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Competition, Compatability and Standards: The Economics of Horses, Penguins and Lemmings

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COMPETITION, COMPATIBILITY AND STANDARDS: THE ECONOMICS OF HORSES, PENGUINS AND LEMMINGS[1]

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Key words: compatibility, standards, standardization, innovation.

Abstract

We survey the existing economic literature and some promising future avenues of research in the theory of compatibility standards and standardizations.

[1]Forthcoming in "Product Standardization as a Tool of Competitive Strategy," H. Landis Gabel, ed., North-Holland.

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1. Introduction

Compatibility issues have long been important in industrial economies: railroad gauges are an early example, and the use of interchangeable parts was an important step in the industrial revolution. With the rapid growth of importance of the computer and telecommunications industries (and especially with their recent convergence), compatibility has become more important than ever. Remarkably, the subject has until very recently received little attention from academic economists. In this paper, we survey some important economic questions in compatibility and standardization.[1] We also provide a fairly complete bibliography of the literature on the economics of standards.

2. Compatibility and Standardization

Compatibility

Compatibility is the result of coordinated product design. We call products compatible when their design is coordinated in some way, enabling them to work together.

We can distinguish three classes of compatibility. First, physical compatibility: physical objects are designed to fit together physically or electromagnetically. For example, hydrants and hoses (Hemenway 1975, Nesmith 1985), peripheral and CPU equipment for computers (Gabel 1986), stereo components, auto parts (Hemenway 1975), cameras and lenses, or cameras and film, building parts, railway gauges and rolling stock, TVs and TV broadcasting systems (Besen and Johnson 1986; Crane 1979, Pelkmans 1986), farm machinery

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[1] We do not consider quality standards, but restrict attention to compatibility.

(Kudrle 1975), modems (Sirbu and Stewart 1985). Of course, the components may differ in durability (or in costs): sometimes the two components are more or less equal partners in a system, while in other cases one is considerably more permanent. Sometimes the interchangeability is used a lot (cameras and lenses); in other cases the point is ease and flexibility of putting together a system that will remain in place as one system and not interact with others (Sirbu and Stewart 1985, Matutes and Regibeau 1986).

Second, communications compatibility. Here, two physical devices are able to communicate with one another. Telephone protocols, common language within a country, conventions for road signs, are examples in this category.

Third, compatibility by convention. Here, there are benefits from coordination that are not physically embodied. Examples include bank cards (Phillips 1986), standard time (Nesmith 1985), currency.

These categories, while useful, are neither exhaustive nor mutually exclusive. An example of compatibility that does not fit neatly into our categories is typewriter keyboards (David 1985a).

Compatibility is also not a matter of yes or no. Often, there can be degrees of compatibility. For instance, personal computers can be more or less compatible with the IBM PC (Hergert 1986), UNIX operating systems can be more or less the same as one another, FORTRAN implementations may be more or less different, and so on.

As Gabel (1986) points out, different issues may arise in considering compatibility between different vintages produced by the same vendor, different vendors' versions of "the same" product, and different products. For the most part in our work, we think of compatibility between different vendors' versions of the "same" product: for instance, "PC compatibility" in personal computers. Many of the insights will carry over to other kinds of compatibility, however.

Standardization

Standardization is a *process* by which compatibility is attained. There are many such processes.

First, there may be standardization by internal decision, as when there is only one relevant vendor. This need not trivialize issues of standardization: many choices remain difficult. For example, the decision whether to keep compatibility with previous vintages is an important one: IBM's System/360 was a shock to the computing community because IBM broke with its usual practice of retaining retro-compatibility (Fisher et al. 1983). But it does shift the standardization decision from the market (often characterized by problems of coordination) to an internal organization, in which we might expect better coordination although perhaps at the expense of other incentive problems.

Second, there may be mutual agreement by manufacturers, whether formal or informal, binding or voluntary. These face all the problems faced by single vendors, and more: besides having to solve difficult technical problems, they must reconcile the often conflicting interests of their members. In the US these boards normally operate by consensus. This can make it hard to reach agreement, given firms' entrenched and conflicting interests. (One factor that can lead to such agreement is pressure from large buyers. Notably, government procurement practices have often taken the lead in demanding standardization, for instance the ASCII standard for binary coding of text (Brock 1975). However, private buyers can play the same role: for instance GM is demanding standardization of robot-control languages ("MAP"). Boeing's TOP system is another example.)

