"STRATEGIC STANDARDIZATION IN TRADE WITH NETWORK EXTERNALITIES"

by

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Strategic Standardization in Trade with Network Externalities

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Abstract

This paper shows the effects on profits and consumer surplus of standardizing a good from which consumers derive greater utility the more consumers there are of a compatible good. The model is of a two-period, two-country world in which there is at most one firm developing the good in each country. In this framework one of the firms licensing its technology to other firms in the same country is a credible commitment to increase the output and thus the network of the licensed good. The results show that if the network externalities are large enough, licensing can increase the profit of the licensor even if there is no foreign competitor producing a similar good. If there is a foreign competitor, licensing increases profits of the licensor at the expense of the rival firm regardless of the level of network externalities. Therefore, because licensing increases profits of the licensing country at home and abroad, licensing in this framework is a strategic trade policy. In all cases licensing, by increasing the size of the network of compatible goods, increases both domestic and foreign consumer surplus.

1 Introduction

Network externalities arise when a consumer's utility from using a product increases the larger the network of compatible products. An example of a product for which users enjoy network externalities is personal computers, where there are both direct and indirect benefits from belonging to a large user base of compatible personal computers. The direct benefits include being able to trade data and programs easily with other users. The indirect benefits of a larger network of users of compatible personal computers are perhaps even greater. The indirect benefits include the following: a greater variety of software will be available, the more users there are; firms and individuals are more willing to invest in training, the more applicable it is; and the body of knowledge embodied in magazines and bulletin boards increases with the size of the user base.

This paper shows the results of licensing a product with network externalities to other firms in an attempt to create a *de facto* standard for the product. Within a trade context I am interested whether or not the domestic licensing of a standard can lead to a strategic gain *vis á vis* a foreign country. The total gain is measured both in terms of domestic profit and consumer surplus, so that the strategic licensing question is of interest to both the firm and the government.

A major motivation for this line of research is the contrasting experience of the U.S. and Japanese machine tool industries, as illustrated in the book Made in America, pp. 105-106:

> One of the most important obstacles to the development in the United States of a strong industry for numerically controlled (NC) machine tools was the proliferation of vendors producing the numerical controls themselves (as distinct from the lathes, milling machines, and other devices being controlled). No interface standards were developed, and as a result, incompatibility of controls became a major problem. Users

> hesitated about what products to buy, because today's purchase might not be able to communicate with tomorrow's. The fear of antitrust action held the machine-tool builders back from trying to standardize the interface.
>
> In Japan, by contrast, the design and manufacturing of the control part of the NC tools was concentrated in one company, FANUC, with the active encouragement of MITI. This not only led to economies of scale but also avoided the incompatibilities that plagued American machine-tool users. Machine-tool builders were relieved of the burden of developing their own controls, and FANUC's concentration on the electronic side of electromechanical products reduced direct competition between itself and the builders. FANUC gained 80 to 90 percent of the Japanese market for controls during the 1970s and 40 to 50 percent of the world market by the early 1980s.

The introduction of numerical controls made network externalities an important consideration for machine tool buyers because of similar network effects which exist with computers. Numerical controls require software skills which were not required with manual tools. In addition, it is easier to integrate a line of tools with standard interfaces. Finally, the electronics in the numerical controls made service much more complex. A greater network of compatible numerically controlled machine tools will lead to more skilled programmers, a wider variety of tools to integrate, and better service.

The scope of government action in the numerical control example is very broad, ranging from the very proactive role taken by MITI in encouraging a firm to develop the NC standard to the perceived reactive role of U.S. antitrust laws in discouraging standardization. While choosing a firm to develop a standard may not always be desirable or feasible, it is possible that relaxed antitrust laws with respect to standardization could increase U.S. welfare.[1]

A model of strategic standardization is developed below which could be applied to the machine

[1]In 1984 Congress passed the National Cooperative Research Act which allows more joint research and development of industry standards.

tool case. One firm develops a standard and licenses it to other firms in the same country. The results show an increase in welfare at the expense of a trading partner producing an incompatible product. Furthermore, in a dynamic framework under certain conditions it may even be profitable for a monopolist not facing foreign competition to license a proprietary technology.

