to be given by $f^e v_i$. Each consumer will buy either one or no units of the good depending on how the price p compares with the consumer's willingness to pay $f^e v_i$. Specifically, the demand by consumer i for a hook up to the communications service is assumed given by

$$q_i^D = \begin{cases} 0 \text{ if } f^e v_i < p \\ 1 \text{ if } f^e v_i \geq p \end{cases} \tag{22.1}$$

Equation (22.1) makes clear that consumer i's willingness to pay for the service $f^e v_i$ increases with the fraction of potential buyers f^e that are expected to buy it. It is this interdependence between the willingness to pay and the fraction of the market that one expects to be served that leads to network externalities. Note that all potential users of the network consider only the value to themselves of joining the network. In particular, they do not take into account the fact that by joining they will improve the usefulness of the network to all of the other users because now the network is bigger.

We can use equation (22.1) to calculate the actual fraction f of consumers who buy into the service at any given price p. As usual, we start by focusing on the marginal consumer denoted by the reservation valuation $\widetilde{v}_i$. This is the consumer who is just indifferent between buying into the service network and not buying into it, so that $\widetilde{v}_i = p/f^e$. All consumers with a valuation less than $\widetilde{v}_i$ will not subscribe to the service. The remainder will subscribe. Because v_i is distributed uniformly between 0 and 100, the fraction of consumers with a valuation below $\widetilde{v}_i$ is simply $\widetilde{v}_i/100$. Hence, the fraction of consumers f with valuations greater than $\widetilde{v}_i$ and who therefore acquire the service is

$$f = 1 - \frac{\widetilde{v}_i}{100} = 1 - \frac{p}{100 f^e} \tag{22.2}$$

If we now solve for p we obtain the inverse demand function confronting the monopolist expressed in terms of the fraction f of the maximum potential number of customers who actually buy the service as

$$p = 100 f^e - 100 f^e f = 100 f^e (1 - f) \tag{22.3}$$

It may help to express equation (22.3) in terms of actual demand Q. Recall that the total number of potential customers is N. Hence, $Q = fN$ implying that $f = Q/N$. We may therefore rewrite equation (22.3) as:

$$p = 100 f^e - 100 f^e Q/N \tag{22.4}$$

For a given expected fraction f^e (assumed common to all consumers), a given maximum valuation of \$100, and a given potential market size N, the demand equation (22.4), which is mathematically equivalent to (22.3), describes a conventional downward-sloping inverse demand curve with price intercept of $100 f^e$ and slope of $-100 f^e/N$. Note though that the position of the curve depends critically on the fraction expected f^e to buy into the service. That is, for any price p the actual fraction of the N consumers that buy into the service will change as the faction f^e expected to buy into it changes.

Because the demand curve depends critically on the expected fraction f^e of service users, we need to have some way of resolving the value of this parameter if we are to determine the equilibrium outcome. For this purpose, we will assume that a full equilibrium requires that the expected and actual fraction of users be equal $f = f^e$, otherwise rational individuals would be changing their expectations to eliminate their forecast error. This requirement implies that in a full, rational expectations equilibrium, equation (22.3) may be rewritten as:

$$p = 100f - 100f^2 = 100f(1 - f) \tag{22.4}$$

This expectations equilibrium demand curve is illustrated in Figure 22.1. This diagram also includes a horizontal line through the value $p = \$22.22$, which we shall explain later.

The curve shown in Figure 22.1 is interesting in a number of respects. Note first that for all prices greater than \$25, no equilibrium with a positive value of f exists. If for some reason, the monopolist must charge a price greater than \$25, perhaps to cover fixed costs, then the network will simply fail. This is true even though the network might be socially efficient.

To illustrate, suppose that the monopolist incurs a fixed cost of \$15 million to set up the system but that the marginal cost of one more customer signing in is zero. This means that when half the market ($f = 0.5$) or 500,000 consumers are served, the firm has an average cost of $\$15/0.5 = \$30$ per customer. We also know, however, that if half the population were to buy the product, it would be those consumers with v_i values in the range of \$50 to \$100. The average $v_i = \left(\frac{1}{50}\right)\sum_{I=51}^{100} v_i$ value for this group is therefore \$75. Hence, with $f = 0.5$, the average actual willingness to pay across these consumers would be $\$75/2 = \$37.50$—enough it would seem to cover the \$30 cost per consumer.

Yet as we have stated and as Figure 22.1 illustrates, the network will not be viable at a price of \$30. Why? Because while the average consumer valuation at $f = 0.5$ is \$37.50, there are some current consumers (those for whom $\$50 \le v_i < \$60$) whose willingness to pay is less than \$30. As the price rises toward \$30, these consumers drop the service. Some (those for whom $\$50 \le v_i < \$52$) drop as soon as the price rises to \$26, more drop as it hits \$27, and so on. The loss of these consumers, however, reduces the value of the network to

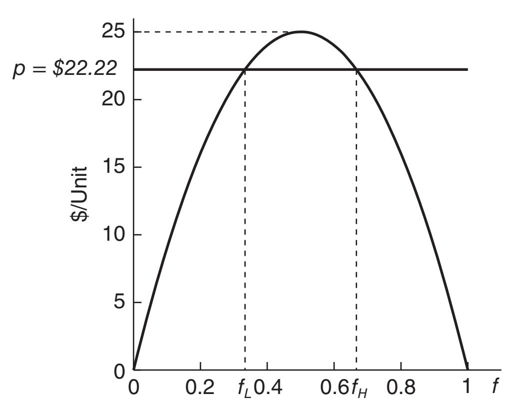

Figure 22.1 Demand to a monopoly provider of a network service
At price p if fewer than f_L consumers subscribe to the network, the equilibrium will fall to $f = 0$. If more than f_L consumers subscribe to the network, the equilibrium will rise to f_H.

those remaining. Those who were previously just willing to pay \$30 when the service had 500,000 subscribers, no longer will be willing to do so now that fewer people are signed on. These consumers will also cease to purchase the product, reducing still further the network's value to the now even fewer customers left behind. This process will continue until the entire market unravels and the network fails. Here, one can see the externality quite explicitly. A consumer does not consider the impact of her choice to join or to leave the network has on the value of the network to others.

We have not of course shown that \$25 is the firm's profit-maximizing price. All we have shown is that no rational expectations equilibrium exists with $p > \$25$ and that the market can suboptimally fail. Determining the monopolist's profit-maximizing price (or output) is tricky in this case because the quadratic quality of the demand curve means that we cannot simply apply our standard twice-as-steep rule to determine marginal revenue. However, as we show in the Appendix to this chapter, simple calculus quickly reveals that the optimal price is \$22.22. This points to a second common feature of network markets, namely, the existence of multiple equilibria, with the result that one cannot be sure which outcome will obtain.

As noted earlier, the horizontal line in Figure 22.1 is drawn through the value $p = \$22.22$, i.e., through the monopolist's profit-maximizing price. This line indicates the three rational expectations equilibria associated with this price. The first is where the line intersects the vertical axis at $f^e = f = 0$. If no one expects anyone else to subscribe to the service, no one does. The second is where the line intersects the demand curve at $f^e = f = 0.333$, an outcome we will refer to as the low-fraction equilibrium $f_L(p)$. The final possible equilibrium occurs where price is again $p = \$22.22$ and $f^e = f = 0.667$, an outcome we will refer to as the high-fraction equilibrium $f_H(p)$. Which of these three might we expect to occur?

Rohlfs points out that the low-fraction equilibrium is actually unstable. To see what this means, consider, for example, a case in which the market is at this equilibrium with $p = \$22.22$ and $f = f^e = f_L(p) = 1/3$. Suppose that starting from this point, there is a small increase in the expected fraction f^e to 0.40. At this value of f^e, the marginal consumer is now given by: $\widehat{v}_i = p/100f^e = 22.11/0.40 = 55.5$. Because all consumers with v_i values greater than this buy into the service, this implies that the actual fraction f of subscribers would rise to $f = (100 - 55.5)/100 = 0.445$. In other words, the expectation that $f^e = 0.40$ would lead to an actual proportion $f = 0.445$ even higher than expected. This difference between the actual and expected network size cannot persist as it is not an equilibrium. Sooner or later the reality of the higher actual fraction f would lead consumers to raise their expectations f^e further as well. In turn, this would raise the actual proportion f higher still. This process will continue until the high proportion equilibrium $f^e = f = f_H(p) = 0.667$ is reached at which point the expectation that 2/3 of the population will subscribe induces precisely the same actual fraction of consumers to subscribe. Analogously, if the expected fraction f^e suddenly fell to 0.25, $\widehat{v}_i$ would fall to $\widehat{v}_i = p/100f^e = 22.22/0.40 = 0.888$, implying that the actual fraction of subscribers would fall below f^e to $f = 0.112$. Once again, this process would continue until the alternative equilibrium of $f^e = f = 0$ is reached. Thus, the low fraction equilibrium $f^e = f = f_L(p) = 0.3333$ is unstable in the sense that any small deviation away from $f^e = 0.333$ immediately leads the market to one of the two alternative equilibria.

