is inefficient and it is adopted, the situation is called *excess momentum*.

Farrell and Saloner (1985) discuss a two-period model where consumers have varying willingness to pay for the change of the technology, measured by θ. Users can switch in Period 1 or 2, and switching is irreversible. Users fall in four categories according to the strategy they pick: (i) they never switch, whatever the behavior of others in the first period; (ii) they switch in Period 2 if other users

Fig. 14.

[34] See Katz and Shapiro (1992) for a different view arguing for excess momentum (which they call *insufficient friction*).

have switched in Period 1 – jumping on the bandwagon; (iii) they switch in Period 1; (iv) switch in Period 2 even if others have not switched in Period 1. The last strategy is dominated by strategy (iii). Consumers of low θ use strategy (i), consumers of intermediate θ use strategy (ii), and consumers of high θ use strategy (iii). Consumers would like to coordinate themselves and switch in the first period (thereby getting the bandwagon rolling) but are unable to do so, thus creating excess inertia. This inertia can be reduced through communication among the consumers, though contracts, through coordination in committees or through new product sponsorship and special introductory pricing.[35]

In a sequential setting, preannouncement (i.e. announcement of a new product before its introduction) may induce some users to delay their purchase. Also penetration pricing can be important. Katz and Shapiro (1986a) examine the effects of sponsorship (allowing firms to price differently than at marginal cost). Katz and Shapiro (1986b) examine the effects of uncertainty in product adoption and introduction.

Nevertheless, there is much more work to be done on multiperiod and on continuous time dynamic games with network externalities. The issues of foreclosure and predation have not been sufficiently discussed in the context of network externalities. More generally, much more work is required on multiperiod dynamic games in this context, especially for durable goods.

6. Markets for adapters and add-ons

Not enough research has been done on the economics of adapters and interfaces. One strand of the mix-and-match literature assumes that compatibilities introduced by one firm cannot be corrected by the other, so that adapters are unfeasible. Economides (1991a) assumes that adapters are provided by a competitive industry at cost, but decisions of the firms determine the extent of incompatibility, and therefore the cost of the adapters. Farrell and Saloner (1992) assume that converters make the technologies only partially compatible, in the sense that hybrid goods that utilize incompatible components as well as an adapter give lower utility than a system composed of fully compatible components. In this framework, the availability of converters can reduce social welfare, since, in the presence of converters, some consumers would buy the converter and the 'inferior' technology rather than the 'best' technology, although the 'best' technology gives more externalities.

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[35] See also Farrell and Saloner (1988) for mechanisms to achieve coordination, and Farrell and Saloner (1985) for a discussion of network product sponsorship.

7. Concluding remarks

In this paper, we have noted some of the interesting issues that arise in networks and vertically related industries, especially in the presence of a fragmented ownership structure. As is evident, many open questions remain. One of the most important issues that remains largely unresolved is the joint determination of an equilibrium market structure (including the degree of vertical integration) together with the degree of compatibility across firms. The extent of standardization in markets with more than two participants and the structure of 'standards' coalitions also remain open questions. Markets for adapters and add-ons have not been sufficiently analyzed. An analysis of market structure in multiperiod dynamic games with network externalities is also unavailable. Further, issues of predation and foreclosure in networks have not been fully analyzed yet. On a more fundamental level, there is no good prediction yet of the 'break points' that define the complementary components in a modular design structure. Even if these break points are known, little analysis has been done of competition in a multilayered structure of vertically related components. Nevertheless, it is exactly this kind of modelling that is needed for an analysis and evaluation of the potential structures of the 'information superhighway'.

References

Armstrong, M. and C. Doyle, 1994, Interconnection and the Effects of Entry, mimeo.

Arthur, W.B., 1988, Self-reinforcing mechanisms in economics, in: P.W. Anderson, K.J. Arrow and D. Pines, eds., The Economy as an Evolving Complex System (Addison Wesley).

Arthur, W.B., 1989, Competing technologies, increasing returns, and lock-in by historical events, The Economic Journal 99, 116–131.

Baumol, W.J. and J.G. Sidak, 1994a, The pricing of inputs sold to competitors, Yale Journal of Regulation 11(1), 171–202.

Baumol, W.J. and J.G. Sidak, 1994b, Toward Competition in Local Telephony (The MIT Press and The American Enterprise Institute, Washington, DC).