Section 2 contains a description of recent literature concerned with the issues raised here. Section 3 contains a two-period, two-country model of equilibrium when there is either only one firm producing the good, or one firm in each country. Section 4 shows the effects of a firm licensing its proprietary technology in both the single-firm or the two-firm case.

2 Literature Review

Although there is a large literature concerning network externalities, strategic trade policy, and licensing, this is a first attempt to combine aspects of these areas. The existence of network externalities affects competition because consumers must consider not only the current network size, but also future sales, when making their purchase decision. Strategic trade policies are concerned with improving a country's welfare through a credible intervention in a domestic industry. Finally, there are examples in the literature where licensing a product is a strategic policy for a monopolist. This paper shows how a government, by actively encouraging a firm to license a standard for a product with network externalities, can improve domestic welfare.

The network externalities literature provides a framework within which to explore the effects of licensing to create a *de facto* standard. Katz and Shapiro (1985) use a one-period Cournot model to explore both the effects of network externalities on competition between firms and the compatibility decision that firms face. Their equilibrium concept, which they call Fulfilled Expectations Cournot Equilibrium, assumes that consumers first form expectations about the size of each network, and then firms engage in Cournot competition treating these expectations as given. There is a Cournot equilibrium for any given expectations, so the possible equilibria are arbitrarily restricted to those where consumers' expectations are fulfilled. Because there is only one period, consumers do not have to form expectations about the future size of the network that they plan to join and firms, when making compatibility decisions, do not have to take into account the effects of these decisions on future expectations.

In two later papers Katz and Shapiro (1986a, 1986b) use a two-period Bertrand model to introduce these dynamic effects. They show that a new technology which costs more in the first period has a "second-mover advantage" if it will be cheaper in the second period. First-period consumers expect the new technology to be more competitive in the second period and will thus be more inclined to buy it in the first period even when it is at a cost disadvantage because of the large expected network. The firm with the new technology can price its product so as to exploit the expectations of first-period consumers and become the dominant technology in both periods.

Brander and Spencer began the literature on strategic trade policy by showing how a government could use an export subsidy to credibly alter the conditions of Cournot competition in favor of a domestic firm competing against a foreign rival in a third market. In their model (1985) the export subsidy acts as a credible commitment enabling the domestic firm to effectively be a Stackelberg leader. As Eaton and Grossman (1986) pointed out, the success of this policy depends critically on the assumption of Cournot competition.

Several papers have combined aspects of the network externalities literature with those of the strategic trade policy literature. Krishna (1987) extends the strategic trade policy analysis described above to a model with network externalities to argue that credible subsidies can influence consumers' expectations of the network size and in turn improve the sales and profits of the home firm. Yanagawa (1990) introduces trade into the Katz and Shapiro (1985) framework. To solve the problem of multiple equilibria, which Katz and Shapiro solve by simply restricting the possible outcomes, he argues that high tariffs on foreign imports will eliminate any expectations, and thus realizations, of equilibria where the foreign firm is the only seller in the domestic market.

Finally, there is a separate literature analyzing strategic incentives to license proprietary technology. In the standard models, a monopolist has no incentive to license because monopoly profits are always at least as high as total duopoly profits. Papers by Farrell and Gallini (1986) and Shepard (1987) explore incentives for monopolists to license proprietary technology. In both papers licensing, by creating competition, is a credible commitment to either high quality or low prices. This commitment is necessary to induce potential consumers to sink setup costs without fear of *ex post* appropriation by the monopolist.