It is straightforward to show that in contrast to the low-fraction equilibrium, both the zero fraction and high fraction equilibria are stable. That is, deviations away from these equilibria set in motion forces that tend to restore them. Therefore, it seems likely that one of these two must ultimately prevail. Because there is no consumer or producer surplus when $f^e = f = 0$, the high-fraction surplus of $f^e = f = f_H(p) = 0.667$ is obviously preferable. There is however no guarantee that it will be reached. Yet if the market can somehow reach the low-fraction equilibrium $f^e = f = f_L(p)$, then it seems virtually certain that the high-fraction equilibrium will be attained because only a trivial increase in f^e (or a trivial decrease in p) is necessary to do so. For this reason, Rohlfs refers to the fraction $f_L(p)$ as a "critical mass" for the network. If $f_L(p)$, can be established, the network will grow to contain the high fraction, $f_H(p)$, of the population.

The critical mass $f_L(p)$ is a key feature confronting firms in network markets. When network firms compete, those that do not reach the critical mass are not just smaller. They fail to survive at all. An important question therefore is whether and how the monopolist can reach the critical mass. One possibility is to provide the service free for a limited period of time, perhaps by bundling the service with some other product. Another option is to lease the equipment to potential users with a promise to cancel the service with no penalty if it does not achieve critical mass. A further possibility, one used when fax machines were first marketed, would be to target groups of large users first. In this regard, national and multinational companies or government agencies are the obvious examples of institutions that might want to operate their own internal networks. Once the network comes into common use for internal company communications, there may well be a demand for it to be extended to those with whom the company does business. Before long, this may grow into a demand by company users of the service for it to be available in their homes.

How do the monopolist's choices of $p = \$22.22$ and $f = 2/3$ compare with the social optimum? Because that optimum requires that the market be as large as possible at a price equal to marginal cost, it requires in this case that all N consumers should be served, i.e., $f = 1$. Clearly then the monopolist sets too high a price and serves too small a market. Because we know that monopolies typically restrict output, this result should come as no surprise. In this case though, there is a second reason for the market to be suboptimally small, namely, the presence of the network externality. The fact that each consumer ignores the impact of the decision to subscribe on the service valuation of other consumers, market demand tends to be too low at any price. Even a competitive market will tend to under produce a network good. Indeed, competitive firms may have difficulty coordinating on the collective actions necessary to push demand beyond the critical mass.

22.1 **Practice Problem**

Imagine that consumer valuations v_i are distributed uniformly between 0 and 100. Each consumer will buy at most one unit of the good depending on his or her willingness to pay. However, that willingness to pay depends on the fraction f of population that buys the good. In particular, consumer i will buy one unit of the good only if $(0.4 + 6f^2)v_i \geq p$. Otherwise, consumer i buys zero.

a. Assume that the price is $p = \$50$. Show that the marginal consumer has basic valuation $v^M = 50/(0.4 + 6f^2)$.
b. Show that at this price, two non-zero market equilibria are possible: one with $f = 0.1905$ and one with $f = 0.906$. Which, if either of these, is stable?

22.2 NETWORKS, COMPETITION, AND COMPLEMENTARY SERVICES

While the Rohlfs (1974) model focuses on the provision of network services by a monopolist, it makes clear many of the major difficulties that network externalities raise when competition is considered. The market will generally be too small and could fail altogether. Alternatively, there could be more than one equilibrium outcome and there is no guarantee that the market will choose the best one. Indeed, the multiplicity of equilibria may rise once competition is permitted. Further, and perhaps more importantly, competition in network markets tends to be particularly fierce owing to the fact that gaining just a few more customers raises the value of a firm's network to all potential subscribers. We illustrate these points below.

For example, suppose that there are two firms, firm A and firm B, competing for the 1,000,000-customer market above. Suppose further that while fixed costs are zero, each firm now has a positive marginal cost of \$11.11. Consumers buy the service of the network that gives them the biggest net surplus, $f_A v_i - p_A$, and $f_B v_i - p_B$, respectively. In the case of a tie, consumers are split randomly between the two services. One possible equilibrium occurs with each firm setting a price $p_A = p_B =$ marginal cost $=$ \$11.11 and two-thirds of the market being served. The firms offer identical products and, given the tie-breaking assumption, each serves half of the consumers ranging from valuations \$33.33 and up. However, because each firm individually serves only one-third of the market, the valuation of the least valuable consumer in each case is $fv_i = 0.333 \times \$33.33 = \$11.11$. Neither firm has an incentive to raise its price unilaterally. This would only lose customers and make its network even less valuable to consumers. Nor does either firm have an incentive to lower its price. While this may give it an edge in attracting customers, each one served now involves a loss as the firm would be selling below cost. Hence, $p_A = p_B = \$11.11$ and two-thirds of market being served is one possible equilibrium.

However, there are a number of other possible outcomes. Clearly, one possibility is that neither firm's network attracts any customers at prices $p_A = p_B = \$11.11$. Again, no one will subscribe to a network to which no one else is expected to belong, and neither firm has an incentive to sell below marginal cost. Yet two alternative equilibria also occur. They arise when either firm A or firm B has a monopoly with respect to all consumers actually subscribing to a network at the monopoly price while its rival has zero customers at a price equal to or greater than marginal cost. We show in the appendix, for example, that with a marginal cost of \$11.11, the monopoly price would be \$23.89 and that at this price, the monopolist would serve about 60.5 percent of the market and earn a profit of \$12.78 on each customer. Suppose that firm A is doing precisely this while firm B is charging a lower price but has zero consumers. Clearly, firm A has no incentive to raise or lower its price because it already has set a price that maximizes its profit. Firm B has no incentive to change its price either. Raising it surely will not help it attract any customers. Yet lowering it won't either because no one will choose a network that has no other customers regardless of the price.

Price competition is also more intense in network markets. To see this, consider our linear Main Street market with two firms located at either end of the one mile long street and N consumers distributed uniformly between them. Firm A is located at the west end of town ($x = 0$) and firm B is located at the east end of town ($x = 1$). Each firm has a constant marginal cost of c. Each consumer buys at most one unit of the good either from firm A or firm B and incurs a cost of t per unit of distance travelled. Absent network effects, the net surplus earned by a consumer at location x is: $V - tx - p_A$ if the consumer buys from firm A, and $V - t(1-x) - p_B$ if the consumer buys from firm B. V is large enough that consumers always buy from one of the two firms, i.e., the market is covered. Firms compete in prices, p_A and $p_{B,}$ respectively. The location of the marginal consumer who is just indifferent between the two products is identified by x^m. Because this consumer gets the same surplus whether goods are bought from firm A to the west or firm B to the east, we must have: $V - tx^m - p_A = V - t(1-x^m) - p_B$. In turn, this implies that $x^m = \frac{1}{2} + \frac{p_B - p_A}{2t}$. Because firm A's demand $q_A = x^m N$ and firm B's demand is $(1-x^m)N$, the inverse demand curve facing each firm is:

$$\text{Inverse Demand for firm } A\text{: } p_A = t + p_B - \frac{2t}{N}q_A$$

$$\text{Inverse Demand for firm } B\text{: } p_B = t + p_A - \frac{2t}{N}q_B \tag{22.5}$$

By the twice-as-steep rule, the marginal revenue curve for each firm is therefore:

$$\text{marginal Revenue for firm } A\text{: } MR_A = t + p_B - \frac{4t}{N}q_A$$

$$\text{marginal Revenue for firm } B\text{: } MR_B = t + p_A - \frac{4t}{N}q_B \tag{22.6}$$

Equating marginal revenue with marginal cost, firm A's optimal output is: $q_A = \frac{N(t + p_B - c)}{4t}$. Likewise, firm B's optimal output is: $q_B = \frac{N(t + p_A - c)}{4t}$. Substituting these values back into the inverse demand functions then yields the best price response curve for each firm:

$$\text{Best Response for Firm } A\text{: } p_A = \frac{c + t + p_B}{2}$$

$$\text{Best Response for Firm } B\text{: } p_A = \frac{c + t + p_B}{2} \tag{22.7}$$

From equations (22.7), it is easy to determine that without the further pressure of any network effects, the equilibrium prices in this market are:

$$p_A = p_B = c + t \tag{22.8}$$

Now consider the same market when network effects are present. To capture these, we assume that a consumer's surplus depending on the consumer's location x is $V + ks_A^e - tx - p_A$ if the consumer buys from firm A, and $V + ks_B^e - t(1-x) - p_B$ if the consumer buys from firm B. Here s_A^e and s_B^e are, respectively, the market shares of consumers that the typical consumer *expects* to purchase good A and good B. To operationalize this expectation, we impose the same rational constraint that we did earlier, namely, $s_A^e = x^m$ and $s_B^e = 1 - x^m$. In other words, we impose the constraint that the expected market share equal the actual market share for each firm. Substitution of these values into the consumer surplus measures then quickly reveals that the location of the marginal consumer x^m is now given by: $x^m = \dfrac{1}{2} + \dfrac{p_B - p_A}{2(t-k)}$.