Baumol, W.J., J. Panzar and R. Willig, 1982, Contestable Markets and the Theory of Industry Structure (Harcourt Brace Jovanovich, New York).

Berg, S.V., 1988, Duopoly compatibility standards with partial cooperation and standards leadership, Information Economics and Policy 3, 35–53.

Bonanno, G. and J. Vickers, 1988, Vertical separation, Journal of Industrial Economics 36(3), 257–265.

Cabral, L., 1990, On the adoption of innovations with 'network' externalities, Mathematical Social Sciences 19, 229–308.

Chou, C. and O. Shy, 1990a, Do Consumers Always Gain When More People Buy the Same Brand? mimeo.

Chou, C. and O. Shy, 1990b, Supporting Services and the Choice of Compatibility, mimeo.

Chou, C. and O. Shy, 1990c, Partially Compatible Brands and Consumer Welfare, mimeo.

Church, J. and N. Gandal, 1992a, Integration, complementary products, and variety, Journal of Economics and Management Strategy 1(4), 653–675.

Church, J. and N. Gandal, 1992b, Network effects, software provision and standardization, Journal of Industrial Economics 40(1), 85–104.

Cournot, A., 1927, Researches into the Mathematical Principles of the Theory of Wealth (Macmillan, New York).

David, P.A., 1985, Clio and the economics of QWERTY, American Economic Review 75(2), 332–337.

Diamond, P., 1982, Aggregate demand management in search equilibrium, Journal of Political Economy 90, 881–894.

Diamond, P., 1984, A Search-Equilibrium Approach to the Micro Foundations of Macroeconomics (MIT Press, Cambridge, MA).

Economides, N., 1984, Equilibrium coalition structures, Discussion Paper No. 273, Department of Economics, Columbia University.

Economides, N., 1988, Variable compatibility without network externalities, Discussion Paper No. 145, Studies in Industry Economics, Stanford University.

Economides, N., 1989, Desirability of compatibility in the absence of network externalities, American Economic Review 78(1), 108–121.

Economides, N., 1991a, Compatibility and the creation of shared networks, in: M. Guerin-Calvert and S. Wildman, eds., Electronic Services Networks: A Business and Public Policy Challenge (Praeger Publishing Inc., New York).

Economides, N., 1991b, Compatibility and market structure, Discussion Paper EC-91-16, Stern School of Business, NYU.

Economides, N., 1993a, Network economics with application to finance, Financial Markets, Institutions and Instruments 2(5), 89–97.

Economides, N., 1993b, A monopolist's incentive to invite competitors to enter in telecommunications services, in: G. Pogorel, ed., Global Telecommunications Services and Technological Changes (Elsevier, Amsterdam).

Economides, N., 1993c, Mixed bundling in duopoly, Discussion Paper EC-93-29, Stern School of Business, NYU.

Economides, N., 1994a, How to enhance market liquidity, in: R.A. Schwartz, ed., Global Equity Markets (Irwin Professional, New York).

Economides, N., 1994b, Quality choice and vertical integration, Discussion Paper EC-94-22, Stern School of Business, NYU.

Economides, N., 1996a, Network externalities, complementarities, and invitations to enter, European Journal of Political Economy, forthcoming.

Economides, N., 1996b, Vertical integration and compatibility of complementary components, forthcoming.

Economides, N. and F. Flyer, 1995, Technical standards coalitions for network goods, Discussion Paper EC-95-12, Stern School of Business, NYU.

Economides, N. and J. Heisler, 1994, Equilibrium fee structure in a monopolist call market, Discussion Paper EC-94-15, Stern School of Business, NYU.

Economides, N. and C. Himmelberg, 1995, Critical mass and network size with application to the US fax market, Discussion Paper EC-95-11, Stern School of Business, NYU.

Economides, N. and W. Lehr, 1995, The quality of complex systems and industry structure. In: W. Lehz (Editor), Quality and Reliability of Telecommunications Infrastructure. (Lawrence Erlbaum, Hillsdale, NJ).

Economides, N. and S.C. Salop, 1992, Competition and integration among complements, and network market structure, Journal of Industrial Economics 40(1), 105–123.