This paper contains a strategic trade policy model in which the government action consists of simply encouraging a firm to license a proprietary technology from which consumers derive network externalities. I use an altered version of the equilibrium concept of Katz and Shapiro (1985) within their dynamic framework (1986a,1986b). The results show that standardizing a product with network externalities can lead to increased domestic profit at the expense of a foreign trading partner as well as increased consumer surplus. In addition, even in the absence of foreign competition a firm may still want to license its proprietary technology. This implies a new incentive for a monopolist to license in addition to those in Farrell and Gallini (1986) and Shepard (1987).

3 Model

The starting point for this model is the reciprocal dumping model of Brander (1981). As in that model, there are two countries, Home and Foreign, separated by a transport cost, τ. The first model below is for one firm producing some good from which consumers derive network externalities. The monopolist sells the good at home and abroad. Then a foreign firm producing a similar good, which is incompatible with the home country's good, is added to the model. At most one firm in each country develops a technology which could be standardized. The existence of a transport cost in conjunction with the network externality provides some natural protection for each country's firm.

Competition with network externalities is modelled as in Katz and Shapiro (1985). However, to avoid the multiple equilibria resulting from their equilibrium concept, consumers form expectations differently here. Katz and Shapiro use a Fulfilled Expectations Cournot Equilibrium, where expectations were simply assumed to be rational. Here, firms engaging in Cournot competition produce first, based on the known level of demand, and then consumers form expectations based on the observed output. Consumers, expecting the network size to be equal to the level of output, purchase accordingly, and these expectations are fulfilled in equilibrium as the market clears. This framework is briefly explored in the appendix of Katz and Shapiro (1985).

The model has three periods, as in Katz and Shapiro (1986a, 1986b), to introduce dynamic effects. During period zero the firms make an entry decision. Having decided to enter each firm develops its respective standard, and in Section 4, one of the firms licenses its standard in period zero to other firms in the same country. In the subsequent two periods the goods are produced and sold.

3.1 Product

The product modelled is one for which there is a durable hardware component and a built-in interface component which could be standardized. The interface is broadly defined to be the component of the product which allows interaction of the hardware with software or a human operator. Examples include the operating system of a computer, the cassette format of a VCR, the keyboard of a typewriter, or the numerical control unit of a machine tool. The interface can either be developed by the individual hardware manufacturer, in which case the product is assumed to be incompatible with others, or be licensed, in which case it is compatible with other licensees. The interface is assumed to be proprietary so that only the products of licensees are compatible. Both the hardware and interfaces are assumed to be homogeneous. The only differentiable product characteristic of interest to consumers is whether or not the product is compatible with those of other firms.

The product is one for which the network externalities do not depend on the future availability of complementary goods such as computer software or videos. This implies that most of the network benefits are related to training, service, and general knowledge. Because these benefits are personnel-specific, I assume that there is no spillover of the network externalities between countries. A good example of this type of product is the machine tool, where the interface is the numerical control unit. The numerical controls must be custom-programmed for each task, so most of the benefits of being in a large network are derived from the size of the pool of programmers trained for the relevant numerical controls. The other benefits are derived from having better service and more spare parts available, the larger the network. These benefits are also mostly country-specific.

3.2 Demand

There is assumed to be one cohort of consumers in each period in each country. Each cohort can only consume in their own respective period. The size of each cohort is normalized to one. The demand curves shown below are similar to those of Katz and Shapiro (1985). They are derived in the Appendix.

$$\begin{aligned}
p_{1c} &= 1 - q_{1h} - q_{1f} + 2nq_{1c} + nq_{2c}^{e} && (1)\\
p_{2c} &= 1 - q_{2h} - q_{2f} + nq_{1c} + nq_{2c} && (2)\\
p_{1c}^{*} &= 1 - q_{1h}^{*} - q_{1f}^{*} + 2nq_{1c}^{*} + nq_{2c}^{*e} && (3)\\
p_{2c}^{*} &= 1 - q_{2h}^{*} - q_{2f}^{*} + nq_{1c}^{*} + nq_{2c}^{*} && (4)
\end{aligned}$$

where:

- p_{tc} = price of good sold at home in period t (t=1,2) by firm c =h(home),f(foreign).
- p^*_{tc} = price of good sold abroad in period t by firm c.
- q_{tc} = output of good sold at home in period t by firm c.
- q^*_{tc} = output of good sold abroad in period t by firm c.
- q^e_{2c} = expected levels of period-two sales at home by firm c.
- q^{*e}_{2c} = expected levels of period-two sales abroad by firm c.
- n = level of network externalities from total size of good's network, $0 \leq n \leq 1$.

Demand depends on both the price of the good and the benefits which the consumer expects to derive from the network compatible with the product she is buying. Note that there is no discounting, so that buyers at home derive network externalities $2nq_{1c}$ from first-period sales of the good they purchase plus nq^e_{2c} from the expected second-period purchases of the same good. In addition the goods are durable and do not depreciate. Note also that the networks in each country are independent, insofar as consumers only derive benefits from the network in their own country.

The hedonic price is the price of the good net of network externalities. For example the hedonic price of either good at home in period two equals:

$$\phi_2 = p_{2c} - nq_{1c} - nq_{2c}. \tag{5}$$

$$\text{From (2)}: \phi_2 = 1 - q_{2h} - q_{2f}. \tag{6}$$

Note that ϕ_{2h} is equivalent to ϕ_{2f} if both firms sell positive quantities at home. A similar analysis can be done for the first period as well as for the hedonic price of the goods sold in the foreign country. Because consumers have "unit demands" and the size of each consumer cohort is normalized to 1, $0 \leq q_{th} + q_{tf} \leq 1$, so $0 \leq \phi_{tc} \leq 1$ for $t = 1, 2$ and $c = h, f$.

3.3 Profits

Each firm faces a fixed cost F of developing a standard, and a constant marginal cost c_o of production. The profit functions are:

$$\begin{aligned}
\pi_{1h} &= q_{1h}(p_{1h} - c_o) + q_{1h}^*(p_{1f}^* - c_o - \tau) && (7)\\
\pi_{1f} &= q_{1f}(p_{1f} - c_o - \tau) + q_{1f}^*(p_{1f}^* - c_o) && (8)\\
\pi_{2h} &= q_{2h}(p_{2h} - c_o) + q_{2h}^*(p_{2f}^* - c_o - \tau) && (9)\\
\pi_{2f} &= q_{2f}(p_{2f} - c_o - \tau) + q_{2f}^*(p_{2f}^* - c_o) && (10)\\
\pi_h &= \pi_{1h} + \pi_{2h} - F && (11)\\
\pi_f &= \pi_{1f} + \pi_{2f} - F. && (12)
\end{aligned}$$

3.4 Welfare

The welfare measure for the home country is developed below. The measure for the foreign country is analogous.

Consumer surplus is derived as in Katz and Shapiro (1985). Let Q_t equal the total quantity sold at home in period t. If there is a home good and a foreign good selling in the home market, $Q_1 = q_{1h} + q_{1f}$, and $Q_2 = q_{2h} + q_{2f}$. The demand curve in period 2, from equation (2), is $Q_2 = 1 - p_{2c} + nq_{1c} + nq_{2c}$. From equation (5), $Q_2 = 1 - \phi_2$. Consumer net surplus in period two at home is thus:

$$CS_2(Q_2) = \int_{1-Q_2}^{1} (1 - \phi_2)d\phi_2 = \frac{Q_2^2}{2} \tag{13}$$

and in period one is $CS_1(Q_1) = \frac{Q_1^2}{2}$. Thus consumer surplus is simply a function of the total quantity sold in the market. The greater the level of network externalities, n, the more will be sold, and the greater the consumer surplus. For the purpose of computing home welfare, profits are simply going to be the home firm's profits,