It is easy now to repeat the logic of the no-network case. The inverse demand functions are:

$$\text{Inverse Demand for firm } A\text{: } p_A = t - k + p_B - \frac{2(t-k)}{N} q_A$$

$$\text{Inverse Demand for firm } B\text{: } p_B = t - k + p_A - \frac{2(t-k)}{N} q_B \tag{22.9}$$

Using the twice-as-steep rule to derive the marginal revenue functions, solving for the optimal output of each firm, and substituting this result back into the demand curves then yields the following best response functions when network effects are present:

$$\text{Best Response for Firm } A\text{: } p_A = \frac{c + t - k + p_B}{2}$$

$$\text{Best Response for Firm } B\text{: } p_A = \frac{c + t - k + p_B}{2} \tag{22.10}$$

In turn, this implies that the price equilibrium when there are network effects is:

$$p_A = p_B = c + t - k \quad [0 < k < t] \tag{22.11}$$

Comparison of equation (22.8) with (22.11) shows that equilibrium prices are definitely lower when network effects are present. The reason is clear. The value to a firm of gaining additional customers from one's rival now is enhanced as that makes consumers more willing to pay for the firm's service. Competition between two or more firms to establish the network can be particularly fierce if it is possible that only one firm or network survives, that is, when the market has a "winner-take-all" feature. The winning network claims the entire (served) population and the loser gets nothing. The market is "tippy" in that once a firm starts to lose customers, the value of its product to the remaining customers falls, causing it to lose more customers, its value to fall further, and so on. In such a setting, more than market share is at stake. Survival itself is on the line. Moreover, while this "winner-take-all" feature would greatly intensify the competition by itself, coupling it with an environment in which pricing below cost may be necessary just to get any network started, makes the competition truly nasty. Some economists have argued that it was precisely this dynamic that was at work in the Microsoft versus Netscape case and that what may look like predatory behavior when applied in other markets is really just normal competition when applied in a setting of network goods.[3]

Market problems become particularly difficult when the network is a system comprised of complementary components and when we consider what happens over time. Suppose for instance that the network in question involves the market for Digital Versatile Disc (DVD) movies. The two components to this network are the DVD player and the movie discs themselves. This complementary relationship complicates the network effect. The desired

[3] See Schmalensee (2000) for a clear statement of the view that competition in network or, (what he calls) "winner take most" markets is likely to be extremely fierce and easily mistaken for predatory conduct when practiced by a dominant incumbent.

outcome is for sufficiently wide use of DVD players and discs to achieve what appear to be rather sizable scale economies that characterize production, especially disc-making. However, no firm or group of firms will sink the large up-front costs necessary to produce a lot of DVDs unless they are sure that there will be a substantial number of DVD players. Yet consumers may be reluctant to purchase a DVD player until they are sure that there will be a large number of films translated to DVDs for playing. In such a setting, one possibility is that the market fails completely because of self-fulfilling expectations. If no consumer expects DVD films to be widely available (or available at a low price), no one will invest in buying a DVD player and, as a result, no firm will produce many DVD films. In turn, this outcome will confirm the initial expectations, justifying the decision not to purchase a DVD player. On the other hand, an alternative outcome is that each consumer expects others to purchase DVD players and therefore anticipates that firms will find it worthwhile to put films on DVDs. In this case, each consumer will purchase a player, inducing firms to produce movie discs, which now confirms this more optimistic expectation. The network externality in this case is reflected in the fact that as I buy a DVD player, I enhance the value of your DVD machine because I increase the likelihood that there will be firms that find it worthwhile to produce DVD films.

The DVD example also highlights another aspect of the multiple equilibria problem, namely, the possibility that the particular equilibrium realized may be one in which the market is "locked" into the wrong or an inferior technology. From a durability and volume of information viewpoint, the DVD technology is an undoubtedly superior and less costly way to provide movie rentals than is the VHS technology based on videocassettes and VCRs. However, because the two systems are substitutes and because VHS was the first system to get established, the DVD system needed to attract customers away from VHS in order to gain a footing. It might have been the case that the number of customers so attracted was not sufficiently large for the DVD manufacturers to exploit the available scale economies and avoid losses. To reach that volume, each potential DVD consumer needed not only to be convinced of the superiority of the DVD system but also to be sure that others shared that conviction and were willing to act on it. In this case, purely by the historical accident that the videocassette system was developed first, consumers could have been locked into the inferior system.[4]

To put it somewhat differently, there is "path dependence" so that whichever system eventually claims the market is the result of an arbitrary process, but one that "locks in" that outcome for a considerable period of time. Instead of the VHS versus DVD example just given, consider a closely related one from the earlier days of home video, namely, the VHS versus Betamax versions of Video Cassette Recorders (VCRs). Imagine that 40 percent of the population has a slight preference for VHS machines *if* the price and market share of these machines are identical to the price and market share of Betamax based products. Similarly, the remaining 60 percent have a slight preference for Betamax. However, these slight preferences can be overcome if one firm has a much larger market share because, again, no one really wants to buy a network product if it does not have a very large network of users. Finally, we assume that all consumers are not initially aware of the general home

[4] David (1985) has argued that the standardized QWERTY keyboard used initially by typewriters and now by all PC keyboards is an example of path dependent lock-in to an inferior technology, with the superior one being the Dvorak keyboard. While Liebowitz and Margolis (1990) cast considerable doubt on this argument, the case nevertheless makes clear that such market failure is a real possibility. See also, Arthur (1989).

video market. Instead, they learn of it over time. Each week a few more consumers randomly find out about home videos and decide to buy a VCR of either a VHS or Betamax type.

On average, we would expect each new wave of new consumers to be made up of 60 percent Betamax preferring consumers and 40 percent VHS preferring consumers. However, it is quite possible that, picking randomly, one could get a batch of new consumers who were comprising, say, 90 or even 100 percent of those who prefer VHS. Starting from a point in which each system has equal market penetration, such a random draw could easily tip the market heavily in favor of VHS. Once that happens, then even those with a slight preference for Betamax will, in subsequent rounds, choose to buy a VHS machine because that network is so much larger that many more films are going to be printed for it. Hence, the small random draw favoring VHS may tip the entire market in favor of this technology forever even though, at base, Betamax is the superior technology in that most consumers favor it over VHS when all else is equal.

Similarly, Microsoft's dominance may reflect just plain good luck as much as it does superior technology. A key development in this regard came in 1980 when IBM decided to enter the personal computer market in a major way. IBM awarded the contract for its disc operating system to Microsoft and *MS-DOS* was born. Some analysts think that Microsoft did not have the best product at that time. Yet having the support of IBM was clearly a major advantage in establishing a network of *MS-DOS* users. Note that the network effect gives Microsoft a strong defense against *Linux* or *Apple* or some other product even if it is a better operating system than *Windows*. Again, the lock in effect raises the possibility that the market may adopt the inferior technology.

22.3 SYSTEMS COMPETITION AND THE BATTLE OVER INDUSTRY STANDARDS

Competition between networks does not always leave just one survivor. The US has four major credit card firms (Visa, Amercian Express, MasterCard and Discover). There is about the same number of major wireless phone service provides (Verizon, AT&T, Sprint, and T-Mobile). When we allow for the coexistence of two or more firms, each operating its own network, a number of additional features enter into the analysis. In such cases, there is the important issue of compatibility. To what extent will the industry adopt a standard product design that enables consumers to "plug in" to any network? If a standard is adopted, what standard will it be? In this section, we address these and related questions using a simple illustrative model described below.

