Economics of Information Technology

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1 Introduction

During the 1990s there were three back-to-back events that stimulated investment in information technology: telecommunications deregulation in 1996, the ``year 2K" problem in 1998-99, and the ``dot com" boom in 1999-2000. The resulting investment boom led to dramatic run-up of stock prices for information technology companies.

Many IT companies listed their stocks on NASDAQ. Figure 1 depicts the cumulative rate of return on the NASDAQ and the S&P500 during most of the 1990s. Note how closely the two indices track each other up until January of 1999, at which point NASDAQ took off on its roller coaster ride. Eventually it came crashing back, but note that the total return over the eight years depicted in the figure ended up being about the same.

Figure 1 actually understates the magnitude of technology firms on stock market performance, since a significant part of the S&P return was also driven by technology stocks. In December 1990, the technology component of the S&P was only 6.5 percent; by March, 2000, it was over 34 percent. By July 2001, it was about 17 percent.

Despite the dramatic run-up and run-down in technology stocks, it is clear that information technology has played, and will continue to play, a significant role in the economy. The increase in productivity growth in the late 1990s is often attributed to the investment in IT during the first half of that decade. If this is true, then it is very good news, since it means we have yet to reap the benefits of the IT investment of the late 1990s. (I will not address the literature on productivity in this survey; see [152000Brynjolfsson and Hitt], [722001Steindel and Stiroh], and [732001Stiroh] for an introduction to this literature.)

2 Motivation

This essay is concerned with the relationship between technology and market structure. High-technology industries are subject to the same market forces as every other industry. However, there are some forces that are particularly important in high-tech, and it is these forces that will be the primary concern of this survey. These forces are not ``new." Indeed, the forces at work in network industries in 1990s are very similar to those that confronted the telephone and wireless industries in the 1890s.

But forces that were relatively minor in the industrial economy turn out to be critical in the information economy. Second-order effects for industrial goods are often first-order effects for information goods.

Figure 1: Return on the NASDAQ and S&P 500 during the 1990s.

Take, for example, cost structures. Constant fixed costs and zero marginal costs are common assumptions for textbook analysis, but are rarely observed for physical products since there are capacity constraints in nearly every production process. But for information goods, this cost structure is very common-indeed it is the baseline case. This is true not just for pure information goods, but even for physical goods like chips. A chip fabrication plant can cost several billion dollars to construct and outfit; but producing an incremental chip only costs a few dollars. It is rare to find cost structures this extreme outside of technology industries.

The effects I will discuss involve pricing, switching costs, scale economies, transactions costs, system coordination, and contracting. Each of these topics has been extensively studied in the economics literature. I do not pretend to offer a complete survey of the relevant literature, but will focus on relatively recent material in order to present a snapshot of the state of the art of research in these areas.

I try to refer to particularly significant contributions and other more comprehensive surveys. The intent is to provide an overview of the issues for an economically literate, but non-specialist, audience.

For a step up in technical complexity, I can recommend the survey of network industries in the *Journal of Economic Literature* consisting of articles by [451994Katz and Shapiro], [131991Besen and Farrell], [521990Leibowitz and Margolis], and the book by [712001Shy]. For a step down in

technical complexity, but with much more emphasis on business strategy, I can recommend [691998aShapiro and Varian], which contains many real-world examples.

3 Intellectual property

There is one major omission from this survey, and that is the role of intellectual property.

When speaking of information and technology to manipulate information, intellectual property is a critical concern. Copyright law defines the property rights of the product being sold. Patent law defines the conditions that affect the incentives for, and constraints on, innovation.

My excuse for the omission of intellectual property from this survey is that this topic is ably covered by my coauthor, [212002David]. In addition to this piece, I can refer the reader to the surveys by [352001Gallini and Scotcher], [342002Gallini] and [542000Menell], and the reviews by [672000Shapiro], [682001Shapiro]. [642002Samuelson and Varian] describe some recent developments in intellectual property policy.

4 Differentiation of products and prices

Information technology allows for fine-grained observation and analysis of consumer behavior. This allows for various kinds of marketing strategies that were previously extremely difficult to carry out, at least on a large scale. For example, a seller can offer prices and goods that are differentiated by individual behavior and/or characteristics. This section will review some of the economic effects that arise from the ability to use more effective price discrimination.

4.1 First-degree price discrimination

In the most extreme case, information technology allows for a ``market of one," in the sense that highly personalized products can be sold at a highly personalized price. This phenomenon is also known as ``mass customization" or ``personalization."

Consumers can personalize their front page at many on-line newspapers and portals. They can buy a personally configured computer from Dell, and even purchase computer-customized blue jeans from Levi's. We will likely see more and more possibilities for customization of both information and physical products.

Amazon was accused of charging different prices to different customers depending on their behavior ([622000Rosencrance]), but they claimed that this was simply market experimentation. However, the ease with which one can conduct marketing experiments on the Internet is itself notable. Presumably companies will find it much easier to fine-tune pricing in Internet-based commerce, eliminating the so-called ``menu costs" from the pricing decision. [161999Brynjolfsson and Smith] found that Internet retailers revise their prices much more often than conventional retailers, and that prices are adjusted in much finer increments.

The theory of monopoly first-degree price discrimination is fairly simple: firms will charge the highest price they can to each consumer, thereby capturing all the consumer surplus. However, it is clear that this is an extreme case. On-line sellers face competition from each other and from off-line sellers, so adding competition to this textbook model is important.

[762000Ulph and Vulkan,772001Ulph and Vulkan] have examined the theory of first-degree price and product differentiation in a competitive environment. In their model, consumers differ with respect to their most desired products, and firms choose where to locate in product space and how much to charge each consumer. Ulph and Vulkan find that there are two significant effects: the enhanced surplus extraction effect and the intensified competition effect. The first effect refers to the fact that personalized pricing allows firms to charge prices closer to the reservation price for each consumer; the second effect refers to the fact that each consumer is a market to be contested. In one model they find that when consumer tastes are not dramatically different, the intensified competition effect dominates the surplus extraction effect, making firms worse off and consumers better off with competitive personalized pricing.

This is an interesting result, but their model assumes full information. Thus it leaves out the possibility that long-time suppliers of consumers know more about their customers than alternative suppliers. Sellers place much emphasis on ``owning the consumer." This means that they can understand their consumer's purchasing habits and needs better than potential competitors. Amazon's personalized recommendation service works well for me, since I have bought books there in the past. A new seller would not have this extensive experience with my purchase history, and would therefore offer me inferior service.