$$\pi_h = \pi_{1h} + \pi_{2h} - F. \tag{14}$$

Home welfare is the sum of home consumer surplus and profit:

$$W(Q_1, Q_2) = \pi_{1h} + \pi_{2h} - F + CS_1(Q_1) + CS_2(Q_2). \tag{15}$$

3.5 Equilibrium without Foreign Competition

The model developed in this section assumes that there is only one firm, located in the home market, producing the good. This firm sells at home as well as abroad. Because there is no spillover of the network externalities between the two countries and the transport cost is assumed to be high enough to separate the two countries, the monopolist can treat the markets independently. Therefore, below I simply show the solution for sales in the home market. The solution for sales in the foreign market is identical, with the inclusion of the transport cost which the home firm faces for exports.

In each market the home firm determines in period zero whether or not to enter the market. In the following two periods the firm produces the profit-maximizing amount, which is observed by consumers before they make their purchase decision. Consumers in both periods make their purchase decisions based on the expectations of the total network size in their country. In the first period consumers base their expectations on the observed first-period production level and rational expectations of second-period sales. In the second period, consumers observe both the existing network size and the second-period production level before making their purchase decisions. Both the firm and consumers solve recursively given the known production technology and demand parameters, so that the firm produces a profit-maximizing amount consistent with demand, and consumers expectations of future production are fulfilled.

3.5.1 Period 2

In the home market in period two, the monopolist maximizes second-period profit in second-period output to determine the optimal level of second-period output as a function of first-period output:

$$\begin{aligned}
\mathrm{Max}_{q_{2h}} \pi_{2h} &= q_{2h}(1 - q_{2h} + nq_{1h} + nq_{2h} - c_o) \\
\mathrm{FOC}: \frac{\partial \pi_{2h}}{\partial q_{2h}} &= 1 - 2q_{2h} + nq_{1h} + 2nq_{2h} - c_o = 0 \\
q_{2h}(q_{1h}) &= \frac{1 + nq_{1h} - c_o}{2(1-n)}.
\end{aligned}$$

3.5.2 Period 1

Consumers are rational, so $q_{2h}^e = q_{2h}(q_{1h})$. Since first-period production has an effect on second-period profits via the network externalities, in the first period the monopolist maximizes total profit in first-period sales:

$$\begin{aligned}
\text{Max}_{q_{1h}}\pi_h &= q_{1h}(1 - q_{1h} + 2nq_{1h} + nq_{2h}(q_{1h}) - c_o) + \\
&\quad q_{2h}(q_{1h})(1 - q_{2h}(q_{1h}) + nq_{1h} + nq_{2h}(q_{1h}) - c_o) \\
\text{FOC}: \frac{d\pi_h}{dq_{1h}} &= \frac{\partial \pi_{1h}}{\partial q_{1h}} + \frac{\partial \pi_{1h}}{\partial q_{2h}}\frac{dq_{2h}}{dq_{1h}} + \frac{\partial \pi_{2h}}{\partial q_{1h}} + \frac{\partial \pi_{2h}}{\partial q_{2h}}\frac{dq_{2h}}{dq_{1h}} = 0 \\
q_{1h}(n, c_o) &= \frac{2(1-c_o)}{4 - 12n + 5n^2} \\
q_{2h}(n, c_o) &= \frac{1 - c_o + nq_{1h}(n, c_o)}{2(1-n)}.
\end{aligned}$$

Note that at $n = .4$ the denominator of $q_{1h}(n, c_o)$ and $q_{2h}(n, c_o)$ equals 0. For $n > .4$, the demand curves slope upward. Therefore, the network externalities are restricted to $n < .4$. The monopolist performs a similar maximization for sales in the foreign country to determine $q^*_{1h}(n, c_o, \tau)$ and $q^*_{2h}(n, c_o, \tau)$.