Consider, for example, the question of technology adoption. Assume that two firms have to decide on whether to stick with their individual, existing technology or switch to a new one. To be specific, suppose that the firms estimate the payoffs to their choices to be those shown in Tables 22.1(a) and 22.1(b). The distinction between these two matrices is that in (a) sticking with the old technology is less profitable jointly than incurring the installation costs of switching to the new technology, while in case (b) both firms switching reduces their joint profits.

The payoff received for either firm depends critically on what choice its rival makes. However, there is also a further complication, namely, the issue of compatibility. Suppose that the old technology and the new technology are incompatible in the sense that they cannot be used together. This means that if each firm makes a different choice, they do not derive any network benefits from being interchangeable with each other. By contrast,

Table 22.1 Excess inertia and excess momentum with network externalities (in US dollars, millions)

		Firm 2	
		Old technology	*New technology*
Firm 1	*Old technology*	5, 4	3, 2
	New technology	3, 3	6, 7

(a) The new technology is Pareto superior to the old. A Nash equilibrium with both firms staying with the old technology exhibits excess inertia.

		Firm 2	
		Old technology	*New technology*
Firm 1	*Old technology*	6, 7	3, 2
	New technology	3, 3	5, 4

(b) The old technology is Pareto superior to the new. A Nash equilibrium with both firms adopting the new technology exhibits excess momentum.

if they choose the same technologies—whether old or new—then they do enjoy network externalities. Such positive network externalities mean that the payoff to each firm if they choose the same technology is greater than if they choose different technologies. This is illustrated in the payoff matrices by the fact that the payoff to either firm when both firms choose the same technology, no matter which, is greater than the payoff to either firm when they choose different (incompatible) technologies.

Regardless of whether both would do best by switching to the new technology [Table 22.1(a)], or both would do best by avoiding the cost of installing the new equipment and sticking with the existing technology [Table 22.1(b)], it can be seen that there are two Nash equilibria: one in which the two firms stay with the old technology, and the other in which they both switch to the new technology. There is no simple way to pick between these two equilibrium outcomes. If the payoffs are as in Table 22.1 (a) and so both switching is efficient, each firm may nevertheless choose not to switch from fear of moving alone into an incompatible technology. Farrell and Saloner (1985) refer to this as a case of excess inertia. Alternatively, with the payoffs of Table 22.1(b), we might find excess momentum with both firms making a costly switch to the new technology out of fear of being stranded alone with the old technology.

There are, of course, ways by which the firms can attempt to avoid either of these unsatisfactory outcomes. For example, the firms might be able to communicate their proposed technology choices—and they have the incentive to do so honestly because lying actually hurts both firms. Coordination may also be more likely if we extend this game over many periods, because then a firm has the potential to correct a "wrong" choice, i.e., one different from that of its rival. Nevertheless, even in these more general settings, Farrell and Saloner show that firms may in particular delay switching technology longer than they should. That is, rather than move promptly to introduce new technology soon, they may wait unduly long until a sufficiently large "bandwagon" has built-up. Thus, some theater owners and film producers in the 1920s did not invest in the equipment to show or to make "talking pictures" until they were certain that the new phenomenon would catch on. As a result, the advent of "talkies" may have been suboptimally delayed.

Compatibility is clearly an important factor in technological choice. However, there is a drawback to compatibility. When each firm adopts the same technical standard, their products become very close substitutes, and so price competition is likely to be intense. Hence, while product differentiation by means of different technologies incurs the cost of foregoing possible network effects it has the benefit of softening price competition. Firms therefore have to make a judgment in this regard. Choosing the same technology will lead the firms into direct, intratechnology competition of the type discussed throughout the earlier chapters of this book—that is, competition on price, quality, and service. By contrast, the choice of different technologies will lead the firms into intertechnology competition.

Of course, if a firm can establish its technology as the industry standard, the rewards from this kind of competition are likely to be very large indeed. When firms choose to compete in different technologies, each is hoping that its technology will someday win the market and become the industry standard. Think of Sony's *PlayStation*, Nintendo's *Wii*, and Microsoft's *Xbox*. These three firms apparently regard the advantages of compatibility to be more than offset by the disadvantages that it would bring in terms of intensified price competition. As a result, the three systems are totally incompatible. Yet each hopes to win the market and to establish its technology as the standard for which all applications, i.e., games are written.

There is no *a priori* means of determining whether rewards will be greater under intratechnology competition "within the market" or intertechnology competition "for the market." There are, however, three main possibilities that we should consider. We illustrate these with three simple games: (1) Tweedledum and Tweedledee, (2) The Battle of the Sexes, and (3) Pesky Little Brother.[5]

22.3.1 Tweedledum and Tweedledee

Assume that the payoffs for this game of technology choice are given in Table 22.2. There are two Nash equilibria, in each of which the firms prefer to adopt incompatible technologies. This implies that the firms believe that network externalities are not particularly strong and that any gains from adopting a common technology will be more than offset by the fact that this will lead to particularly fierce intratechnology price competition. They also believe that a battle to establish the industry standard will not significantly delay its adoption by potential consumers and so offers large rewards.

With these payoffs, each firm willingly enters into a battle to have its technology established as the dominant one, i.e., each will push for the Nash Equilibrium that favors its own product. In terms of the game matrix, firm 1 will fight to establish its technology as

Table 22.2 Tweedledum and tweedledee (in US dollars, millions)

		Firm 2	
		Technology A	*Technology B*
Firm 1	*Technology A*	3, 2	8, 4
	Technology B	4, 8	2, 3

[5] This analysis is developed in depth in Besen and Farrell (1994). The language that follows is also borrowed from their discussion.

the "A" technology, thereby defining firm 2's as the lesser "B" technology, and firm 2 will do exactly the same. Besen and Farrell (1994) suggest four forms that this battle can take:

1. *Build on an Early Lead*. If there are any network externalities at all associated with a particular technology of the type we have discussed, there is considerable benefit to a firm that succeeds in establishing a large installed base of current users. These users will be reluctant to switch to a different technology. At the same time, the existence of such a large installed base makes the technology attractive to new users. (Just think of the choice that a new computer user has to make between buying an IBM compatible running the *Windows* operating system against a similar machine running *Linux* or an Apple computer with the *Apple* operating system.) Under this scenario, there will be intense price competition in the early stages of new technologies as each firm attempts to capture as many customers as possible. Firms will also reveal and perhaps exaggerate their sales figures in order to persuade potential buyers that a large installed base already exists.
2. *Attract Suppliers of Complements*. As we have pointed out many times, the attractiveness of a product is affected by the number of complementary products that are also available. A computer is of little use except to the most advanced users unless there is a wide range of computer software that will run on it. A Nintendo game machine becomes more attractive as Nintendo or other firms expand the number of games it can play. There is little point in owning a CD player unless recording companies offer a wide range of recordings in CD format.

   Owners of a primary technology such as Dell or Microsoft will likely encourage software developers to produce a wide range of programs that will run on their platform. Indeed, one reason that Apple lost its early lead in personal computers may well have been its reluctance to have its operating system installed in clones. This restriction limited the market penetration of Apple's system and consequently reduced the incentives of software developers to produce Apple-compatible software.
3. *Product Preannouncement*. The owner of a particular technology can try to slow the growth of a rival network by regularly "preannouncing" new products in advance of their actual introduction. The idea is to discourage new buyers from choosing the rival's product with the promise of new "goodies" to come. The long-advertised arrival of Microsoft's *Vista* program from 2004 to 2007 may have been in part an effort to attract new buyers who might otherwise have started out buying an alternative operating system. Such a strategy is not without risk, however. Announcing that a new version of a dominant product that is just round the corner may not just cause some new customers to delay their purchase of a rival's product. It may also cause customers already favorable to one's existing product to delay their purchases as well.
4. *Price Commitments*. A contractual commitment to achieve and maintain low prices over the long term is a fourth method by which new consumers can be persuaded to adopt a particular technology. This will be especially beneficial if the firm offering the commitment knows that there are significant economies of scale or learning economies in the manufacture of the primary product. In such circumstances, building a large installed base early generates cost reductions that allow the firm to deliver on its low price while maintaining its profitability.

In short, when rival firms compete to establish an industry standard, a variety of strategies and outcomes emerge. Here again we find that such markets are 'tippy,' with multiple equilibria in which the coexistence of incompatible products may be unstable. The tide of battle can turn rapidly and quite suddenly a dynamic can develop that leads to a single winning standard dominating the market. Moreover, there is no guarantee that the winner will offer the best technology.