Third, there may be follow-the-leader. The leadership role may be taken by a buyer or by a seller. In some cases, it may be clear ex-ante who will lead: often a seller or buyer with a large market share. For example, IBM's leadership in setting the de facto standard in personal computers (Hergert 1986) presumably derives from a common expectation that, as in other computer markets, IBM would have a large share in this market. The lack of standardization in AM stereo may have been resolved (Besen and Johnson 1986) by Delco's choice of the Motorola C-QUAM standard: Delco is a large buyer of AM receivers, because it supplies the car radios for GM cars. Likewise, in encryption of cable TV, HBO's choice of an encryption standard effectively (and rapidly) determined the market standard (Johnson and Besen). In other cases, a de facto standard emerges as one of a number of competing standards wins the bandwagon competition: Swann (1986) describes this process in microprocessor design. After the first entrants into an industry have broadly spanned the product space, later arrivals begin to imitate the successful products. When there are agglomeration economies, this process is not self-limiting; rather, it snowballs.

The leader may or may not welcome being followed; this depends on how much it enhances "his" standard versus how much he loses of the profits from it. In some cases, a vendor may choose to give up proprietary control of a technology, or licence it cheaply (as with the Ethernet local area network standard) in order to make it more credible as a market standard. This contrasts with the case under diminishing returns, in which imitation not only reduces the leader's market share in "his" product but also (by increasing supply) reduces the price of the product; here, imitation enhances the value of the product, and so the "price" may rise.

Fourth, there may be direct government regulation, for instance the FCC's 1949 mandatory choice of the CBS color television standard.

Fifth, the international standardization commissions such as the CCITT (for telephone protocols), the CCIR (for broadcast standards), and the ISO, work to achieve international compatibility. These commissions suffer from two interrelated problems (present, in less extreme form, in all voluntary standards organizations). First, they are slow: often, many months pass between meetings of the relevant committees, and even once the committee makes its recommendation there are further processes to go through. Because of this,[2] firms and countries often begin working on their prototype technologies before a standard is officially set. Once some costs are sunk, the firms have an incentive to fight hard for "their" standard to be adopted, even if objectively it may not be the best. Interacting with these problems are all the problems of democratic organizations, and of organizations without direct enforcement powers. Television standards differ across the world because of these problems (Crane 1979, Pelkmans 1986).

Of course, these are not mutually exclusive nor independent processes. For instance, the same firms that are involved in voluntary standards boards may also simultaneously try to create de facto standards. In some cases, this might create incentives for a de facto standard setter to sabotage the work of the standards board, in order to avoid the creation of a rival to his de facto standard. Or he may be able to combine market forces and political action to choose a standard.

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[2] It might not help to speed up the process to a realistic (or desirable) degree: one view is that firms and nations are engaged in a "race to sink costs" and will do so as fast and as prematurely as is necessary to preempt their rivals.

3. Benefits of Compatibility

We describe four types of benefit from compatibility: network externalities, competitive effects, variety or mix-and-match benefits, and cost savings.

Network Externalities

One major source of compatibility benefits is the fact that we are often linked in physical or conceptual "networks", whose value depends on their size in a direct way. Perhaps the most obvious examples are electronic communications networks (Rohlfs 1974) such as telephone networks and computer networks. But language itself can be seen as another example: the repeated attempts to develop a lingua franca (whether by selecting a dominant natural language, such as Latin, French or English, or by creating an artificial one such as Esperanto) pay tribute to the potential benefits of compatibility.

Competitive Effects

When competing products are compatible, they compete more on price and less on design. This makes the market more of a "commodity" market,[3] and it is natural to think that this enhances price competition, which is in itself a good thing for economic efficiency. Moreover, some aspects of compatibility may encourage entry: for instance, it is possible to enter the market for computer printers without having to develop and market an entire line of computers.

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[3] The same is true of quality standards, which reduce the role of reputation and of advertising. See Shapiro (1983) and Grant (1986).