3.5.3 Period 0

The monopolist enters the market if

$$\pi_h = \pi_{1h}(n, c_o, \tau) + \pi_{2h}(n, c_o, \tau) - F \geq 0.$$

3.5.4 Simulations

The results of some simulations are in Table 1. The first column of each of the three groups is the no-licensing case. Within each column, for a given marginal cost and network externality, the prices abroad are always higher than those at home because of the transport cost. However, the price differential is less than the transport cost, τ, because the monopolist absorbs some of the transport costs, so there is no possibility of arbitrage. In addition, in each country the sales in the first period are always greater than those in the second. The price is relatively low in the first period in order to be able to exploit the network benefits of a larger network in the second period. Finally, as the network externality rises from group one to group two in Table 1, the level of sales and profits rise because consumers are more willing to buy, the greater the benefits that they enjoy.

3.6 Equilibrium with Foreign Competition

A foreign firm selling a product which is incompatible with that of the home firm is now introduced into the model. In period zero the firms decide whether or not to enter the market. In each subsequent period of production, the home and foreign firms engage in Cournot competition in each market. In the first period of production, the firms produce the optimal amount based on the known demand parameters. Consumers base their first-period purchases on the amount produced by the firms and rational expectations of second-period purchases, which will be fulfilled in equilibrium. In the second period the firms again produce the optimal amount based on demand. Consumers base their second-period purchases on the amount produced by each firm and the size of the existing networks.

Because the countries are separated by the transport cost and consumers only derive network externalities from the domestic network, competition in each country is independent of the other country. Because the firms and countries are assumed to be symmetrical, the outcome in each country is symmetrical. Competition in the home country is modelled below.

3.6.1 Period 2

In the second period at home the domestic firm performs the following maximization:

$$\begin{aligned}
\text{Max}_{q_{2h}} \pi_{2h} &= q_{2h}(1 - q_{2h} - q_{2f} + nq_{1h} + nq_{2h} - c_o) \\
\text{FOC}: \frac{\partial \pi_{2h}}{\partial q_{2h}} &= 1 - 2q_{2h} - q_{2f} + nq_{1h} + 2nq_{2h} - c_o = 0 \\
q_{2h}(q_{2f}, q_{1h}) &= \frac{1 - q_{2f} + nq_{1h} - c_o}{2(1-n)} \qquad (16) \\
\text{and } q_{2f}(q_{2h}, q_{1f}) &= \frac{1 - q_{2h} + nq_{1f} - c_o - \tau}{2(1-n)} \text{ by symmetry.} \qquad (17)
\end{aligned}$$

Equations (16) and (17) are the standard downward-sloping Cournot reaction curves. If the marginal cost increases, both firms' reaction curves shift in. If the transport cost increases, the foreign reaction curve shifts in and the home firm's sales increase at the expense of the foreign firm's sales. If it shifts in enough so that the curves no longer intersect, then there will be no intra-industry trade. In this section it is assumed that the transport cost is low enough so that there is trade. Solving the reaction functions simultaneously gives $q_{2h}(q_{1h}, q_{1f})$ and $q_{2f}(q_{1h}, q_{1f})$.

3.6.2 Period 1

Consumers are rational, so $q^e_{2h} = q_{2h}(q_{1h}, q_{1f})$ and $q^e_{2f} = q_{2f}(q_{1h}, q_{1f})$. As in the monopolist case each firm produces an amount in the first period which maximizes total profits in the respective market.

