

High-Technology Industries and Market Structure

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Abstract

This is a review of various economic phenomenon that are important in high-technology industries, such as personalization of products and pricing, versioning, bundling, switching costs, lock-in, economics of scale, network effects, complements and computer-mediated contracts. Most of these forces tend to point towards higher industry concentration ratios for technology-intensive industries.

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1 Introduction

The term “New Economy” refers to a golden, or at least gilded, age in the late 1990s that was driven by optimism about the financial prospects for information technology (IT). There were three back-to-back investment shocks during this period: telecommunications deregulation in 1996, the “year 2K” problem in 1998-99, and the “dot com” boom in 1999-2000. These events stimulated significant investment in information technology in a number of industries, leading to a very rapid expansion of IT-producing industries.

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 takes off on its roller coaster ride. Eventually it came crashing back, but note that the total return over the eight years depicted in the two indices is 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. As of July 2001, it is about 17 percent.

Despite the dramatic run-up and run-down in technology stocks, it is clear that 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. (See Brynjolfsson and Hitt [2000], Steindel and Stiroh [2001], and Stiroh [2001], among the many papers on IT and productivity growth.)

2 Outline

This paper 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 strong in high-tech, and these 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.

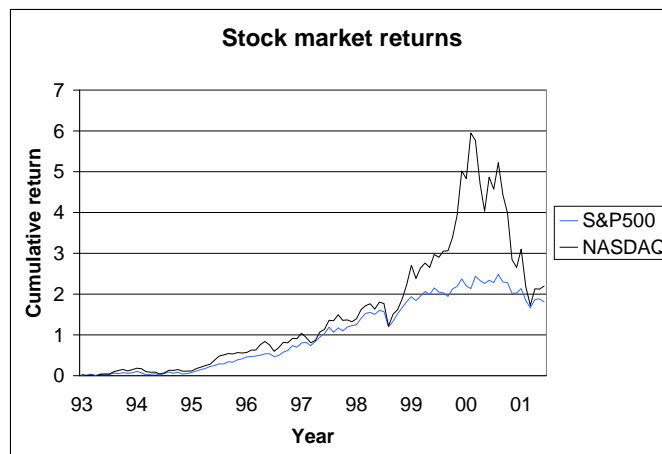


Figure 1: Return on the NASDAQ and S&P 500 during the 1990s.

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.

Take, for example, cost structures. Constant fixed costs and zero marginal costs are common assumptions for textbook treatments, but 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 we discuss involve pricing, switching costs, scale economies, transactions costs, and 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 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, but with more emphasis on business strategy, I can recommend the survey of network industries in the *Journal of Economic Literature* consisting of articles by Katz and Shapiro [1994], Besen and Johnson [1986], Leibowitz and Margolis [1990], and the book by Shy [2001]. For a step down in technical complexity, I can recommend Shapiro and Varian [1998a].

3 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.

3.1 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 online newspapers and portals. They can buy a personally configured computer from Dell, and even purchase 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 (Rosencrance [2000]), 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. Brynjolfsson and Smith [1999] 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. Online sellers face competition from each other and from offline sellers, so adding competition to this model is important.

Ulph and Vulkan [2000, 2001] 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. They 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 now 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” which means, in part, 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 byproduct, they found that their records about customer orders allowed them to provide better analysis and forecasts of their customers’ needs than the customers themselves. This allowed them to offer services such as templates with recommended orders for restock. This service was valuable to AmeriServe’s customers, and therefore gave it an edge over competitive suppliers, allowing. to charge 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 Varian [1997]. 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 better 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 about personal information can be used will 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 need, 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 Varian [1997].

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.

3.2 Second degree price discrimination

Second-degree price discrimination refers to a situation where everyone faces the same menu of prices for a set of 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, in airplanes, on tape, on DVD,

and on TV. Newspapers are available online 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 Shapiro and Varian [1998a,b], and Varian [2000] 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 Denerke and McAfee [1996] for a general treatment and Shapiro and Varian [1998a] for applications in the information goods context.

Varian [2000] 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 Schmalensee [1981] and Varian [1985]. 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.

Versioning is being widely adopted in the 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.

3.3 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. Armstrong and Vickers [2001] 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 satisfying this objective. However, if there are no fixed costs, consumer utility falls, 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 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 Greenwald and Kephart [1999], Baye et al. [2001] and others. The structure of the problem is similar to that of Varian [1980], 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. Baye et al. [2001] and Brynjolfsson and Smith [1999] show that online firms do engage in frequent small price adjustments, similar to those predicted by the theory.