Of course, I could search on Amazon and purchase elsewhere, but there are other cases where free riding of this sort is not feasible. For example, a company called AmeriServe provides paper supplies to fast food stores. As a by-product, they found that their records about customer orders allowed them to provide better analysis and forecasts of their customers' needs than the customers themselves. Due to this superior information, Ameriserve as able to services to their customers such as recommended orders for restock. This service was valuable to AmeriServe's customers, and therefore gave it an edge over competitive suppliers, allowing it to charge a premium for providing this service, either via a flat fee or via higher prices for their products.

Personalized pricing obviously raises privacy issues. I have discussed some of these issues in [801997Varian]. A seller that knows its customers' tastes can sell them products that fit their needs better but it will also be able to charge more for the superior service.

Obviously, I may want my tailor, my doctor, and my accountant to understand my needs and provide me with customized services. However, it is equally obvious that I do not, in general, want them to share this information with third parties, at least without my consent. The issue is not privacy, per se, but rather trust: consumers want to control how information about themselves is used.

In economic terms, bilateral contracts involving personal information can be used to enhance efficiency, at least when transactions costs are low. But sale of information to third parties, without consumer consent, would not involve explicit contracting, and there is no reason to think it would be efficient. What is needed, presumably, are default contracts to govern markets in personal information. The optimal structure of these default contracts will depend on the nature of the transactions costs associated with various arrangements. I discuss these issues in more detail in [801997Varian].

Another issue relating to personalized pricing and mass customization is advertising. Many of the services that use personalization also rely heavily on revenue from advertising. Search engines, for example, charge significantly more for ads keyed to ``hot words" in search queries since these ads are being shown to consumers who may find them particularly relevant. This particular practice is widespread, but has been modeled in much detail, so far as I know.

4.2 Second-degree price discrimination

Second-degree price discrimination refers to a situation where everyone faces the same menu of prices for a set of related products. It is also known as ``product line pricing," ``market segmentation," or ``versioning." The idea is that sellers use their knowledge of the *distribution* of consumer tastes to design a product line that appeals to different market segments.

This form of price discrimination is, of course, widely used. Automobiles, consumer electronics, and many other products are commonly sold in product lines. We don't normally think of information goods as being sold in product lines but, upon reflection, it can be seen that this is a common practice. Books are available in hardback or paperback, in libraries, and for purchase. Movies are available in theaters, on airplanes, on tape, on DVD, and on TV. Newspapers are available on-line and in physical form. Traditional information goods are very commonly sold in different versions.

Information versioning has also been adopted on the Internet. To choose just one example, 20-minute delayed stock prices are available on Yahoo free of charge, but real-time stock quotes cost $9.95 a month. In this case, the providers are using ``delay" to version their information.

Information technology is helpful in both collecting information about consumers, to help design product lines, and in actually producing the different versions of the product itself. See [691998aShapiro and Varian,701998bShapiro and Varian], and [812000Varian] for analysis of versioning.

The basic problem in designing a product line is ``competing against yourself." Often consumers with high willingness to pay will be attracted by lower-priced products that are targeted towards consumers with lower willingness to pay. This ``self-selection problem" can be solved by lowering the price of the high-end products, or by lowering the ``quality" of the low-end products.

Making the quality adjustments may be worthwhile even when it is costly, raising the peculiar possibility that the low-end products are more costly to produce than the high-end products. See [231996Denerke and McAfee] for a general treatment and [691998aShapiro and Varian] for applications in the information goods context.

[812000Varian] analyzes some of the welfare consequences of versioning. Roughly speaking, versioning is good in that it allows markets to be served that would otherwise not be served. This is the standard output-enhancing effect of price discrimination described in [661981bSchmalensee] and [791985Varian]. However, the social cost of versioning is the quality reduction necessary to satisfy the self-selection constraint. In many cases the output effect appears to outweigh the quality reduction effect, suggesting that versioning is often welfare-enhancing.

Versioning is being widely adopted in the technology-intensive information goods industry. Intuit sells three different versions of their home accounting and tax software, Microsoft sells a number of versions of their operating systems and applications software, and even Hollywood has learned how to segment audiences for home video. The latest trend in DVDs is to sell a ``standard" version for one price and an enhanced ``collectors edition" for five to ten dollars more. The more elaborate version contains outtakes, director's commentary, storyboards and the like. This gives the studios a way to price discriminate between collectors and viewers, and between buyers and renters. Needless to say, the price differences between the two versions is much greater than the difference in marginal cost.

4.3 Third-degree price discrimination

Third degree price discrimination is selling at different prices to different groups. It is, of course, a classic form of price discrimination and is widely used.

The conventional treatment examines monopoly price discrimination, but there have been some recent attempts to extend this analysis to the competitive case. [32001Armstrong and Vickers] present a survey of this literature, along with a unified treatment and a number of new results. In particular they observe that when consumers have the essentially the same tastes, and there is a fixed cost of servicing each consumer, then competitive third-degree price discrimination will generally make consumers better off. The reason is that competition forces firms to maximize consumer utility, and price discrimination gives them additional flexibility in dealing with the fixed cost. If there are no fixed costs, consumer utility falls with competitive third-degree price discrimination, even though overall welfare (consumer plus producer surplus) will still rise.

With heterogeneous consumers, the situation is not as clear. Generally consumer surplus is reduced and profits are enhanced by competitive price discrimination, so welfare may easily fall.

4.4 Conditioning on purchase history

Another form of price discrimination that is of considerable interest in high-tech markets is price discrimination based on purchase history. [321998Fudenberg and Tirole] investigate models where a monopolist can discriminate between old and new customers by offering upgrades, enhancements, and the like. [332000Fundenberg and Tirole] investigate a duopoly model which adds an additional phenomenon of ``poaching:" one firm can offer a low-ball price to steal another's customers. These results are extended by [821999Villas-Boas] and [832001Villas-Boas].

[12001Acquisti and Varian] examine a simple model with two types of consumers: high-value and low-value. They find that although a monopolistic seller is able to make offers conditional on previous purchase history, it is never profitable for it to do so, which is consistent with the earlier analysis of intertemporal price discrimination by [741979Stokey] and [631989Salant].

However, [12001Acquisti and Varian] also show that if the monopolist can offer an enhanced service such as one-click shopping or recommendations based on purchase history, it may be optimal to condition prices on earlier behavior and extract some of the value from this enhanced service.