However, there may also be adverse competitive effects from compatibility. We return to this subject below.

Variety

While compatibility requirements can limit variety, as discussed for instance in Farrell and Saloner (1986a), compatibility can also increase available variety, by allowing mix-and-match purchases, as Matutes and Regibeau (1986) point out. For example, the buyer of a stereo system can combine any amplifier and any turntable. By contrast, because the body-lens interface is not standardized across vendors, camera buyers are limited in their combinations of bodies and lenses.

Evidently, the value of this benefit depends on the value of variety in each component (do people's preferences differ?) and also on the absence of perfect correlation between buyers' preferences over the components (if everyone who wanted a brand-X turntable also wanted a brand-X amplifier, there would be no mix-and-match gains).

Cost Savings

By allowing greater scale economies (for instance, by enabling different manufacturers to exploit economies of scale in using a common supplier), and by allowing the use of interchangeable parts, standardization reduces production costs.[4]

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[4] This is a staple of economic history; see for instance Landes (1969, 1983), Hemenway (1975). Cost reductions may be valued by users or by makers (or both), depending on call the incidence of cost savings, which is a matter of market structure. In a perfectly competitive market, all cost savings that reduce marginal costs are passed on to buyers, but cost savings that reduce fixed costs are not. In imperfectly competitive markets, some cost savings may enhance the profits of sellers.

A complementary product may be more readily or more cheaply available as more people have the original product. An example is the provision of software for personal computers. The importance of ready availability of a repair network for a product is another example. This network externality was behind much of the success of the Singer sewing machine company in the late 1870s.[5]

Standardization also saves on the costs of learning how to use a good. Thus, typewriter keyboards are standardized (David 1985a) because it is desirable for each user to be able to "carry" his skill from one machine to another. This can have subtle implications. For instance, Brock (1975) discusses how pressure for standardization of the programming language COBOL increased when machine time became cheaper relative to programmer time, making it less important to design programs that run efficiently and more important to make it easier to write or transfer programs.

4. The Policy Importance of Economies of Scale

The benefits discussed above encourage users and vendors to do the same as others do. This advantage to going along with the crowd is a form of demand-side economy of scale. When there are economies of scale, textbook economic analysis, based on diminishing returns, can be misleading. For instance, when two product designs compete in the conventional framework, there is a stable outcome in which typically both are produced in optimal proportions, and these proportions can effectively track any changes in tastes or in technology, whether predictable or no t. With agglomeration economies, by contrast, the typical outcome is for one good or the other to take over the market, and which one wins may depend excessively on historical accident or on early preferences (Arthur 1983), or on strategic considerations (Katz and Sha-

[5] Chandler, 1977.

piro 1986a,b). As we will see below, conventional wisdom about the possibility of predation is also misleading in our context, and issues of lock-in become important. (This is not the only way in which nonconvexities can arise: see David 1985b). Overall, we must be careful in applying views formed by thinking about price-taking competitive economies to economic problems in which economies of scale are central.

5. Does Standardization Enhance Competition?

A common view is that incompatibility restricts competition via product differentiation. In this view, under incompatibility, each vendor has a monopoly on his part of the market.

It is true that this view ignores competition between systems. If the entire system is purchased at one time, then such between-systems competition may make within-system competition unnecessary. See Fisher (1979) for an exposition of this view. However, if buyers do not buy entire systems at once, and if sellers do not commit themselves to prices on the later-purchased components, then the "ex-ante" competition between systems need not adequately substitute for the "ex-post" competition within systems (Klemperer 1984, Farrell 1985, Farrell and Shapiro 1986). Buyers become, to some extent, captives of the vendor from whom they began buying. Where such issues of lock-in arise, standardization can commit producers to compete in an "aftermarket" for spare or replacement parts, complementary inputs, or peripheral devices. Absent standardization, we will see some monopoly power in the aftermarket, perhaps partly compensated by fierce competition in the original market, as vendors compete to lock-in buyers.