5 Bundling

Bundling refers to the practice of selling two or more distinct goods together for a single price. (Adams and Yellen [1976].) This is a particularly attractive structure 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 willingnesses to pay for the bundle is the sum of the willingnesses to pay for the components, then each consumer is 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.

Bakos and Brynjolfsson [1999, 2000, 2001] 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.

Whinston [1990], Nalebuff [1999, 2000] and Bakos and Brynjolfsson [2000]

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 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 compete against either product would be to offer a bundle with both products. This not only increases development costs dramatically, but it also make 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.

6 Switching costs and lock-in

When you switch from Ford to GM, 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, Klemperer [1987], Farrell and Shapiro [1989], Farrell and Shapiro [1988], Beggs and Klemperer [1992], and Klemperer

[1995]. The last work is a particularly handy survey of earlier work. Shapiro and Varian [1998a] examine some of the business strategy implications of switching costs at a lay reader level.

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 than 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-test strategy of effectively giving away the razor to sell the blade.

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 ink jet cartridges reportedly have over 50% profit margins. (Roman [2001])

In a related story, Cowell [2001] 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..."

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 Klemperer [1995] 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.

7 Supply-side economies of scale

We have already noted that many information and technology-related businesses have cost structure 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. 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 online retailing, and consumers benefitted 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 Kuczynski [2001]. The same thing will happen to other content industry, 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 sorts of inefficiencies. See DeLong and Froomkin [2001] 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 Coase [1972] 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 Fudenberg and Tirole [1985], Fudenberg and Tirole [1987].

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 “completion” can be a very powerful force.

Inventing around. Even when intellectual property rights create apparently strong barriers to entry, competitive firms will attempt to invent around a patent, often creating new products.

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

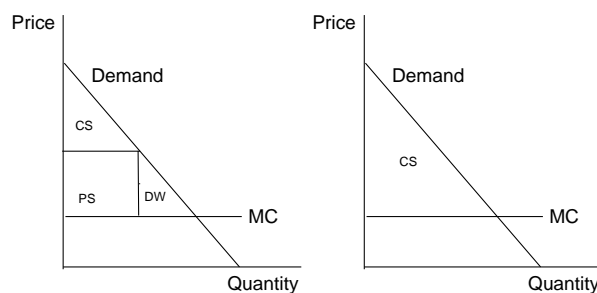


Figure 2: Competition for perfectly price discriminating monopolist.

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, two 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.

8 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 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 10. 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 valuations.

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,

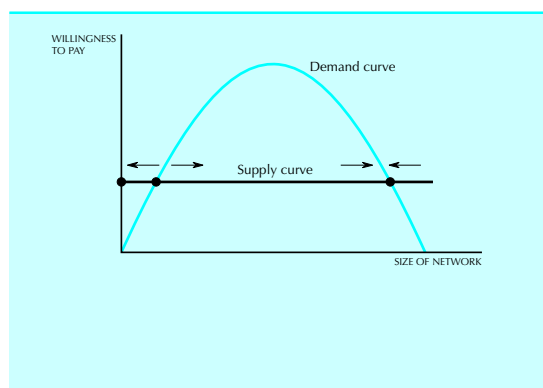


Figure 3: Demand and supply for a network good.

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 price and shipments of fax machines in the US. 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. Economides and Himmelberg [1995] 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.

There have been some attempts to empirically examine network models using cross sectional data. Goolsbee and Klenow [2000] examines the diffusion of home computers and finds 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 indus-

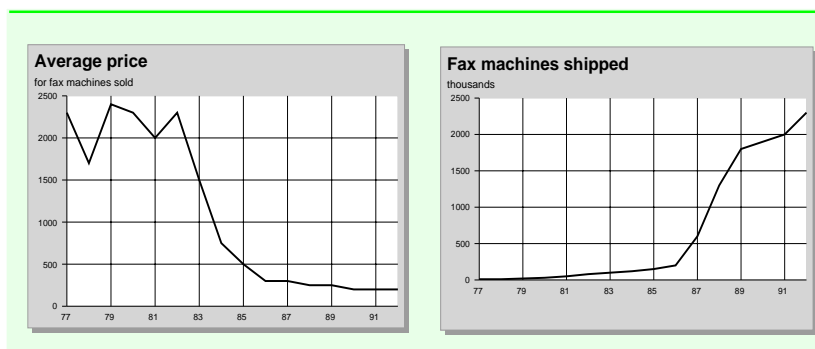


Figure 4: Price and shipments of fax machines.

try selling a compatible product: a fax machine, email, or similar product. Katz and Shapiro [1985, 1986a,b, 1992] have examined the impact of network externalities in oligopoly models in which technology adoption is a key strategic variable. Economides [1996] and Katz and Shapiro [1994] and provide a useful reviews of the literature.