4.5 Search

One interesting effect of the Internet is that it can lower the cost of search quite dramatically. Even in markets where there are relatively few direct transactions over the Internet, such as automobiles, consumers appear to do quite a bit of information gathering before purchase.

There are many shopping agents that allow for easy price comparisons. According to Yahoo, mySimon, BizRate, PriceScan, and DealTime are among the most popular of these services. What happens when some of the consumers use shopping agents and others shop at random? This question has been addressed by [381999Greenwald and Kephart], [102001Baye et al.Baye, Morgan, and Scholten], [112001Baye and Morgan] and others. The structure of the problem is similar to that of [781980Varian], and it is not surprising that the solution is the same: sellers want to use a mixed strategy and randomize the prices they charge. This allows them to compete for the searchers and still charge, on average, a high price to the non-searchers. In my 1980 paper I interpreted this

randomization as promotional sales; in the Internet context it is better seen as small day-to-day fluctuations in price. [102001Baye et al.Baye, Morgan, and Scholten] and [161999Brynjolfsson and Smith] show that on-line firms do engage in frequent small price adjustments, similar to those predicted by the theory.

One reason that more people don't use ``shopbots" may be that they do not trust the results. [262001Ellison and Ellison] have found that it is common for online retailers to engage in ``bait and switch" tactics: they will advertise an inferior version of a product (i.e., an obsolete memory chip) in order to attract users to their site. Such obfuscation may discourage users from shopbots, leading to the kind of price discrimination described above.

4.6 Bundling

Bundling refers to the practice of selling two or more distinct goods together for a single price. ([21976Adams and Yellen].) This is particularly attractive for information goods since the marginal cost of adding an extra good to a bundle is negligible. There are two distinct economic effects involved: reduced dispersion of willingness to pay, which is a form of price discrimination, and increased barriers to entry, which is a separate issue.

To see how the price dispersion story works, consider a software producer who sells both a word processor and a spreadsheet. Mark is willing to pay $120 for the word processor and $100 for the spreadsheet. Noah is willing to pay $100 for the word processor and $120 for the spreadsheet.

If the vendor is restricted to a uniform price, it will set a price of $100 for each software product, realizing revenue of $400.

But suppose the vendor bundles the products into an ``office suite." If the willingness to pay for the bundle is the sum of the willingness to pay for the components, then each consumer will be willing to pay $220 for the bundle, yielding a revenue of $440 for the seller.

The enhanced revenue is due to the fact that bundling has reduced the dispersion of willingness to pay: essentially it has made the demand curve flatter. This example is constructed so that the willingnesses to pay are negatively correlated, so the reduction is especially pronounced. But the Law of Large Numbers tells us that unless a number of random variables are *perfectly* correlated, summing them up will tend to reduce relative dispersion, essentially making the demand curve flatter.

[81999Bakos and Brynjolfsson,92000Bakos and Brynjolfsson,72001Bakos and Brynjolfsson] have explored this issue in considerable detail and show that bundling significantly enhances firm profit and overall efficiency, but at the cost of a reduction in consumer surplus. They also note that these effects are much stronger than with physical goods, due to the zero marginal cost of information goods.

[841990Whinston], [561999Nalebuff,572000Nalebuff] and [92000Bakos and Brynjolfsson] examine the entry deterrent effect of bundling. To continue with the office suite example, consider a more general situation where there are many consumers with different valuations for wordprocessors and spreadsheets. By selling a bundled office suite, the monopoly software vendor reaches many of those who value both products highly and some of those who value only one of the products highly.

If a competitor contemplates entering either market, it will see that its most attractive customers are already taken. Thus it finds that the residual demand for its product is much reduced-making entry a much less profitable strategy.

The only way a potential entry could effectively compete would be to offer a bundle with both products. This not only increases development costs dramatically, but it also makes competition very intense in the suite market-a not so sweet outcome for the entrant. When Sun decided to enter the office suite market with StarOffice, a competitor for Microsoft Office, they offered the package at a price of zero, recognizing that it would take such a dramatic price to make headway against Microsoft's imposing lead.

5 Switching costs and lock-in

When you switch automobiles from Ford to G.M., the change is relatively painless. If you switch from Windows to Linux, it can be very costly. You may have to change document formats, applications software, and, most importantly, you will have to invest substantial time and effort in learning a new operating environment.

Changing software environments at the organizational level is also very costly. One study found that the total cost of installing an Enterprise Resource Planning (ERP) system such as SAP was eleven times greater than the purchase price of the software due to the cost of infrastructure upgrades, consultants, retraining programs, and the like.

These switching costs are endemic in high-technology industries and can be so large that switching suppliers is virtually unthinkable, a situation known as ``lock-in."

Switching costs and lock-in has been extensively studied in the economics literature. See, for example, [481987Klemperer], [271989Farrell and Shapiro], [291988Farrell and Shapiro], [121992Beggs and Klemperer], and [501995Klemperer]. The last work is a particularly useful survey of earlier work. [691998aShapiro and Varian] examine some of the business strategy implications of switching costs and lock-in.

5.1 Simple analytics of lock-in

Consider the following simple two-period model, adopted from [501995Klemperer]. There are n consumers, each of whom is willing to pay v per period to buy a non-durable good. There are two producers that produce the good at a constant identical marginal cost of c. The producers are unable to commit to future prices.

In order to switch consumption from one firm to the other, a consumer must pay a switching cost s. We suppose $v \geq c$, but $v+s < c$, so that it pays the consumer to purchase the good but not to switch.

The unique Nash equilibrium in the second period is for each firm to set its price to the monopoly price v, making profit of v–c. The seller can extract full monopoly profit second period, since the consumer are ``locked-in," meaning that their switching costs are so high that the competitive seller is unable to offer them a price sufficiently low to induce them to switch.

The determination of the first-period price will be discussed below.

5.2 Competition to acquire customers

When switching costs are substantial, competition can be intense to attract new customers, since, once they are locked in, they can be a substantial source of profit. Everyone has had the experience of buying a nice ink jet printer for $150 only to discover a few months later that the replacement cartridges cost $50. The notable fact is not that the cartridges are expensive, but rather that the printer is so cheap. And, of course, the printer is so cheap *because* the cartridges are so expensive. The printer manufacturers are following the time-tested strategy of giving away the razor to sell the blades.