Often, the aftermarket (for instance, replacement fenders for a car model) is a natural monopoly, and the original manufacturer (car maker) has an advantage in taking the market (because he makes the original fenders). Absent standardization, this is a possible source of after-sale profits; indeed, in the auto industry, it is notorious that spare parts have a much higher profit margin than cars do. But often such pricing policies are inefficient (for instance, because buyers will inefficiently substitute away from the complementary input), and if that is anticipated by buyers, it may be profitable for the seller to commit to low or reasonable prices for afterparts. Standardization will achieve this.

We briefly discuss two other competitive benefits of standardization. First, market compatibility protects buyers against the threat of being orphaned in a losing technology. If it is feared that a supplier may go bankrupt, or suffer a crippling strike, buyers will worry about support for their purchases.[6] Standardization avoids this problem, and thus enhances competition, since a seller no longer need be seen as both financially secure and committed to the industry in order to sell a product. Sometimes buyers insist on "second-sourcing" to protect themselves against these problems. This is equivalent to guaranteeing (limited) standardization of their selected technology.[7]

Second, standardization can help in, or help replace, regulation. Long-distance telecommunications have been (partly) deregulated in the United States by requiring local telephone companies to interconnect with non-AT&T

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[6] See for instance Hemenway's (1975) discussion of the auto parts industry before the ASME achieved standardization. If a seller is large enough, there may be a presumption that someone would take over these support services, but it is typically not the large sellers that suffer from this fear.

[7] See Porter (1985), p. 209.

long-distance carriers (the OCCs). Mark Fowler, chairman of the US Federal Communications Commission (FCC), has recently suggested that some aspects of local telephone service could also be deregulated if switching protocols were standardized and suitable provision were made for interconnections between rival part-networks in the local exchange. The traditional view of telephone service as a natural monopoly is based on the inefficiency of having duplicate networks. This assumes that competing telephone companies would not have interconnection (a form of compatibility). While this may be a plausible result of unregulated competition (see Brock 1981 for a history), it is possible that requiring interconnection would make it unnecessary to regulate some other aspects of competition.

In contrast to these competitive benefits, compatibility may have adverse effects on competition. First, the mix-and-match effect of compatibility means that sellers sell their brand of each component only to those buyers who most value it. In some circumstances (Matutes and Regibeau, 1986) this can lead to higher equilibrium prices, and some buyers may be worse off.

Second, if competing standards are "sponsored" or proprietary, their sponsors may compete fiercely to have them adopted as the de facto standard. In early periods, this competition may be very good for buyers; although once one standard has "won," the proprietary de facto standard may become a source of monopoly power. Katz and Shapiro (1986a,b) analyze these problems.

6. Compatibility and Innovation

In recent decades, technological progress has been especially impressive in two industries, telecommunications and computers, in which questions of compatibility are of paramount importance. Because options and needs change so fast, and because the standardization process is in any case imperfect, it is important that we not be inefficiently locked into old choices. Of course, since the old choice is likely to be embodied in costly physical and human capital, we would not want to switch to a new standard every week, but sometimes a change is worthwhile. The optimal decision must depend on the gross benefits from switching (how much better is the new standard?), on the costs (replacement of physical capital, disruption of complementary markets, retraining costs), and on the extent to which there might be an even better alternative available soon. Evidently, we cannot expect any single agency to have all this information, especially since there are often incentives for those who do know things to misrepresent and exaggerate if asked to reveal them. In practice, of course, the problem is often "left to the market." How well does the market cope?

Suppose that there is a status-quo standard, and a new, possibly better, technology appears on the scene. In Farrell and Saloner (1985,1986b) we showed that sometimes the market will not switch even though it should. We called this effect "excess inertia". We also discussed the opposite phenomenon of wrongly abandoning a technology, which we called "excess momentum". These inefficiencies can arise either from problems of coordination and communication, or from the importance of installed base.

Coordination Problems

To illustrate how coordination problems can result in inefficient adoption decisions, we use a zoological analogy. In movies of the old West, cowboys who camped for the night where there were no trees to which to tie their horses would often tie the horses to one another. Even though the horses as a group were free to go wherever they wanted, they would not go far -- whereas a single horse left free overnight would. The horses' difficulty in coordinating on just where they would move at any instant prevented them from moving effectively. The fact that it is not only horses who have this problem is shown whenever a group of more than half a dozen people walk from office to restaurant: progress is far slower than with a smaller group.