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 Gilbert and Katz [2001], Klein [2001], and Whinston [2001] 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.

9 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 an other systems. In 1910-1920 Ford showed no interest in automobile industry parts standardization industry, since was already a vertically-integrated dominant 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 standard can be so compelling that it is worth adopting even from a purely private, profit-maximizing perspective.

Shapiro and Varian [1998a] describes why with a simple equation:

$$\text{your value} = \text{your share} \times \text{total industry value.}$$

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.

Besen and Farrell [1991] 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 Besen and Farrell [1991] 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 may disagree about what the standard should be.

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

9.1 Standards wars

With respect to standards wars, Besen and Farrell [1991] 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.

9.2 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 Libicki et al. [2000] 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 a firm 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 the hope will be a competitor to Java. They have submitted the language to 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. Babcock [2001] 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.

9.3 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 (Farrell and Saloner [1992]). AM and FM radio never did reach a common standard, but the 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 be integrated with Microsoft networks. Similarly, there are many open source converters for Microsoft applications software such as Word and Excel.

9.4 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 economies of scale in manufacture and risk reduction. Thompson [1954] 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 one customer.

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 GM 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.

10 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 Cournot [1838].

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.

Let us assume that one unit of copper and one unit of zinc combine to create one unit of brass. Competition will push the price of brass down to the its cost, which will simply be the sum of the two prices. Demand for brass can then be written as $D(p_1 + p_2)$. Given our assumptions about the technology, this is also the demand for copper and zinc.

The copper producer, say, wants to maximize the profit of producing copper:

$$\max_{p_1} p_1 D(p_1 + p_2).$$

Here we have assumed that the cost of copper production is zero for simplicity. The zinc producer has the analogous problem;

$$\max_{p_2} p_2 D(p_1 + p_2).$$

If the two complementary monopolists merged, they would solve the joint profit maximization problem

$$\max_{p_1, p_2} (p_1 + p_2) D(p_1 + p_2).$$

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. Consider again the formula for a complementor's profit:

$$p_1 D(p_1 + p_2).$$

Cutting p_1 may or may not increase profit, depending on elasticity of demand. But cutting p_2 definitely increases revenue in all circumstances. 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 total 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 penetration 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 pushing prices down, 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.

11 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, allow 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 purchase, 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 Dana and Spier [2000] and Mortimer [2001] for further details about these contracts, along with theoretical and empirical analysis of their properties. Mortimer [2001] finds that these contracts increased revenue of both studios and rental outlets by about 7 percent and consumers benefitted 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 only 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 unobservable, thereby increasing efficiency.

Another example of such computer-enabled contracting occurs in the trucking industry. (Hubbard [1998], Baker and Hubbard [2000]) 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, 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.

12 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 and relax 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.

References

- William James Adams and Janet L. Yellen. Commodity bundling and the burden of monopoly. *The Quarterly Journal of Economics*, 90(3):475–498, 1976.
- Mark Armstrong and John Vickers. Competitive price discrimination. Technical report, Oxford University, 2001. <http://www.nuff.ox.ac.uk/economics/people/armstrong/markpapers.html>.
- Charles Babcock. Will open source get snagged in .net? *ZDNet News*, August 6 2001. <http://www.zdnet.com/zdnn/stories/news/0,4586,2801560,00.html>.
- G. Baker and T. Hubbard. Contractibility and asset ownership: Computers and governance in the U.S. trucking industry. Technical report, University of Chicago, 2000.
- J. Y. Bakos and Erik Brynjolfsson. Aggregation and disaggregation of information goods: Implications for bundling, site licensing and micropayment systems. In Brian Kahin and Hal R. Varian, editors, *Internet Publishing and Beyond: The Economics of Digital Information and Intellectual Property*. MIT Press, Cambridge, MA, 2001. <http://ebusiness.mit.edu/erik/>.
- Yannis Bakos and Erik Brynjolfsson. Bundling information goods: Pricing, profits and efficiency. *Management Science*, Dec 1999.
- Yannis Bakos and Erik Brynjolfsson. Bundling and competition on the internet: Aggregation strategies for information goods. *Marketing Science*, January 2000. <http://ebusiness.mit.edu/erik/>.
- M. Baye, J. Morgan, and P. Scholten. Price dispersion in the small and in the large: Evidence from an internet price comparison site. Technical report, Woodrow Wilson School, Princeton University, 2001. <http://www.princeton.edu/~rjmorgan/working.htm>.
- Alan Beggs and Paul Klemperer. Multi-period competition with switching costs. *Econometrica*, 60(3):651–666, 1992.