Business Week reports that HP's printer supply division made an estimated $500 million in operating profit on sales of $2.4 billion. The rest of HP's businesses lost $100 million on revenues of $9.2 billion. The inkjet cartridges reportedly have over 50% profit margins. ([612001Roman])

In a related story, [192001Cowell] reports that SAP's profits rose by 78 percent in the second-quarter of 2001, even in the midst of a widespread technology slump. As he explains, ``... because SAP has some 14,000 existing customers using its products, it is able to sell them updated Internet software..."

[41991Ausubel] and [462001Kim et al.Kim, Kliger, and Vale] examine switching costs in the credit card and bank loan markets and find that they are substantial: in the bank loan case, they appear to amount to about a third of the average interest rate on loans.

As these examples illustrate, lock-in can be very profitable for firms. It is not obvious that switching costs necessarily reduce consumer welfare, since the competition to acquire the customers can be quite valuable to consumers. For example, consumers who use their printers much less than average are clearly made better off by having a low price for printers, even though they have to pay a high price for cartridges.

The situation may be somewhat different for companies like SAP, Microsoft, or Oracle. They suffer from the ``burden of the locked-in customers," in the sense that they would like to sell at a high price to their current customers (on account of their switching costs) but would also like to compete aggressively for new customers, since they will remain customers for a long time and contribute to future profit flows. This naturally leads such firms to want to price discriminate in favor of new customers, and such strategies are commonly used.

Though he acknowledges that in many cases welfare may go either way, [501995Klemperer] concludes that switching costs are generally bad for consumer welfare: they typically raise prices over the lifetime of the product, create deadweight loss, and reduce entry.

5.3 Analytics of competition to acquire customers

Return to the model of section 5.1. Suppose for simplicity that the discount rate is zero, so that the sellers only care about the sum of the profit over the two periods. In this case, each firm would be willing to pay up to $v-c$ to acquire a customer.

Bertrand competition pushes the present value of the profit of each firm to zero, yielding a first period price of $2c-v$. The higher the second-period monopoly payoff, the smaller the first period price will be, reflecting the result of the competition to acquire the monopoly.

If we assumed the goods were partial substitutes, rather than perfect substitutes, we would get a less extreme result, but it is still typically the case that the first-period price is lower because of the

second-period lock-in. See [491989Klemperer] and [501995Klemperer] for a detailed analysis of this point.

It is worth noting that the conclusion that first-period prices are lower due to switching costs depends heavily on the assumption that the sellers cannot commit to second-period prices. If the sellers *can* commit to second period prices, the model collapses to a one-period model, where the usual Bertrand result holds. In the specific model discussed here, the price for two periods of consumption would be competed down to 2c.

Both firms would, of course, prefer the lock-in outcome, so they would normally be reluctant to adopt commitment devices, such as contracts. See [332000Fundenberg and Tirole] for more on this issue.

5.4 Switching costs and price discrimination

One common example of switching costs involves specialized supplies, as with inkjet printer cartridges. In this example, the switching cost is the purchase of a new printer. The market is competitive *ex ante* , but since cartridges are incompatible, it is monopolized *ex post* .

This situation can also be viewed as a form of price discrimination. The consumer cares about the price of the printer plus the price of however many cartridges the consumer buys. If all consumers are identical, a monopolist would set the price of the cartridges equal to their marginal cost and use its monopoly power on the printer. This is just the two-part tariff result of [581971Oi] and [651981aSchmalensee].

6 Supply-side economies of scale

We have already noted that many information and technology-related businesses have cost structures with large fixed costs and small, or even zero, marginal costs. They are, to use the textbook term, ``natural monopolies." However, this isn't to say that the textbook analysis of natural monopoly immediately applies.

First, competition in the real world is much more dynamic than in the textbook examples. The textbook analysis starts with the existence of a monopoly, but rarely does it examine how that monopoly came about.

If the biggest firm has the most significant cost advantages, firms will compete intensively to be biggest, and consumers will benefit from that competition. Amazon believed, rightly or wrongly, that scale economies were very important in on-line retailing, and consumers benefited from the low prices it charged while it was trying to build market share.

Second, it is often possible to overcome cost advantages when the market is growing rapidly. Even though the largest firm may have a cost advantage at any point in time, if the market is growing at 40 percent per year, the tables can be turned very rapidly. Wordstar, and Wordperfect once dominated the word processor market; Visicalc and Lotus once dominated the spreadsheet market. Market share alone is no guarantee of success.

Third, information technology has also reduced the minimum efficient scale of operation in many markets. Typography and page layout used to be tasks that only experts could carry out; now anyone with a $1000 computer can accomplish reasonably professional layout. Desktop publishing

has led to an explosion of new entrants in the magazine business. Of course it is also true that many of these entrants have been subsequently acquired due to other economies of scope and scale in the industry; see [512001Kuczynski]. The same thing will happen to other content industries, such as movie making, where digital video offers very substantial cost reductions. Even chip making may be vulnerable: experimenters are now using off-the-shelf inkjet printers to print integrated circuits on metallic film, a process that could dramatically change the economics of this industry.

Nevertheless, the presumption has to be that price will typically exceed marginal cost in these industries, leading to the conventional inefficiencies. See [222001Delong and Froomkin] for a treatment of this issue.

However, it should be remembered that, even in a static model, the correct formulation for the efficiency condition is that *marginal* price should equal marginal cost. If the information good (or chip, or whatever) is sold to different consumers at different prices, it may well happen that users with low willingnesses to pay may end up facing very low prices, implying that efficiency losses are not substantial.

Furthermore, it should also be remembered that many declining average cost industries involve durables of one form or another. PCs and operating systems are technologically obsolete far before they are functionally obsolete. In these industries the installed base creates formidable competition for suppliers since the sellers continually have to convince their users to upgrade. The ``durable goods monopoly" literature inspired by [171972Coase] is not just a theoretical curiosum, but is rather a topic of intense concern in San Jose and Redmond.

In summary, although supply side economies of scale may lead to more concentrated industries, this may not be so bad for consumers as is often thought. Price discipline still asserts itself through four different routes.

Competition to acquire monopoly.
: In many cases the competition to acquire a monopoly will force lower prices for consumers. However, competition can also produce rent dissipation, as described in [301985Fudenberg and Tirole], [391989Hillman and Riley], and [311987Fudenberg and Tirole].