In much the same way, it can happen that an industry may get stuck on an old and inferior technology, even when all participants might prefer to move to a new technology. This happens because the group is "tied together" by reluctance to sacrifice the benefits of being compatible.

To formalize this, consider a model in which each of a number of users chooses (in predetermined order) to switch to a new technology or to stay with the old. Because of network externalities or other benefits of standardization, we assume that whatever choice a user makes, it will prefer others to make the same choice. Assuming that agents have complete information[8] we showed (1985) that, if all users would be better off on the new technology, then they will all switch (in the unique perfect Nash equilibrium). If their preferences differ, then the early movers have considerable power to determine the outcome, because of the bandwagon effect. This result (which we called "the New Hampshire Theorem", from the timing of political primaries in the US) comes from our assumption that a user has only one chance to switch; thus, the early movers are Stackelberg leaders. More realistically, whatever makes a user able to commit itself early to a decision on standards will give it power.

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[8] This term means that each decisionmaker knows the preferences of all others, and everyone knows that, etc.

However, when we allowed for the fact that preferences are not perfectly known, and studied a model in which each user could choose to switch or not at each period, we showed that there can be symmetric excess inertia: all prefer the new technology, but none switch. With incomplete information about others' preferences, no user can be sure that it would be followed in a switch to the new standard. This uncertainty can lead all the users to remain with the status quo even when they do all in fact favor switching, because they are unwilling to risk switching without being followed. This we called "symmetric excess inertia".

Non-binding communication about preferences and intentions eliminates that possibility: each agent will tell the others that he would like a joint switch, and we will be back in the complete-information case. But communication actually exacerbates the asymmetric problem (if one user would be much better off if both switched, but the other would be somewhat worse off). The reason for this is that a "discouraging" message will prove more discouraging than it should if in fact the opponent of switching is only somewhat opposed. Thus, there can be excess inertia. Similarly, "excess momentum" is possible: all users may switch, even though it would be more efficient not to do so.

Thus only a user with a strong preference for the new standard will be an early adopter; and if there are no early adopters then the standard will never be adopted. Excess inertia arises when not enough users are willing to go out on a limb by adopting the new technology. This is most likely when network externalities are strong and there is a great deal of uncertainty about whether a lead would be followed. In practice, there are also questions of delay in following a lead, as we now discuss.

Installed Base Problems

In the model just described, time did not play an essential role (except that decisions were sequential). In particular, any transient incompatibility resulting from adoption of the new standard was ignored. In fact, however, there are generally real delays in achieving compatibility on a new standard after compatibility on an old one has been abandoned. These delays can create inefficiencies that are absent in the previous model. We study this problem in two related models in our 1986b paper.

In the first model, we suppose for simplicity that old users do not switch to the new standard, and that the new network must be built up by the adoption decisions of new users. Because new users arrive at a finite rate, this imposes delays in achieving a satisfactory network.

The incompatibility costs of these delays are borne disproportionately by the first users to adopt the new standard. Because of this, they may be unwilling to adopt it, even when (in the long run) it is socially desirable that they do so: this is excess inertia. Moreover, if the first users who could adopt the new standard choose instead to swell the installed base on the old, then a fortiori we cannot expect that later arrivals will start the new-standard bandwagon, for the old network is now larger (and thus more attractive) than ever. Thus these early choosers have a great deal of power: it is their preferences, their expectations, and their choices that determine the outcome.

We see therefore how these pivotal users may be unwilling to switch to a new standard when, from a social point of view, they should. In other cases, however, these pivotal users may find the new standard attractive and adopt it, thus stranding the earlier users who are committed to the old standard. These earlier users may lack a voice in this decision, and so there can be excess momentum.

The new standard is less likely to succeed the more important the transient incompatibility costs, and the larger the installed base. If one standard is proprietary, its sponsor may be able to take actions to affect the likelihood of adoption of the new standard. Some of these actions may be socially undesirable, and may have conventionally anticompetitive features.