- Stanley Besen and Joseph Farrell. The role of the ITU in standardization. *Telecommunications Policy*, pages 311–321, Aug 1991.
- Stanley M. Besen and Leland Johnson. *Compatibility Standards, Competition, and innovation in the Broadcasting Industry*. The Rand Corporation, 1986.
- Erik Brynjolfsson and Lorin M. Hitt. The resurgence of growth in the late 1990s: Is information technology the story? *Journal of Economic Perspectives*, 24(4):23–28, 2000.
- Erik Brynjolfsson and Michael Smith. Frictionless commerce? A comparison of Internet and conventional retailers. *Management Science*, 46(4), April 1999. <http://ebusiness.mit.edu/erik/>.
- Ronald Coase. Durability and monopoly. *Journal of Law and Economics*, 15(1):143–149, 1972.
- Augustin Cournot. *Recherches sur les principes mathématiques de la théorie des richesses*. L. Hachette, Paris, 1838.
- Alan Cowell. Profit soars at SAP. *New York Times*, Jul 20 2001.
- J. Dana and K. Spier. Revenue sharing, demand uncertainty, and control of competing firms. Technical report, Northwestern University, 2000.
- J. Bradford DeLong and A. Michael Froomkin. Speculative microeconomics for tomorrow's economy. In Brian Kahin and Hal R. Varian, editors, *Internet Publishing and Beyond*. MIT Press, 2001. <http://www.j-bradford-delong.net/OpEd/virtual/technet/spmicro.html>.
- R. Denerke and Preston McAfee. Damaged goods. *Journal of Economics and Management Strategy*, 5(2):149–174, 1996.
- Nicholas Economides. The economics of networks. *International Journal of Industrial Organization*, 16(4):673–699, 1996. <http://raven.stern.nyu.edu/networks/>.
- Nicholas Economides and Charles Himmelberg. Critical mass and network size with application to the US fax market. Technical report, Stern School of Business, N.Y.U, 1995. <http://raven.stern.nyu.edu/networks/papers.html>.

- Joe Farrell and Carl Shapiro. Optimal contracts with lock-in. *American Economic Review*, 79(1):51–68, 1989.
- Joseph Farrell and Garth Saloner. Converters, compatibility, and the control of interfaces. *Journal of Industrial Economics*, pages 9–35, March 1992.
- Joseph Farrell and Carl Shapiro. Dynamic competition with switching costs. *Rand Journal of Economics*, 19:123–137, 1988.
- Drew Fudenberg and Jean Tirole. Preemption and rent equalization in the adoption of new technology. *Review of Economic Studies*, 52:383–402, 1985.
- Drew Fudenberg and Jean Tirole. Understanding rent dissipation: On the uses of game theory in industrial organization. *American Economic Review Papers and Proceedings*, 77:176–183, 1987.
- Richard J. Gilbert and Michael L. Katz. An economist’s guide to U.S. v. Microsoft. *Journal of Economic Perspectives*, 15(2):25–44, 2001.
- Austan Goolsbee and Peter Klenow. Evidence on learning and network externalities in the diffusion of home computers. Technical Report NBER WP 7329, Graduate School of Business, University of Chicago, 2000.
- Amy R. Greenwald and Jeffrey O. Kephart. Shopbots and pricebots. Technical report, IBM Watson Labs, 1999. http://www.research.ibm.com/infoecon/paps/html/amec99_shopbot/shopbot.h%tml.
- Thomas N. Hubbard. Why are process monitoring technologies valuable? the use of on-board information technology in the trucking industry. Technical Report 6482, NBER, 1998.
- Michael Katz and Carl Shapiro. Product compatibility choice in a market with technological progress. *Oxford Economic Papers, Special Issue on the New Industrial Economics*, Nov 1986a.
- Michael Katz and Carl Shapiro. Product introduction with network externalities,. *Journal of Industrial Economics*, 40:55–84, Mar 1992.
- Michael L. Katz and Carl Shapiro. Network externalities, competition, and compatibility. *American Economic Review*, 75(3):424–440, 1985.