Competition with yourself.
: Often, the installed base of a firm's own output is a formidable competitor, especially when technological progress is so rapid as to exceed the ability to utilize technology fully.

Pressure from complementors.
: Providers of complementary products want to see lower prices, and have various ways to exert pressure to accomplish this. This sort of ``co-opetition" can be a very powerful force. [] have explored several ramifications.

Inventing around.
: Even when a monopolist is entrenched due to strong intellectual property rights, scale effects or other forms of barriers to entry, competing firms will attempt to invent around the patent, or bypass the entry barriers, creating new products and services.

The traditional view of monopoly is that it creates deadweight loss and producer surplus, as shown in Figure 2A. However, perfect price discrimination eliminates the deadweight loss and competition for the monopoly transfers the resulting monopoly rents to the consumers, as shown in Figure 2B.

This is, admittedly, an extreme case. In reality price discrimination is never perfect, and competition for monopoly is never costless. Still it offers a cautionary note: one should not necessarily assume that large returns to scale will necessarily impose large costs on consumers.

Even in the ideal world depicted in Figure 2, several important qualifications must be kept in mind. First, this is an analysis only of pricing behavior: quality choice, innovation, and other important aspects of firm behavior are not examined. Second, if there is no competition to acquire the monopoly, the story is much worse for consumers. Antitrust policy still has an important role in ensuring that the competition for monopoly is fair, open and non-discriminatory. Third, there can definitely be social losses from attempts by an incumbent to *defend* a monopoly when challenged by a potentially more efficient entrant.

Fourth, we have implicitly assumed that the competition for the monopoly takes the form of price competition, which benefits consumers. It is possible that competition could take more perverse forms, such as political lobbying, that would dissipate the monopoly profits in a way that would not benefit consumers. For more on ``rent dissipation" see [301985Fudenberg and Tirole] and [391989Hillman and Riley].

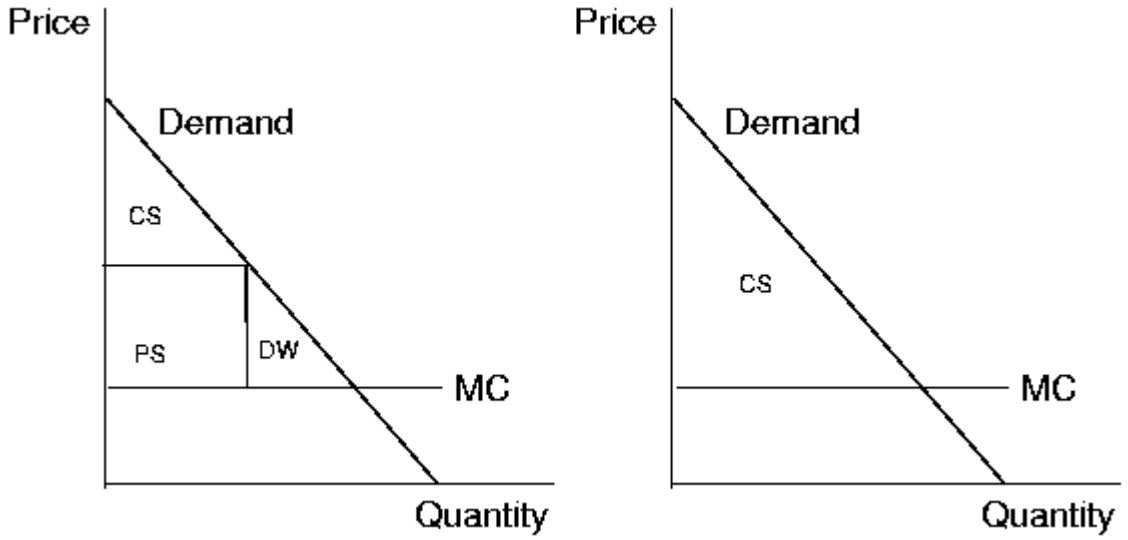

Figure 2: Competition for perfectly price discriminating monopolist.

The rules of the ``competing for monopoly" game are quite important. It may be take the form of an *English auction,* where the highest bidder gets the monopoly. Pure cases are the airwaves auctions or bidding (implicitly or explicitly) for a patent license. Alternatively, competing for the monopoly could be an *everyone pays auction* such as a patent race, or a race to build scale. This is the rent dissipation case analyzed in [391989Hillman and Riley]. However, ``dissipation" is too negative a term in that consumers can easily benefit from this form of competition. Yet a third example is a *war of attrition* in which both players compete until one drops out.

Note the payoff structure of these three games: in the English auction, the winner pays the second highest bid. In the ``all pay" auction, it can be shown that the sum of the payments by the players equals the value of the prize. In the ``war of attrition" the winner again pays the second highest bid.

7 Demand-side economies of scale

Demand-side economies of scale are also known as ``network externalities" or ``network effects," since they commonly occur in network industries. Formally, a good exhibits network effects if the demand for the good depends on how many other people purchase it. The classic example is a fax machine; picture phones and email exhibit the same characteristic.

The literature distinguishes between ``direct network effects," of the sort just described, and ``indirect network effects," which are sometimes known as ``chicken and egg problems." I don't directly care whether or not you have a DVD player-that doesn't affect the value of my DVD player. However, the more people that have DVDs, the more DVD-readable content will be provided, which I do care about. So, indirectly, your DVD player purchase tends to enhance the value of my player.

Indirect network effects are endemic in high-tech products. Current challenges include residential broadband and applications, and 3G wireless and applications. In each case, the demand for the infrastructure depends on the availability of applications, and vice versa. The cure for the current slump, according to industry pundits, is a new killer app. Movies on demand, interactive TV, mobile commerce-there are plenty of candidates, but investors are wary, and for good reason: there are very substantial risks involved.

I will discuss the indirect network effects in Section 9. In this section, I focus on the direct case.

I like to use the terminology ``demand side economies of scale" since it forms a nice parallel with the classic supply side economies of scale discussed in the previous section. With supply side economies, average cost decreases with scale, while with demand side economies of scale, average revenue (demand) increases with scale.

When network effects are present, there are normally multiple equilibria. If no one adopts a network good, then it has no value, so no one wants it. If there are enough adopters, then the good becomes valuable, so more adopt it-making it even more valuable. Hence network effects give rise to positive feedback.