22.3.2 The Battle of the Sexes[6]

Rather than fight to have their own technology adopted as the industry standard, firms may agree on the adoption of a common technology. The payoff matrix in this case is as in Tables 22.3(a) and (b). The simplest case is that illustrated in Table 22.3(a). Here, both firms are agreed that they should adopt technology 1. Accordingly, they should be able to establish this technology as a common standard by simple communication between them.

In the case of Table 22.3(b), however, there is no such agreement. The firms would prefer a common standard but they are not agreed on which of the two technologies the standard should be. Firm 1 will fight to establish technology 1 as the standard, and firm 2 will fight to establish technology 2. This is another instance in which commitment plays a crucial role. Firm 1, for example, may be able to persuade firm 2 to accept technology 1 as the standard by irrevocably committing itself to this technology. It could, for example, build an installed base rooted in technology 1. Alternatively, it could invest in production capacity to build more units embodying this technology, or establish a large R&D program devoted to improving this technology. The common intent here is to broadcast the clear message that firm 1 will never give in on its demand that technology 1 be the standard because to do so would cost firm 1 too much.

Other possible commitments take the form of concessions rather than threats. Thus, firm 1 could offer to license technology 1 to firm 2 for a low fee in return for firm 2 agreeing that technology 1 will be the standard. Alternatively, firm 1 can promise to develop the

Table 22.3 The battle of the sexes (in US dollars, millions)

		Firm 2	
		Technology 1	*Technology 2*
Firm 1	*Technology 1*	10, 10	5, 4
	Technology 2	6, 5	8, 8

(a) Agreement on compatible standard and choice of standard.

		Firm 2	
		Technology 1	*Technology 2*
Firm 1	*Technology 1*	10, 7	5, 4
	Technology 2	6, 5	8, 12

(b) Agreement to be compatible but disagreement on standard.

6 This title comes from a well-known game in which two individuals, perhaps husband and wife, in choosing their entertainment for the night, agree that they would rather be together than apart, but put very different valuations on the entertainment they might share. These could be, for example, going to a ball game or to an opera.

technology jointly, or it can suggest that the two firms develop a hybrid technology that combines the best features of each.

22.3.3 Pesky Little Brother

In the "Tweedledum and Tweedledee" case, the two firms pursue inter-technology competition rather than adopt a common technology and confront each other in the market with technologically undifferentiated products. In the "Battle of the Sexes," each firm prefers competition between technically compatible products, but the question of which technology is the appropriate standard remains an issue. What these two cases have in common is that there is some degree of consensus, if only on the terms on which competition between the firms will occur. If, however, there are asymmetries between the firms, it may be impossible for them to reach even this limited kind of consensus.

Assume, for example, that firm 1 has established a dominant position with a large installed base and a powerful reputation. It will prefer incompatibility with a small rival in order to hold its customers. The smaller rival, firm 2, will prefer compatibility in order to derive benefits from the network that the larger firm has established. As Besen and Farrell indicate, "The firms' problem is like the game between a big brother who wants to be left alone and a pesky little brother who wants to be with his big brother."

The payoff matrix now looks something like Table 22.4. There is no Nash equilibrium (in pure strategies) to this game if the firms make simultaneous choices—the two firms' strategic choices are inconsistent.[7] Resolution of the game then comes down again to a question of timing and commitment.

Suppose that the dominant firm must commit to its technology choice first. This is perhaps the most plausible assumption, given that we have motivated the game by describing firm 1 as a preexisting firm with a large installed base. In this case, the smaller firm 2 may actually enjoy a second-mover advantage. If firm 1 is committed to its existing technology either because it is costly to change or because such change would lose firm 1 the guaranteed patronage it now enjoys from its customers, it may be unable to prevent firm 2 from following. In this case, firm 2's clear choice will be to follow with a compatible system, precisely the outcome firm 1 had hoped to avoid.

Two tactics might be available to firm 1 that would prevent firm 2 from imitating its lead and offer firm 1 relief from its "pesky little brother." These are: (a) aggressive protection of its property rights and (b) changing its technology frequently. The first tactic relates to

Table 22.4 The pesky little brother (in US dollars, millions)

		Firm 1	
		Technology 1	*Technology 2*
Firm 1	*Technology 1*	12, 4	16, 2
	Technology 2	15, 2	10, 5

There is no (pure strategy) Nash equilibrium in simultaneous play. Firm 1, the dominant firm (or big brother) prefers that the technologies be incompatible. Firm 2 (the little brother) prefers that they be compatible.

[7] With a game of this type with a finite number of strategies, there is always a Nash equilibrium in mixed strategies in which the firms randomize their choice of technologies, but we shall not consider this equilibrium.

the use of patents. If the technology the dominant firm has built up is protected by patents, then imitation may be preventable through strict enforcement of the protection such patents give and by building up a stock of sleeping patents that make it difficult for a smaller firm to invent around the current technology.

Alternatively, firm 1 can try to hamper firm 2's imitation efforts by changing its technology frequently. This, of course, can be expensive and runs the risk of alienating users of the existing installed base unless they can be protected by, for example, being given favorable access to the new generation of products. The advantage to this approach is that the target at which the smaller rival is aiming is constantly shifting in ways that are difficult for the small firm to predict. If you really want to avoid your pesky little brother, don't tell him where you are going!

In short, competition over technology has a variety of implications. Often, there may be large social gains from all firms adopting a common technical approach. But the incentive for firms to differentiate their products, as well as the rivalry over which technology should become the industry standard, can frequently thwart the realization of such gains. While the gains from price competition are generally clear, the network externality effects make the gains from technology competition more ambiguous.

22.4 NETWORK GOODS AND PUBLIC POLICY

Our analysis of network services suggests many ways in which the market mechanism may fail to produce an efficient outcome. In some cases, a socially desirable service may fail to be provided. In other cases, multiple possible outcomes raise the possibility that the market may choose the wrong equilibrium and lock into an inferior technology. Competition may not be a feasible market structure. Moreover, even where feasible, competition may not be a remedy for these failures. To the contrary, competition may intensify the rush to a particular standard or technology, which later is realized to be inferior. Competition may also lead firms to reject compatibility even when it might actually be desirable. When the market will only support one system or network, competition is likely to be very intense and border on predatory conduct. How should public policy deal with these issues?

It is important to understand that in many respects, the problems raised by network effects are not new. The presence of dramatic scale economies and externalities have long been recognized as potential sources of market failure. Large scale economies make marginal cost pricing unlikely because such large scale economies means that marginal cost is below average cost over a wide range of production. Further, even when it is possible to operate at a sufficiently large size that all the scale economies are exploited, doing so will likely imply that there is room for only a few firms. Similarly, externalities always imply a divergence between private and social benefit (or cost) with the result that market outcomes based on the maximizing choices of individuals and firms are not likely to be optimal.

Saying that the problems raised by network effects are not new, however, is not the same thing as saying that they are easy. Three problems are particularly difficult in the case of network goods. The first of these is the problem of detecting or proving anticompetitive behavior. The second is the difficulty of devising an appropriate remedy once anticompetitive actions have been identified. The third is determining the proper role that the government should play in coordinating the technology choices of different firms with a view towards achieving standardization.

Reality Checkpoint

The Battle over High Standards

In the late 1970s, Sony introduced the BetaMax technology for videocassette recorders (VCRs) and thereby initiated the war with the Video Home System (VHS), initially engineered by JVC Corporation, over the format standard for VCRs. VHS eventually won this war leaving Sony and many consumers with worthless BetaMax machines.

Thirty years later, Sony had to fight this war all over again, as the rise of affordable high definition TVs and disc players in the early 2000s, raised the issue of the industry standard disc format. Sony was the developer and primary proponent of the Blu-Ray technology. Its chief rival was Toshiba, the developer and main advocate for an alternative format known technically as the Advanced Optical Disc (AOD) format, but commonly referred to as HD DVD. Both technologies used a short wavelength blue-violet laser technology employing a very fine laser beam that permitted storing a great amount of information on a single disc.

Because each side had a considerable investment at stake, each fought hard to win. Among film companies, Sony persuaded Columbia, Disney, and Fox to use Blu-Ray. Toshiba won the support of Paramount, Universal, and Warner Brothers. Each also lined up support from other electronics firms such as Hitachi, Samsung, Dell, and Hewlett Packard (Sony), and NEC, RCA, Microsoft, and Intel (Toshiba). This of course created difficulties for retailers and consumers uncertain about which machines and DVD's to buy or stock.

As the battle raged on it became increasingly bloody. Sony took the very costly but important strategic step of building the Blu-Ray technology into its *Play Station 3* game consoles. Toshiba brokered a deal to sell its machines through Wal-Mart, the largest DVD retailer, for under $200. The decisive moment came in January 2008, when Warner Brothers announced that it would switch to Blu-Ray. Although Toshiba cut prices another 40 percent, Wal-Mart announced in February that it would phase out HD DVD within six months. The battle was over. Toshiba suspended HD DVD in March. Sony's Blu-Ray won albeit at a cost of much red ink.