For instance, there may be anticompetitive product preannouncements (as alleged in the Justice Department suit against IBM). In a standard economic framework, it is hard to see how product preannouncements can be anticompetitive. One would expect[9] that an announcement of a superior product would be socially beneficial (though detrimental to competitors) while an announcement of an inferior product would have no effect. However, both these views can be misleading if network externalities and installed base are important. In these circumstances, it is possible that if a new technology does not begin to sell by some critical date, the old standard will have an invulnerable advantage because the market will refuse to adopt anything incompatible with the large installed base.

In such a case, announcing the future availability of a product can encourage some potential users to wait for it, and can thus ensure its success when otherwise it would have failed. While this may be a good thing, it can also be socially undesirable and can be predatory in the sense that the firm that undertakes the action is sacrificing short-run profits in order to cause the exit or failure of a rival, and when it succeeds in doing so it enhances its future profits.

The importance of installed base can also provide an incentive for predatory pricing. If a seller with market power is threatened by new incompatible entry, it may prove worth his while to reduce his prices temporarily in

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[9] See Fisher et al., 1983

order to make his installed base large enough that his market position becomes invulnerable, at which time he can raise his prices again without inducing entry. We also observe that standard tests for predation may fail to detect the predation.

In our second model, by contrast, we assume that there are no new users, and that the new network is built up through old users switching. We suppose that a user who switches is not immediately followed by the others; more precisely, we suppose that switching is only convenient for a given user at certain times, which we suppose arrive stochastically. For instance, he may only consider a switch when some costly capital good needs replacing anyway.

The fact that he would not be immediately followed makes each user more reluctant to switch first than he otherwise would be; he may rather prefer to wait for another user to switch first, even if he would be better off switching first than not switching at all. (This we have dubbed the *penguin effect*: penguins gather on the edges of ice floes, each trying to jostle the others in first, because although all are hungry for fish, each fears there may be a predator lurking nearby.) However, if being temporarily stranded on the old standard is undesirable, then this excess inertia may disappear and even be reversed: in fact it is possible to get a pre-emptive equilibrium in which each user is poised to switch first only because he fears that otherwise another would do so.

Katz and Shapiro (1985b) study the problem of technology choice when installed base is important and there is "sponsorship" of one or both technologies, so that sellers may engage in strategic pricing or cross-subsidization between early and late users. They show that the market outcome may involve standardization on the "wrong" standard, and may standardize when there should not be standardization. In their model, there is a tendency towards excess momentum, in the sense that the technology that is cheaper in "the future" is too likely to prevail over that which is better today.

A striking result that emerges from these analyses is that excess momentum can arise in all models in which excess inertia is possible, and indeed sometimes when excess inertia is impossible, as in Katz and Shapiro. The externality in excess momentum is the stranding effect: early adopters may be left high and dry by later users who do not take their predecessors' preferences into account. Moreover, the fear of such stranding may deter early potential users from adopting the technology at all. (For instance, this is plausibly the case at present with local area networks.)

This suggests that some form of commitment to an early, even if arbitrary, choice of standard may be desirable. An alternative suggestion might be that the capital goods that embody an early and tentative standard should be leased rather than sold: this at least relieves early adopters of the capital risk in the physical plant (although they cannot avoid investing in some human capital). By putting this risk onto the vendor, who may have some control over whether there is a switch, we may internalize at least part of the stranding externality. If buyers are aware of this problem, as they often are, the vendor may find it profitable to offer to lease, even if he may have to take back old-fashioned machines at a loss. We see this strategy adopted in the market for AM stereo broadcast equipment (Besen and Johnson 1986), where broadcasters are in any case moving very slowly in adopting stereo technology, partly because of compatibility problems.

7. Timing of Standardization

Much discussion of standardization is couched in terms of *whether* to standardize and if so on *what standard*. A third important problem that has received much less attention is *when* to standardize.

Cognate with all the advantages to compatibility are advantages of early standardization. First of all, early standardization yields a longer and earlier flow of benefits from compatibility. But there are other advantages too. For instance, users may wait to adopt until there is a standard: thus early standardization hastens the growth of the market. Another strategic consideration is that delay in standardization encourages vendors of incompatible products to develop their installed bases and to sink costs in developing their technologies. In this way they become entrenched in their different product designs, and thus *delayed standardization is difficult standardization*.