We can depict this process in a simple supply-demand diagram. The demand curve (or, more precisely, the ``fulfilled expectations demand curve") for a network good typically exhibits the hump shape depicted in Figure 3. As the number of adopters increases the marginal willingness to pay for the good also increases due to the network externality; eventually, the demand curve starts to decline due to the usual effects of selling to consumers with progressively lower willingness to pay.

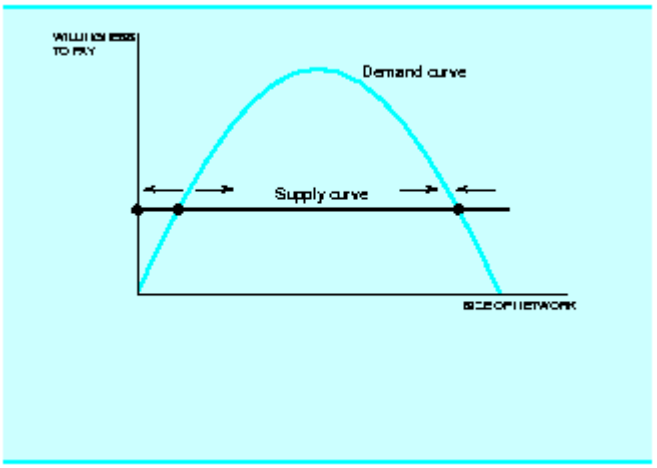

Figure 3: Demand and supply for a network good.

In the case depicted, with a perfectly elastic supply curve, there are three equilibria. Under the natural dynamics, which has quantity sold increasing when demand is greater than supply and

decreasing when demand is less than supply, the two extreme equilibria are stable and the middle equilibrium is unstable.

Hence the middle equilibrium represents the ``critical mass." If the market can get above this critical mass, the positive feedback kicks in and the product zooms off to success. But if the product never reaches a critical mass of adoption, it is doomed to fall back to the stable zero-demand/zero-supply equilibrium.

Consider an industry where the price of the product-a fax machine, say-is very high, but is gradually reduced over time. As Figure 3 shows, the critical mass will then become smaller and smaller. Eventually, due to random fluctuation or due to a deliberate strategy, the sales of the product will exceed the critical mass.

Though this story is evocative, I must admit that the dynamics is rather ad hoc. It would be nice to have a more systematic derivation of dynamics in network industries. Unfortunately, microeconomic theory is notoriously weak when it comes to dynamics and there is not very much empirical work to really determine what dynamic specifications make sense. The problem is that for most network goods, the frequency of data collection is too low to capture the interesting dynamics.

Figure 4 depicts the prices and shipments of fax machines in the U.S. during the 1980s. Note the dramatic drop in price and the contemporaneous dramatic increase in demand in the mid-eighties. This is certainly consistent with the story told above, but it is hardly conclusive. [251995Economides and Himmelberg] make an attempt to estimate a model based on these data, but, as they acknowledge, this is quite difficult to do with low-frequency time-series data.

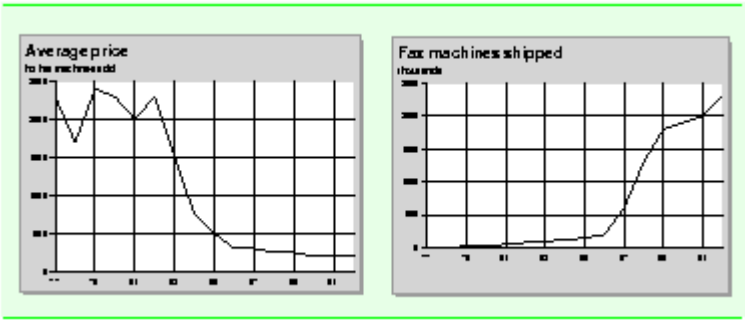

Figure 4: Price and shipments of fax machines.

There have been some attempts to empirically examine network models using cross sectional data. [372000Goolsbee and peter J. Klenow] examine the diffusion of home computers and find a significant effect for the influence of friends and neighbors in computer purchase decisions, even when controlling for other income, price, and demographic effects.

All these examples refer to network externalities for a competitive industry selling a compatible product: a fax machine, email, or similar product. [591974Rohlfs] was the first to analyze this case in the economics literature; he was motivated by AT&T's disastrous introduction of the PicturePhone.

[431985Katz and Shapiro,411986aKatz and Shapiro,441986bKatz and Shapiro,421992Katz and Shapiro] have examined the impact of network externalities in oligopoly models in which technology adoption is a key strategic variable. [241996Economides] and [451994Katz and

Shapiro] and provide a useful reviews of the literature, while [602001Rohlfs] provides a history of industries in which network effects played a significant role.

Network effects are clearly prominent in some high-technology industries. Think, for example, of office productivity software such as word processors. If you are contemplating learning a word processor, it is natural to lean towards the one with the largest market share, since that will make it easy to exchange files with other users, easier to work on multi-authored documents, and easy to find help if you encounter a problem. If you are choosing an operating system, it is natural to choose the one that has the most applications of interest to you. Here the applications exhibit direct network effects and the operating system/applications together exhibit indirect network effects.

Since many forms of software also exhibit supply side increasing returns to scale, the positive feedback can be particularly strong: more sales lead to both lower unit costs and more appeal to new customers. Once a firm has established market dominance with a particular product, it can be extremely hard to unseat it.

In the context of the Microsoft antitrust case, this effect is known as the ``applications barrier to entry." See [362001Gilbert and Katz], [472001Klein], and [852001Whinston] for an analysis of some of these concepts in that context.

Network effects are also related to two of the forces I described earlier: price discrimination and lock-in.

When network effects are present, early adopters may value the network good less than subsequent adopters. Thus, it makes sense for sellers to offer them a lower price, a practice known as ``penetration pricing" in this context.

Network effects also contribute to lock-in. The more people that drive on the right-hand side of the road, the more valuable it is to me to follow suit. Conversely, a decision to drive on the left-hand side of the road is most effective if everyone does it at the same time. In this case, the switching costs are due to the cost of coordination among millions of individuals, a cost that may be extremely large.

8 Standards

If the value of a network depends on its size, then interconnection and/or standardization becomes an important strategic decision.

Generally dominant firms with established networks or proprietary standards prefer not to interconnect. In the 1890s, the Bell System refused to allow access to its new long distance service to any competing carriers. In 1900-1912 Marconi International Marine Corporation licensed equipment, but wouldn't sell it, and refused to interconnect with other systems. In 1910-1920 Ford showed no interest in automobile industry parts standardization industry, since it was already a dominant, vertically-integrated firm. Today Microsoft has been notorious in terms of going its own way with respect to industry standards and American Online has been reluctant to allow access to its instant messaging systems.