- Michael L. Katz and Carl Shapiro. Technology adoption in the presence of network externalities. *The Journal of Political Economy*, 94(4):822–84, 1986b.
- Michael L. Katz and Carl Shapiro. Systems competition and network effects. *Journal of Economic Perspectives*, 8(2):93–115, 1994.
- Benjamin Klein. The Microsoft case: What can a dominant firm do to defend its market position? *Journal of Economic Perspectives*, 15(2):45–62, 2001.
- Paul Klemperer. Markets with consumer switching costs. *Quarterly Journal of Economics*, 102(2):375–394, 1987.
- Paul Klemperer. Competition when consumers have switching costs: an overview with applications to industrial organization, macroeconomics and international trade. *Review of Economic Studies*, 62:515–539, 1995. <http://www.paulklemperer.org/index.htm>.
- Alex Kuczynski. Big magazines get bigger as small ones get gobbled up. *New York Times*, Jul 30 2001. <http://www.nytimes.com/2001/07/30/business/30MAG.html?pagewanted=print>.
- S. J. Liebowitz and Stephen Margolis. The fable of the keys. *Journal of Law and Economics*, pages 1–26, April 1990.
- Martin Libicki, James Schneider, Dave R. Frelinger, and Ann Slomovic. *Scaffolding the New Web: Standards and Standards Policy for the Digital Economic*. RAND, Santa Monica, CA, 2000. <http://www.rand.org/publications/MR/MR1215/>.
- Judith Holland Mortimer. The effects of revenue-sharing contracts on welfare in vertically-separated markets: Evidence from the video rental industry. Technical report, Economics Department, Harvard University, 2001.
- Barry Nalebuff. Bundling. Technical Report 99-14, School of Management, Yale University, November 1999.
- Barry Nalebuff. Competing against bundles. Technical Report 7, School of Management, Yale University, 2000.

- Monica Roman. Black ink all over Hewlett-Packard. *Business Week*, 2001. http://www.businessweek.com/@@8zC3j2QQgISnLgEA/premium/content/01_22/.
- Linda Rosencrance. Amazon charging different prices on some DVDs. *Comptuerworld*, September 05 2000. http://www.computerworld.com/cwi/story/0,1199,NAV47_ST049569,00.html.
- Richard Schmalensee. Output and welfare implications of monopolistic third-degree price discrimination. *American Economic Review*, 71:242–247, March 1981.
- Carl Shapiro and Hal R. Varian. *Information Rules*. Harvard Business School Press, 1998a. <http://www.inforules.com>.
- Carl Shapiro and Hal R. Varian. Versioning: the smart way to sell information. *Harvard Business Review*, November-December 1998b.
- Oz Shy. *The Economics of Network Industries*. Cambridge University Press, Cambridge, England, 2001.
- Charles Steindel and Kevin J. Stiroh. Productivity: What is it and why do we care? Technical report, NY Federal Reserve Bank, 2001. <http://www.ny.frb.org/rmaghome/staffrp/2001/sr122.pdf>.
- Kevin Stiroh. Information technology and the U.S. productivity revival: What do the industry data say? Technical report, NY Federal Reserve Bank, 2001. http://www.ny.frb.org/rmaghome/staff_rp/2001/sr115.html.
- George V. Thompson. Intercompany technical standardization in the early americna automobile industry. *Journal of Economic History*, 14(1):1–20, 1954.
- David Ulph and Nir Vulkan. Electronic commerce and competitive first-degree price discrimination. Technical report, University College, London, 2000. <http://www.ecn.bris.ac.uk/www/ecnv/welcome.htm>.
- David Ulph and Nir Vulkan. E-commerce, mass customization and price discrimination. Technical report, University College, London, 2001. <http://www.ecn.bris.ac.uk/www/ecnv/welcome.htm>.

- Hal R. Varian. A model of sales. *American Economic Review*, 70:651–659, 1980.
- Hal R. Varian. Price discrimination and social welfare. *American Economic Review*, 75(4):870–875, 1985.
- Hal R. Varian. Economic aspects of personal privacy. In Larry Irving, editor, *Privacy and Self-Regulation in the Information Age*. National Telecommunications and Information Administration, 1997. http://www.ntia.doc.gov/reports/privacy/privacy_rpt.htm.
- Hal R. Varian. Versioning information goods. In Brian Kahin and Hal R. Varian, editors, *Internet Publishing and Beyond*. MIT Press, 2000. <http://www.sims.berkeley.edu/~hal/people/hal/papers.html>.
- Michael D. Whinston. Tying, foreclosure, and exclusion. *American Economic Review*, 80(4):837–859, 1990.
- Michael D. Whinston. Exclusivity and tying in U.S. v Microsoft: What we know, and don't know. *Journal of Economic Perspectives*, 15(2):63–80, 2001.