These benefits from early standardization have tempted people to identify early standardization with successful standardization. But this may be quite wrong. There are also good reasons to wait. When we do not know for sure which standard will be the best in the long run, and information is coming in on that question, a later decision will on average be a better decision. The technology that would be chosen today may not turn out to be the best tomorrow. Choosing today sacrifices the option value of "waiting to see." This is especially important where a choice is largely irrevocable, as it will be if the physical and learning costs of changing the network are large. Moreover, if there is excess inertia in switching standards ex post, then a choice is hard to revoke even if the costs would not be very great,

There is thus a difficult trade-off in choosing the timing of standardization. A great deal of information is required to make the correct choice.

For instance, we must know what are the important attributes of a standard and how they compare in importance in users' preferences. We must know the "scores" of each possible standard on these attributes, not only now but also in probabilistic terms in the future. Costs, current and future, are needed. How important is it to allow for compatibility with each possible change that might be made later? Currently undeveloped technologies are also relevant: their prospects for success and for making a significant improvement on the current technologies must be accurately assessed. Clearly, no agency can have all this information, especially since there are often powerful incentives for those who do have the information to misreport it. This may be the reason for the widespread view that the choice is perhaps best "left to the market", but in our view that is not necessarily a good solution.

While the market is capable of aggregating preferences and information in some contexts, the main intellectual foundations of the laissez-faire approach depend on assumptions of diminishing returns. In this problem, as we have pointed out above, there are many aspects of increasing returns, and we can make no presumptions about the efficiency of market performance.

There are at least two kinds of bias in market outcomes in such a problem. First, the power to determine what gets adopted is often effectively vested in a few market participants: sometimes because they are large, and sometimes because they are early. These few powerful participants may not be especially well-informed, and even if they are, their preferences may differ from those of the other participants. Second, a vendor's incentives to standardize early versus late depend on the extent to which it appropriates the benefits from early standardization compared to the extent to which it appropriates the benefits from waiting. For example, a vendor may be able to appropriate (in enhanced profits) a considerable fraction of the benefits from early standardization, but may be unable to capture the benefits from waiting. In this case, it would tend to standardize too soon. Or it could equally go the other way. While market structure, among other things, is probably relevant here, we have no reason to expect that competitive or unconcentrated industries will do well on this score: attributing problems of market standardization to conventional "imperfections" of market structure is a mistake.

While the market always produces some outcome and often produces a de facto standard, we should not confuse this with success. The story of the QWERTY typewriter keyboard, related by David (1985a), is an instructive lesson. Lemmings would be well advised to look before they leap.

8. Industrial Policy

Since the benefits from compatibility are not limited by national boundaries, and since compatibility choices affect the nature of competition, standardization has consequences for international trade. We briefly describe two aspects of this. The interested reader should consult Crane (1979).

First, the economies of scale on the demand side can act in the same way as supply-side scale economies. When there is a dynamic element, as when the network externalities are embodied in installed base, an early start or a protected market could in principle lead to lasting competitive advantage. For a treatment of this problem (in the case of learning-by-doing) see Krugman (1986).

Second, international standard-setting is often a two-stage affair. National interests are represented in international committees. As a result, the more entrenched a nation is in one standard, the more power it has in getting its standard adopted (though it also loses more if it loses). This may encourage premature standardization at the national level, and may give a strategic advantage to countries with central direction of standardization activities.

9. Conclusion

Standardization is extremely important in modern economies, especially in the information processing industries. While it has many benefits, it may also have serious social costs. There has been little economic analysis of the policy problems.

Conclusions reached by traditional economic reasoning, in which convexity and diminishing returns are generally assumed, are likely to be misleading when bandwagon effects, windows of opportunity for entry, and installed base problems are important. We have seen that the analysis of such staples of industrial organization as pricing, predation, innovation, and variety, is very different when compatibility is important.

There is no easy prescription for microeconomic policy in markets in which network externalities play an important part. In this paper and in our other work, we have identified some of the factors that should be kept in mind, and we have shown how certain standard lessons of economics must be treated cautiously. Further work on the subject is needed.

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