However standards are not always anathema to dominant firms. In some cases, the benefits from standardization can be so compelling that it is worth adopting even from a purely private, profit-maximizing perspective.

[691998aShapiro and Varian] describe why using a simple equation:

your value = your share ×total industry value.

When ``total industry value'' depends strongly on the size of the market, adopting a standard may increase total value so much that it overcomes the possible dilution in market share.

[131991Besen and Farrell] survey the economic literature on standards formation. They illustrate the strategic issues by focusing on a standards adoption problem with two firms championing incompatible standards, such as the Sony Betamax and VHS technologies for videotape. Each standard exhibits network effects-indirect network effects in this particular example.

Following [131991Besen and Farrell] we describe the three forms of competition in standards setting.

Standards war.
Firms compete to determine the standard.

Standards negotiation.
Both firms want a standard, but disagree about what the standard should be.

Standards leader.
One firm leads with a proprietary standard, the other firms wants to interoperate with the existing standard.

8.1 Standards wars

With respect to standards wars, [131991Besen and Farrell] identify common tactics such as 1) penetration pricing to build an early lead, 2) building alliances with suppliers of complementary products, 3) expectations management such as bragging about market share or product pre-announcements, and 4) commitments to low prices in the future.

It is not hard to find examples of all of these strategies. Penetration pricing has already been described above. A nice recent example of building alliances is the DVD Forum, which successfully negotiated a standard format in the (primarily Japanese) consumer electronics industry, and worked with the film industry to ensure that sufficient content was available in the appropriate format at low prices.

Expectations management is very common; when there were two competing standards for 56 Kbs modems, each producer advertised that it had an 80 percent market share. In standards wars, there is a very real sense in which the product that people expect to win, *will* win. Nobody wants to be stranded with an incompatible product, so convincing potential adopters that you have the winning standard is critical.

Pre-announcements of forthcoming products are also an attractive ploy, but can be dangerous, since customers may hold off purchasing your current product in order to wait for the new product. This happened, for example, to the Osborne portable computer in the mid-eighties.

Finally, there is the low-price guarantee. When Microsoft introduced Internet Explorer it announced that it was free and would always be free. This was a signal to consumers that they would not be subject to lock-in if they adopted the Microsoft browser. Netscape countered by saying that its products would always be open. Each competitor played to its strength, but it seems that Microsoft had the stronger hand.

8.2 Standards negotiations

The standards negotiation problem is akin to the classic Battle of the Sexes game: each player prefers a standard to no standard, but each prefers its own standard to the other's.

As in any bargaining problem, the outcome of the negotiations will depend, to some extent, on the threat power of the participants-what will happen to them if negotiations break down. Thus it is common to see companies continuing to develop proprietary solutions, even while engaged in standards negotiation.

Sometime standards are negotiated under the oversight of official standards bodies, such as the International Telecommunications Union (ITU), the American National Standards Institute (ANSI), or the Internet Engineering Task Force (IETF). These have the advantage of experience and authority; however, they tend to be rather slow moving. In recent years, there have been many ad hoc standards bodies that have been formed to create a single standard. The standard set may not be as good, but it is often developed much more quickly. See [532000Libicki et al.Libicki, Schneider, Frelinger, and Slomovic] for a description of standards setting involving the Internet and Web.

Of course, there is often considerable mistrust in standards negotiation, and for good reason. Typically participating firms are required to disclose any technologies for which they own intellectual property that may be relevant to the negotiations. Such technologies may eventually be

incorporated into the final standard, but only after reaching agreements that they will be licensed on ``fair, reasonable, and non-discriminatory terms." But it is not uncommon to see companies fail to disclose *all* relevant information in such negotiations, leading to accusations of breach of faith or legal suits.

Another commonly-used tactic is for firms to cede the control of a standard to an independent third party, such as one of the bodies mentioned above. Microsoft has recently developed a computer language called C# that it hopes will be a competitor to Java. They have submitted the language the ECMA, a computer industry standards body based in Switzerland. Microsoft correctly realized that in order to convince anyone to code in C# they would have to relinquish control over the language.

However, the extent to which they have actually released control is still unclear. [52001Babcock] reports that there may be blocking patents on aspects of C#, and ECMA does not require prior disclosure of such patents, as long as Microsoft is willing to license them on non-discriminatory terms.

8.3 Standards leader

A typical example is where a large, established firm wants to maintain a proprietary standard, but a small upstart, or a group of small firms, wants to interconnect with that standard. In some cases, the proprietary standard may be protected by intellectual property laws. In other cases, the leader may choose to change its technology frequently to keep the followers behind. Frequent upgrades have the advantage that the leader also makes its own installed base obsolete, helping to address the durable goods monopoly problem mentioned earlier.

Another tactic for the follower is to use an adapter ([281992Farrell and Saloner]). AM and FM radio never did reach a common standard, but they peacefully co-exist in a common system. Similarly, ``incompatible" software systems can be made to interoperate by building appropriate converters and adapters. Sometimes this is done with the cooperation of the leader, sometimes without.

For example, the open source community has been very clever in building adapters to Microsoft's standards through reverse engineering. Samba, for example, is a system that runs on Unix machines that allows them to interoperate with Microsoft networks. Similarly, there are many open source converters for Microsoft applications software such as Word and Excel.

8.4 Cost advantages of standardization

The economic literature on standardization has tended to focus on strategic issues, but there are also considerable cost savings due to economics of scale in manufacture and risk reduction. [751954Thompson] describes the early history of the U.S. automobile industry, emphasizing these factors.

He shows that the smaller firms were interested in standardization in order to reap sufficient economies of scale to compete with Ford and G.M., who showed no interest in standardization efforts. Small suppliers were also interested in standardization, since that allowed them to diversify the risk associated with supplying idiosyncratic parts to a single assembler.

The Society of Automotive Engineers (SAE) carried out the standardization process, which yielded many cost advantages to the automotive industry. By the late 1920s, Ford and G.M. began to see the advantages of standardization, and joined the effort, at first focusing on the products of

complementors (tires, petroleum products, and the like) but eventually playing a significant role in automobile parts standardization.