Economides, N. and R.A. Schwartz, 1995a, Electronic call market trading, Journal of Portfolio Management 21(3), 10–18.

Economides, N. and R.A. Schwartz, 1995b, Equity trading practices and market structure: assessing asset managers' demand for immediacy, Financial Markets, Institutions and Instruments 4(4): 1–46.

Economides, N. and A. Siow, 1988, The division of markets is limited by the extent of liquidity: spatial competition with externalities, American Economic Review 78(1), 108–121.

Economides, N. and L.J. White, 1994, Networks and compatibility: implications for antitrust, European Economic Review 38, 651–662.

Economides, N. and L.J. White, 1995, Access and interconnection pricing: how efficient is the 'efficient component pricing rule'? Antitrust Bulletin XL(3), 557–579.

Economides, N. and White, L.J., 1996b. The inefficiency of ECPR yet again: a reply to Lazon, Antitrust Bulletin.

Economides, N. and G.A. Woroch, 1992, Benefits and pitfalls of network interconnection, Discussion Paper EC-92-31, Stern School of Business, NYU.

Encaoua, D., M. Moreaux and A. Perrot, 1992, Demand Side Network Effect in Airline Markets, mimeo.

European Commission, 1994, Europe and the Global Information Society – Bangemann Report.

Farrell, J. and G. Saloner, 1985, Standardization, compatibility, and innovation, Rand Journal of Economics 16, 70–83.

Farrell, J. and G. Saloner, 1988, Coordination through committees and markets, Rand Journal of Economics 19(2), 235–252.

Farrell, J. and G. Saloner, 1992, Converters, compatibility, and the control of interfaces, Journal of Industrial Economics 40(1), 9–36.

Gabszewicz, J. and J.-F. Thisse, 1979, Price competition, quality, and income disparities, Journal of Economic Theory 20, 340–359.

Garbade, K. and W. Silber, 1976a, Price dispersion in the government securities market, Journal of Political Economy 84.

Garbade, K. and W. Silber, 1976b, Technology, communication and the performance of financial markets, 1840–1975, Journal of Finance 33.

Garbade, K. and W. Silber, 1979, Structural organization of secondary markets: clearing frequency, dealer activity and liquidity risk, Journal of Finance 34, 577–593.

Kahn, A. and Taylor, W., 1994, The pricing of inputs sold to competitors: comment, Yale Journal of Regulation 11(1), 225–240.

Katz, M. and C. Shapiro, 1985, Network externalities, competition and compatibility, American Economic Review 75(3), 424–440.

Katz, M. and C. Shapiro, 1986a, Technology adoption in the presence of network externalities, Journal of Political Economy 94, 822–841.

Katz, M. and C. Shapiro, 1986b, Product compatibility choice in a market with technological progress, Oxford Economic Papers 38, 146–165.

Katz, M. and C. Shapiro, 1992, Product introduction with network externalities, Journal of Industrial Economics 40(1), 55–84.

Liebowitz, S.J. and S.E. Margolis, 1990, The fable of keys, Journal of Law and Economics 33(1), 1–26.

Matutes, C. and P. Regibeau, 1988, Mix and match: product compatibility without network externalities, Rand Journal of Economics 19(2), 219–234.

Matutes, C. and P. Regibeau, 1989, Standardization across markets and entry, Journal of Industrial Economics 37, 359–371.

Matutes, C. and P. Regibeau, 1992, Compatibility and bundling of complementary goods in a duopoly, Journal of Industrial Economics 40(1), 37–54.

Oren, S. and S. Smith, 1981, Critical mass and tariff structure in electronic communications markets, Bell Journal of Economics 12(2), 467–487.

Rohlfs, J., 1974, A theory of interdependent demand for a communications service, Bell Journal of Economics 5(1), 16–37.

Shaked, A. and J. Sutton, 1982, Relaxing price competition through product differentiation, Review of Economic Studies 49, 3–14.

Sharkey, W.W., 1995, Network Models in Economics. In: M.O. Ball et al. (Editors), Handbook in OR and MS, 8: 713–765.

Yi, S.-S. and H. Shin, 1992a, Endogenous Formation of Coalitions Part I: Theory, mimeo.

Yi, S.-S. and H. Shin, 1992b, Endogenous Formation of Coalitions Part II: Applications to Cooperative Research and Development, mimeo.