Source: N. Wingfield, "Format Face-Off: Bringing the DVD War Home," *The Wall Street Journal*, June 20, 2006, p. D1; W. Mossberg, "Don't Get Caught in a Losing Battle over DVD Technology," *The Wall Street Journal*, March 8, 2007, p. B1.; and M. Fackler, "Toshiba Concedes Defeat in the DVD Battle," *New York Times*, February 20, 2008, p. C1.

Consider the problem of determining anticompetitive tactics. The presence of network externalities requires that the developer of a new product such as a facsimile machine sell to a large number of consumers in order to establish any market at all. In turn, this may well mean pricing below cost, at least initially. This may result in a competitor being driven out of the business. When later, the winning firm raises its price so as to earn a return on its investment, the historical record of selling below cost, eliminating a rival, and then raising price looks a lot like a case of predatory pricing. Indeed, such a record is essentially the evidence called for by Baumol (1979) to determine predation. (See Chapter 12.) Yet such a finding may simply reflect the need to price low so as to penetrate the market and the fact that the market can only support one supplier.

Similarly, the developer of a platform such as *Windows* or *Wii* or a DVD player requires that there be a large number of applications (programs, games, or films) available at a low cost in order to gain wide acceptance of the overall system. One way to achieve this aim is to produce and market such complementary goods itself. Yet to the extent that one can only play Nintendo *Wii* cartridges on a Nintendo *Wii* machine the market outcome begins to look like illegal tying or possibly an attempt at foreclosure. To borrow from an example earlier in the text, Microsoft's *Windows* almost certainly gained from the availability of a compatible, low-cost web browser. Yet Microsoft's decision to bundle its *Explorer* browser with *Windows* raised substantial concerns of tying with a view to driving Netscape out of the browser business.[8]

With regard to technology adoption and product improvement, the case of Microsoft is again relevant. Sun Microsystems' *Java* programming language offered the possibility of greatly enhancing the functionality of *Windows*. However, this required that *Windows* be made compatible with *Java*. Microsoft was generally reluctant to do this at least in part because there was a widespread view that *Java* could provide the basis for an alternative applications platform if it ever became widely accepted. Making it compatible with *Windows* would have this effect. So, while providing that compatibility might greatly improve the technology available for PC users, it might also provide an opportunity for entry to a new rival. Does Microsoft's reluctance in this case reflect an illegal effort to deter entry?[9]

As difficult as it is to identify anticompetitive behavior in network or systems markets, devising an appropriate remedy when such actions are discovered is perhaps even more problematic. The just mentioned case of Microsoft and Sun Microsystems is instructive in this connection. Is the appropriate policy to force Microsoft to make *Windows* compatible with *Java*? Adoption of such a policy would place the government in the awkward position of pushing a particular technology, and it is far from clear that the government has the skill to do this well. What if *Java* really does not offer any real improvement on the *Windows* product? Indeed, what if there is an alternative programming language that would offer much greater enhancement? That alternative may never break through if antitrust officials require that *Windows* work with *Java*. In other words, antitrust policy may also result in an inferior technology lock-in.

This raises the general question as to the proper role for the government in coordinating the technology choices of different firms with a view toward achieving widespread standardization. Consider the market for mobile telephone service. Relatively early on, the European Telecommunications Standards Institute (ETSI) imposed a requirement that cell phone service providers adopt GSM as the 2G standard to be used throughout Europe. Consequently, a British resident traveling on the continent was able to use a mobile phone to make calls in Italy just as easily as at home in the United Kingdom. This was much less feasible for US residents at that time, in part, because no centralized authority had acted to coordinate the digital standards of American mobile phone companies. Instead, US mobile service providers initially adopted four different standards that left interservice communication quite difficult, if not impossible. However, competition between these different standards spurred further technical development. Indeed, this advantage was implicitly recognized by ETSI when it later chose to adopt the American-based CDMA standard for 3G systems. [See Cabral and Kretschmer (2007).]

8 This point was made forcibly by Schmalensee (2000). See Fisher (2000) for an opposing point of view. Note that if Schmalensee's argument is that in some industries, e.g., web browsers, only one firm can survive, this is really a statement that such a market is a natural monopoly. The only difference is that here the scale economy lies on the demand side via the network externality. See also Eisenach and Lenard (1999).

9 Microsoft and Sun eventually did reach an agreement of sorts, but Sun was never happy with it and the agreement was later abandoned.

22.5 EMPIRICAL APPLICATION: NETWORK EXTERNALITIES IN COMPUTER SOFTWARE—SPREADSHEETS

As noted earlier, computer software such as operating systems and web browsers are likely to exhibit important network effects. Users care about being able to run their programs on the computers of their friends or business associates. The more people using a specific software package or the more compatible a software package is with add-on programs, the more valuable it should be. Gandal (1994) offers empirical evidence of this phenomenon from the early days of desktop computing.

A spreadsheet was initially a pencil-and-paper operation. Essentially, it was a large sheet of paper with columns and rows organizing all the relevant data about a firm's transactions. Its name comes from the fact that costs or revenues connected to a specific operation were spread or displayed over the sheet in a manner allowing sums over a given row or column. In that way, management is able to focus on a specific factor, say energy costs, in making an informed decision about company operations. The advantage of a spreadsheet format is that if a given cost factor or revenue assumption is changed, decision makers can trace through the implications of this change rather quickly. However, there is a natural limit to the speed of such adjustments when spreadsheets are "hard copy" and changes must be made by hand.

Beginning about 1980, electronic spreadsheets suitable for use on desktop computers began to make their commercial appearance. The first of these was *VisiCalc (Visible Calculator)*. Computerization greatly enhanced the speed with which managers could assess the impact of cost or revenue changes. It thereby greatly increased the usefulness of spreadsheets in daily operations. Demand for such products grew and so did the supply. Soon, there were a number of spreadsheet programs including *SuperCalc*, *VP Planner*, *PlanPerfec*, *Quatro Pro*, *Multiplan*, *Excel*, and *Lotus 1-2-3*.

These early products differed both from each other and over time. The earliest versions had very limited, if any, graphing abilities. Some could link entries in one spreadsheet to others in another spreadsheet. Some could not. Only a few were able to link with external data and incorporate that data into the spreadsheet cells directly. The most flexible of all was the *Lotus 1-2-3* program. Throughout the late 1980s and into the 1990s, this was the dominant product. Indeed, an important attribute of other spreadsheet programs was whether or not they were *Lotus* compatible.

Gandal (1994) notes that spreadsheet demand will likely exhibit network effects for a number of reasons because users like to be able to share their information and the results of their spreadsheet analyses with each other. Gandal then identifies three features of a spreadsheet program that should promote such networking. The first is whether or not the program was compatible with *Lotus 1-2-3*, the dominant product. This is measured by a variable *LOCOMP* equal to 1 if the program is *Lotus* compatible and 0 if it is not. The second network attribute is *EXTDAT*. This is a variable that takes on the value 1 if the program can import files from external data sources and 0 if it cannot. The final network feature is another 1, 0 variable *LANCOM* that indicates whether or not the program can link independent users through a local area network.

Gandal (1994) hypothesizes that if network externalities were present in the early spreadsheet market, then a program's market price will be higher if it has any of the three features just described, i.e., when for that product, any of the variables *LOCOMP*, *EXTDAT*, or *LANCOM* is positive. A function that specifies how product price changes as the product's attributes change is known as an hedonic function. Estimating such functions is usually done by ordinary least squares (OLS) in an hedonic price regression. Gandal (1994) gathered data for ninety-one computerized spreadsheet products over six years: 1986 through 1991. His basic regression equation is:

$$\begin{aligned}\ln p_{it} = {} & \alpha_0 + \alpha_1 TIME87_t + \alpha_2 TIME88_t + \alpha_3 TIME89_t + \alpha_4 TIME90_t + \alpha_5 TIME91_t \\ & + \beta_1 LMINRC_{it} + \beta_2 LOTUS_{it} + \beta_3 GRAPHS_{it} + \beta_4 WINDOW_{it} \\ & + \gamma_1 LOCOMP_{it} + \gamma_2 EXTDAT_{it} + \gamma_3 LANCOM_{it} + \varepsilon_{it}\end{aligned}$$

The dependent variable is the natural log of the price of spreadsheet model i in year t. Not including the constant, the first five variables are time dummy variables equal to 1 in the year that is indicated by the dummy and zero otherwise. These variables pick up the pure effects of time on spreadsheet program prices while holding the quality attributes fixed. The next four variables are variables that pick up specific features that should add to the value of a spreadsheet program. *LMINRC* is the natural log of the minimum number of rows or columns that the spreadsheet can handle. This is meant to capture the sheer computing power of the program. *LOTUS* is a 1, 0 dummy variable indicating whether the product is a *Lotus* spreadsheet. This term captures any brand premium that *Lotus* enjoyed during these years. GRAPHS is a 1, 0 dummy variable indicating whether or not the program can construct pie, bar, and line graphs. *WINDOW* indicates the number of windows a program can handle on a screen simultaneously. Of course, the final three variables are the networking effects described earlier. If there are network externalities, the coefficients on these variables should be significantly positive.