9 Systems effects

It is common in high-technology industries to see products that are useless unless they are combined into a system with other products: hardware is useless without software, DVD players are useless without content, and operating systems are useless without applications. These are all examples of *complements*, that is, goods whose value depends on their being used together.

Many of the examples we have discussed involve complementarities. Lock-in often occurs because users must invest in complementary products, such as training, to effectively use a good. Direct network effects are simply a symmetric form of complementarities: a fax machine is most useful if there are other fax machines. Indirect network effects or chicken-and-egg problems are a form of systems effects. Standards involve a form of complementarity in that are often designed to allow for seamless interconnection of components (one manufacturer's DVDs will play on other manufacturer's machine.)

Systems of complements raise many important economic issues. Who will do the system integration: the manufacturer, the end user, or some intermediary, such as an OEM? How will the value be divided up among the suppliers of complementarity? How will bottlenecks be overcome, and how will the system evolve?

This is a vast topic, and I cannot do justice to the whole set of issues. I will limit my discussion to the most-studied issue: the pricing of complements, a topic first studied by [181838Cournot].

In one chapter of this work, Cournot analyzed the strategic interactions between producers of complementary products, considering a market with two companies: a monopoly zinc producer and a monopoly copper producer. These two supplied a large number of other companies that combined the metals to produce brass. Cournot asked what would happen to the price of brass if the copper and zinc producers merged.

Cournot showed that the complementary monopolists would set a prices that were higher than if they merged. The intuition is simple. If the copper producer cuts its price, brass producers will buy more zinc, thereby increasing the profits of the zinc producer. But the zinc producer's additional profits are irrelevant to the copper producer, making it reluctant to cut its price too much. The result is that the copper producer sets a price that is higher than the price that would maximize joint profits.

If, however, the copper and zinc producers merged, the merged entity would take into account that the price of copper affected the demand for zinc and set a lower price for both copper and zinc than independent producers would. Hence, a merger of complementors is a win all the way around: prices fall, making producers *and* consumers better off.

Of course a merger is only one way that prices might be coordinated; there are many other possibilities. There are a variety of ways a firm might induce a complementor to cut its price.

Integrate.

One complementor acquires the other, forming a merged entity which internalizes the externality. We have discussed the classic Cournot analysis above.

Collaborate.

The firms set up a formula for revenue sharing, then one firm sets the price of the joint system. For example, an aircraft manufacturer and an engine manufacturer will agree on a revenue sharing arrangement, then the aircraft manufacturer will negotiate a price for the entire system with customers.

Negotiate.

A firms may commit to cutting its price if the other firm also cuts its price. This apparently went on in the DVD industry, where both the content and players were introduced at relatively low prices, since the participants recognized that a low price for the entire system was critical to ensure its adoption.

Nurture.

One firm works with others to reduce their costs. For example, Adobe works with printer manufacturers to ensure that they can effectively use its technology.

Commoditize.

One firm attempts to stimulate competition in the other's market, thereby pushing down prices. Microsoft, for example, has established the Windows Compatibility Lab, to ensure that hardware manufacturers all produce to a common standard. This helps facilitate competition, pushing down the price of hardware.

All of these factors work towards reducing prices, thereby gaining some of the welfare benefits associated with competition. This is especially important since many of the other factors we discussed tend to lead towards high industry concentration ratios and monopoly power. When competitors are not present to discipline monopoly pricing, complementors may sometimes play a similar role.

10 Computer mediated transactions

More and more transactions are being mediated by computers. As we have seen, the data gathered can be mined for information about consumer behavior, allowing for various forms of price discrimination. But this is not the only function that transactions-mediating computers can play. They can also allow firms to contract on aspects of transactions that were previously unobservable.

Consider, for example, video tape rental industry. Prior to 1998, distributors sold video tapes to rental outlets, which proceeded to rent them to end consumers. The tapes sold for around $60 apiece, far in excess of marginal cost. The rental stores, naturally enough, economized on their purchases, leading to queues for popular movies.

In 1998 the industry came up with a new contractual form: studios provided video tapes to rental stores for a price between zero and $8, and then split revenue for rentals, with the store receiving between 40 and 60 percent of rental revenues. See [202000Dana and Spier] and [552001Mortimer] for further details about these contracts, along with theoretical and empirical analysis of their properties. [552001Mortimer] finds that these contracts increased the revenues of both studios and rental outlets by about 7 percent and consumers benefited substantially. Clearly, the revenue sharing arrangement offered a superior contractual form over the system used prior to 1998.

The interesting thing about this revenue-sharing arrangement is that it was made possible because of computerized record keeping. The cash registers at Blockbuster were intelligent enough to record each rental title and send in an auditable report to the central offices. This allowed all parties in the transaction to verify that revenues were being shared in the agreed-upon way. The fact that the transaction was computer mediated allowed the firms to contract on aspects of the transaction that were previously effectively unobservable, thereby increasing efficiency.

Another example of such computer-enabled contracting occured in the trucking industry. ([401998Hubbard], [62000Baker and Hubbard]) In the last twenty years, trip recorders and electronic vehicle management systems (EVMS) have become widespread in the industry. Trip recorders are essentially onboard computers that record when the driver turns the vehicle on or off, how long the truck idles, the average speed of the truck, when it accelerates or decelerates, and many other details of operation. EVMS technology does all of this as well, but also collects information about location and transmits information back to the dispatcher in real time. These capabilities help with dispatch coordination, operation efficiency, insurance liability and fraud detection, making the trucking industry much more cost effective.

As more and more transactions become computer mediated, the costs of monitoring become lower and lower, allowing for more efficient contractual forms.

11 Summary

Better information for incumbents, lock-in, and demand- and supply-side economies of scale suggest that industry structure in high-technology industries will tend to be rather concentrated. On the other hand, information technology can also reduce minimum efficient scale thereby relaxing barriers to entry. People value diversity in some areas, such as entertainment, and IT makes it easier to provide such diversity.

Standards are a key policy variable. Under a proprietary standard, an industry may be dominated by a single firm. With an open standard, many firms can interconnect. Consider, for example, the PC industry. The PC itself is a standardized device: there are many motherboard makers, memory chip makers and card providers. There are even several CPU providers, despite the large economies of scale in this industry.

Compare this to the software world, where a single firm dominates the PC operating system and applications environment. What's the difference? The hardware components typically operate according to standardized specifications, so many players can compete in this industry. In the software industry, standards tend to be proprietary. This difference has led to a profound difference in industry structure.

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