Gandal's (1994) results are presented in Table 22.5, shown below. The first regression shown is the estimated hedonic equation described above. Note that all the attributes hypothesized to raise the value of a spreadsheet program do in fact exert a significantly positive effect on its price. There is a strong brand premium for *Lotus*. There is an almost as strong premium for programs that have graphing abilities. Most important of all, however, the three networking variables are very strongly positive. *LOCOMP*, *EXTDAT*, and *LANCOM* all have a substantial positive effect on a program's price.

Regression 2 shows the effects of allowing the coefficients to change over time. Gandal (1994) splits the sample in half and adds as regressors, values of the independent variables multiplied by 1 if the observation comes in the second half of the sample. Most of these interacted variables are not significant. However, the coefficients on both *MINRC and LINKING* do change over time as indicated by the coefficients on *TMINRC and TLINKING*. These coefficients are interpreted as the difference between the marginal value of these features in the first half of the sample and that value in the second half of the sample. Note that this regression includes *TLANCOM* but not *LANCOM*. This is because connecting to local area networks was generally not possible for any program prior to the second half of the sample.

Gandal (1994) prefers Regression 2 as the better specification of the hedonic price equation. Note again that it implies strong network externalities. The coefficients on *LOCOMP*, *EXTDAT*, and *TLANCOM* are all very significantly positive. Consumers are willing to pay a lot extra for spreadsheets that others can use either because they are *Lotus*-compatible, can easily import data from external programs, or can exchange information over a local area network. These effects are powerful. Because the dependent variable is the log of the price, the coefficient is easily interpreted as the percentage increase in price

Table 22.5 Hedonic regression results for spreadsheet programs, 1986–91

	Regression 1		*Regression 2*	
Variable	*Coefficient*	*t-statistic*	*Coefficient*	*t-statistic*
CONSTANT	3.76	(12.31)	3.12	(9.50)
*TIME*87	−0.06	(−0.38)	−0.07	(−0.43)
*TIME*88	−0.44	(−2.67)	−0.45	(−3.03)
*TIME*89	−0.70	(−4.20)	0.92	(1.71)
*TIME*90	−0.79	(−4.90)	0.90	(1.67)
*TIME*91	−0.85	(−5.30)	0.85	(1.59)
LMINRC	0.11	(1.59)	0.26	(3.24)
LOTUS	0.56	(4.36)	0.46	(3.62)
GRAPHS	0.46	(3.51)	0.52	(4.18)
WINDOW	0.17	(2.14)	0.14	(1.92)
LINKING	0.21	(1.91)	0.26	(2.00)
LOCOMP	0.72	(5.28)	0.66	(5.17)
EXTDAT	0.55	(4.05)	0.57	(3.93)
LANCOM	0.21	(1.65)		
TLANCOM			0.61	(3.28)
TLMINRC			−0.34	(−3.07)
TLINKING			−0.31	(−1.49)

a consumer would pay for that feature. Thus, being *Lotus*-compatible raised the price of a spreadsheet program by 66 percent according to Gandal's (1994) estimates. A program's ability to import data from an external source raised the price by 57 percent.

A frequent use of hedonic price regressions is to construct price indices that trace the movement of a commodity's price over time. This is often difficult to do because we do not have an easy way to adjust for quality. A television set today may cost much more that a television set from ten years ago. However, it would be wrong to interpret all of that price increase as inflation because today's television set has many more features than that of an earlier set such as high definition, DVD compatibility, and a flat screen, to name just a few. Because the hedonic regression controls explicitly the value of quality features, it permits the easy construction of a quality-corrected price index by focusing on the changes that are due simply to the passage of time, i.e., holding quality constant. In Regression 1, these changes are fully captured by the year specific dummies. Because the dependent variable is ln p_{it}, the predicted price for a spreadsheet of constant quality in any year: $p_{it} = e^{\alpha_t YEAR_t}$ so the YEAR_t variable is the dummy for that observation and α_t is the coefficient estimated for that dummy. If we normalize so that the price index P_t is 1 in the first year of 1986, then equation 1 says that the price index will be $e^{-0.06}$ in 1987; $e^{-0.44}$ in 1988; and so on. For Regression 2, constructing the quality-adjusted price index is slightly more complicated because the value of the some of the attributes also changes over time, but the basic idea is the same. We present Gandal's (1994) estimated spreadsheet price indices for both regressions in Table 22.6, below. It indicates that over the six-year period for which Gandal (1994) collected data, the quality-adjusted price of spreadsheet programs—like the price of much software and hardware in this time period—declined substantially. Here, the decline exceeded 50 percent.

Table 22.6 Quality adjusted price indices for spreadsheet programs, 1986–91

	1986	*1987*	*1988*	*1989*	*1990*	*1991*
Price Index from Regression 1	1.00	0.94	0.64	0.49	0.45	0.42
Price Index from Regression 2	1.00	0.93	0.64	0.50	0.48	0.46

Summary

In this chapter, we have focused on the product markets exhibiting important "network externalities." In such markets, the value of the good or service to any one consumer increases as the total number of consumers using the product increases. Services with important network effects, such as telecommunications and home electronics, play an increasingly large role in modern economies.

Markets with strong network effects present special problems. Competition to establish a network service can be unusually fierce, leading to low prices that can be difficult to distinguish from predation. Often, such competition will result in only one firm surviving so that the market's ultimate structure is one of monopoly. There is also a nontrivial risk that the service will be underdeveloped or not developed at all. Similarly, the course of technical development exhibits a path dependency in which the market may eventually lock into an inferior technology.

There are no easy solutions to the problems raised by network goods. On the one hand, the possibilities for anticompetitive outcomes seem sufficiently clear that such markets necessarily invite examination by the antitrust authorities. Yet it must also be acknowledged that it is not easy either to identify anticompetitive actions clearly or to devise workable remedies to the market failures to which network services are prone. Such tensions have dominated the debate over policies regarding the telecommunications industry and other "new economy" markets in the past. They will no doubt continue to be important in the future.

Problems

1. Two banks compete for the checking and savings deposit business of a small town. Each bank has its own ATM network that works only on its own bankcards, but bank 1 has three times as many ATM machines as bank 2. Depositors value a bank's services as an increasing function of the number of machines on the network. Bank 2 approaches bank 1 and suggests that they merge their ATM networks so that depositors of either bank can use either bank's machines.
   a. Is this merger in the interest of deposit consumers in general?
   b. Do you think that bank 1 will agree with bank 2's proposal?
2. Assume that consumers contemplating buying a network service have reservation prices uniformly distributed on the interval [0, 50] (measured in dollars). Demand by a consumer with reservation price w_i for this service is

$$q_i^D = \begin{cases} 0 \text{ if } fw_i < p \\ 1 \text{ if } fw_i \geq p \end{cases}$$

   a. Calculate the demand function for this service.
   b. What is the critical mass if price is set at \$5?
   c. What is the profit-maximizing price for the service?
3. Many social customs exhibit network effects. To this end, consider a party given by a group of individuals at a small university. The group is called the Outcasts and has twenty members. It holds a big party on campus each year. These parties are good, but are

especially good the more people are in attendance. As a result, the number of people who actually come to the Outcasts party depends on how many people are expected to attend. The more people that are expected to attend, the more fun it will be for each attendee and, hence, the more people who actually will come. These effects are captured by the following equation: $A = 20 + 0.95A^e$. Here, A is the number of people actually attending the party. This is equal to the 20 Outcast members plus 0.95 times the number of partygoers A^e that are expected to go.

a. If potential party attendees are sophisticated and understand the equation describing actual party attendance, how many people are likely to attend the Outcasts party?

b. Suppose that each party attendee costs the Outcasts \$2 in refreshments so that the Outcasts need to charge a fee p for attending the party. Suppose as well that when going to the party requires paying a fee, the equation for attendance is: $A = 20 + 0.95A^e - p$. What value of p should the Outcasts set if they want to maximize their profit from the party? How many people will come to the party at that price?

4. Two firms are competing in their choice of technologies. The payoff matrix for the game between them is given below:

   a. Identify constraints on the payoffs a–h that are such that the firms' choices reflect network externalities.

   b. Assume that the constraints in (a) are satisfied. Identify further constraints that must be satisfied for the game between the two firms to be of the form

      i. Tweedledum and Tweedledee;
      ii. The Battle of the Sexes;
      iii. The Pesky Little Brother.

		Firm 2	
		Technology 1	*Technology 2*
Firm 1	*Technology 1*	a, b	c, d
	Technology 2	e, f	g, h

References

Arthur, W. Brian, 1989. "Competing Technologies, Increasing Returns, and Lock-in by Historical Events," *The Economic Journal* 99 (March): 116–31.

Besen, S. M., and J. Farrell, 1994. "Choosing How to Compete: Strategies and Tactics in Standardization," *Journal of Economic Perspectives* 8 (Spring): 117–31.

Cabral, L., and T. Kretschmer. 2007. "Standards Battles and Public Policy." In S. Greenstein and V. Stango, eds. *Standards and Public Policy*. Cambridge: Cambridge University Press, 329–44.

David, P. A., 1985. "Clio and the Economics of QWERTY," *American Economic Review, Papers and Proceedings* (May): 332–37.

Economides, N. 1996. "The Economics of Networks," *International Journal of Industrial Organization* 14 (October): 673–99.

Eisenach, J. A., and T. M. Lenard. 1999. *Competition, Innovation and the Microsoft Monopoly: Antitrust in the Digital Marketplace*, Kluwer Academic Publishers.

Farrell, J., and G. Saloner, 1985. "Standardization, Compatibility and Innovation," *Rand Journal of Economics* 16 (Spring): 70–83.

Fisher, F., 2000. "The *IBM* and *Microsoft* Cases: What's the Difference?" *American Economic Review* 90 (May): 180–83.

Gandal, N., 1994. "Hedonic Price Indexes for Spreadsheets and a Test for Network Externalities," *Rand Journal of Economics* 25 (Spring): 160–70.

Liebowitz, S. and S. Margolis, 1990. "The Fable of the Keys," *Journal of Law and Economics* 33 (April): 1–26.

Rohlfs, J., 1974. "A Theory of Interdependent Demand for a Communications Service,." *Bell Journal of Economics* 5 (Spring): 16–37.

Schmalensee, R., 2000. "Antitrust Issues in Schumpeterian Industries," *American Economic Review, Papers and Proceedings* 90 (May): 192–96.

Appendix

The Profit-Maximizing Network Access Price for a Monopolist

PRICE FOR A MONOPOLIST

Let N potential consumers be ranked in terms of their valuation v_i for a good when all consumers are expected to buy, with v_i distributed in the interval [0,100]. The anticipated surplus any buyer receives given the expected fraction f^e of subscribers is: $S_i^e = f^e v_i - p$. Equation (22.3), then implies:

$$p = 100f^e - 100f^e f \tag{22.A1}$$

The monopolist's revenues $pQ = R(Q)$, and costs $C(Q)$ are given respectively by:

$$R(Q) = 100f^e fN - 100f^e f^2 N \;\text{ and }\; C(Q) = F + cQ = F + cfN;\; F, c \geq 0 \tag{22.A2}$$

In any full expectations equilibrium we have $f^e = f$, so that $R(Q) = 100f^2 N - 100f^3 N$. Combining equations (22.A1) and (22.A2) with $f = f^e$, implies profit of:

$$\pi(f) = 100f^2 N - 100f^3 N - F - cfN$$

The necessary first-order condition for profit maximization is:

$$\frac{d\pi(f)}{df} = 0 \Rightarrow 200f - 300f^2 - c = 0$$

When $c = 0$, the solutions are: $f = 0$; and $f = 2/3$. When $c = \$11.11$, they are: $f = 0.0612$ and $f = 0.6055$.

23

Auctions: Basic Theory and Applications

Historians of the Roman Empire often refer to the year 193 AD as the year of the five emperors.[1] Following the death (by assassination) of Emperor Commodus in 192, the famed Praetorian Guard had arranged for the appointment of Pertinax as the new Roman emperor. However, Pertinax proved to be more honest and more devoted to the ascetic ways of former emperor, Marcus Aurelius, than the Guard had expected. In particular, Pertinax did not give the Guard the generous financial reward they deemed appropriate in return for proclaiming him emperor. Dissatisfaction grew quickly. Although he escaped an initial coup, his inability to placate the Guard led to a final confrontation on March 28, 193, in which Pertinax was killed. Then followed what Roman consul and historian, Dio Cassius, called "a most disgraceful business" in which "both the City and its entire empire were auctioned off."[2] The winner of this auction was Didius Julianus who ruled as emperor for an equally short time until his own assassination and decapitation prior to the ascension of Emperor Septimus Severus.

Of course, auctioning off cities and empires is a rare event. These days, however, the use of auctions is widespread. From the sale of master art works to the market for government bonds to the millions of transactions at on-line sites such as e-Bay, the auction process has become an increasingly common mechanism for awarding ownership and contracts. Indeed, it is probably the leading example of the market mechanism and economics articles and textbooks frequently refer to the "Walrasian auctioneer."[3]

It is somewhat surprising then that development of the formal theory of auctions and auction behavior is comparatively recent. However, the last two decades have made up for this with an explosion of auction research. In this chapter, we review some of the basic results of auction theory. We then show that analysis of auctions offers more than just formal theoretical insights into auction design and bidding strategies. It also offers some deep insights into imperfect competition.[4]

[1] See Scarre (1995), 150–223.
[2] See *Dio's Roman History, Book LXXIV*, translated by Earnest Cary (1960).
[3] See, for example, Loertscher (2008).
[4] Krishna (2010) provides an excellent and rigorous survey of modern auction theory. Klemperer (2003) surveys key results and their critical implications for industrial economics.

23.1 AUCTIONS: A TAXONOMY

Auctions may be categorized along two dimensions. One dimension concerns the auction design—the rules regarding bidding and what the winning bidder pays. The second dimension concerns the nature of the bidder valuations of the item(s) being auctioned. One possibility is that these valuations are totally private. Each individual bidder has his or her own willingness-to-pay for the item, totally unrelated to what others are willing to pay for it. The alternative is a common value auction. In this case, each individual may have an independent idea regarding an item's true worth, but ultimately that item has a market value that is common to all buyers.

Regarding auction design, there are four basic types: the English or ascending auction, the Dutch or descending auction, the first-price sealed bid auction, and the second-price sealed bid auction. This last case is sometimes referred to as a Vickrey auction in honor of the pioneer of auction theory, Nobelist William Vickrey. The rules for each of these auction designs are described below.

The English, or ascending, auction is essentially the type used by the Praetorian Guard. Bidders call out ever increasing bids until just one bidder remains. The last bidder then wins the auctioned good. The Dutch, or descending, auction is similar except that it works in reverse. In this case, the auctioneer starts with a high price and continues to lower it until a buyer is found. Both the English and Dutch auctions are open in the sense that bidders can observe each other' actions.

In contrast, the first-price and second-price sealed bid auctions are closed auctions. In each of these cases, bidders submit sealed or private bids for the item and the highest bid wins. In neither case do bidders observe the bids of others. The difference between the two is that in the first-price sealed bid auction, the winner pays precisely what was bid, while in the second-price case, the winning bid pays an amount only so high as the second-highest bid.

23.2 PRIVATE VALUES AUCTIONS AND THE REVENUE EQUIVALENCE THEOREM

All auctions, but perhaps most especially English ascending auctions are characterized by strategic interaction. Every bidder knows that the chances of winning the auction and the price that will be paid if the bidder does win is profoundly affected by the bids made by others. Precisely for this reason, it is natural to view auctions through the prism of game theory and to determine the auction's outcome by determining the Nash equilibrium strategy combination for this game. This is the approach adopted here.

We begin with the study of auctions in which bidders have independent private values. This analysis is relatively straightforward but it does require some work. That effort is worthwhile because the insights from private value auctions are substantial. Further, it is much easier to understand the key features of common value auctions once one has a foundation in auctions with private values.

23.2.1 Equilibrium Bidding Strategies in English and Second-Price Private Value Auctions

It is readily apparent that if bidders bid their true valuations, the English ascending auction and the second-price or Vickrey auction are formally identical. Suppose for example that