$$\begin{aligned}
\text{Max}_{q_{1h}} \pi_h &= q_{1h}(1 - q_{1h} - q_{1f} + 2nq_{1h} + nq_{2h}(q_{1h}, q_{1f}) - c_o) + \qquad (18)\\
&\quad q_{2h}(q_{1h}, q_{1f})(1 - q_{2h}(q_{1h}, q_{1f}) - q_{2f}(q_{1h}, q_{1f}) + nq_{1h} + nq_{2h}(q_{1h}, q_{1f}) - c_o)\\
\text{FOC} : \frac{\partial \pi_h}{\partial q_{1h}} &= \frac{\partial \pi_{1h}}{\partial q_{1h}} + \frac{\partial \pi_{1h}}{\partial q_{2h}}\frac{\partial q_{2h}}{\partial q_{1h}} + \frac{\partial \pi_{2h}}{\partial q_{1h}} + \frac{\partial \pi_{2h}}{\partial q_{2h}}\frac{\partial q_{2h}}{\partial q_{1h}} + \frac{\partial \pi_{2h}}{\partial q_{2f}}\frac{\partial q_{2f}}{\partial q_{1h}} = 0\\
q_{1h}(q_{1f}) &= q_{1h}(n, c_o, \tau, q_{1f}) \qquad (19)\\
\text{and } q_{1f}(q_{1h}) &= q_{1f}(n, c_o, \tau, q_{1h}) \text{ by symmetry.} \qquad (20)
\end{aligned}$$

Equations (19) and (20) are the Cournot reaction curves for the first period. The slopes of the first-period reaction curves converge, like closing scissors, as n increases. When $n = .197$ the reaction curves are parallel. If $\tau = 0$ the reaction curves coincide and the two firms would split the total output in half. For $\tau > 0$ the foreign reaction curve shifts inwards so that the two curves don't touch, and the home firm, facing a perfectly elastic demand curve, is unrestricted in output up to the corner solution. For $n > .197$ the first-period reaction curves switch relative slopes so that the equilibrium is no longer stable. Therefore I limit analysis to $n < .197$.

Solving the reaction curves simultaneously gives:

$$\begin{aligned}
q_{1h} &= q_{1h}(n, c_o, \tau)\\
q_{1f} &= q_{1f}(n, c_o, \tau)\\
\text{and } q_{2h}(q_{1h}, q_{1f}) &= q_{2h}(n, c_o, \tau)\\
q_{2f}(q_{1h}, q_{1f}) &= q_{2f}(n, c_o, \tau).
\end{aligned}$$

As long as n is less than .197, if there is a positive transport cost $\frac{\partial \pi_{tf}}{\partial n} < 0$, implying that network externalities, combined with transport costs, provide natural protection for the domestic firm in both periods. For this range of n, $\frac{\partial \pi_{th}}{\partial n} > 0$, meaning that the home firm's profits at home increase with the level of the network externalities in both periods. The network effects magnify for the home firm the advantage of being the "low-cost" firm due to the presence of the transport cost.

3.6.3 Period 0

The firms solve the system recursively and enter if total profits net of the fixed cost are greater than or equal to zero.

$$\pi_h = \pi_{1h}(n, c_o, \tau) + \pi_{2h}(n, c_o, \tau) - F \geq 0$$

$$\pi_f = \pi_{1f}(n, c_o, \tau) + \pi_{2f}(n, c_o, \tau) - F \geq 0.$$

3.7 Simulations

Tables 2 and 3 show simulated results for different levels of network externalities. The first group of results in each table show the symmetric results for trade with one firm in each country. The columns Home and Foreign in the table correspond in the top part of the tables to quantities and profits of the respective firms, and in the bottom part to welfare results for the respective markets. For example in Table 3 the home firm had sales of .43 (q_{1h}) in Home and .20 (q_{1h}^*) in Foreign in period one, whereas the foreign firm's sales in period one were .20 (q_{1f}) in Home and .43 (q_{1f}^*)

in Foreign. The consumer surplus in each market is .36, each firm's total profit is .30, and each country's welfare is .66.

Due to the network externalities and transport costs, in each country imports are lower than domestic sales regardless of the magnitude of n. In addition, as in the monopoly case first-period sales in each country are always larger than second-period sales by the same firm as firms raise prices to exploit the market power resulting from their network size. In this case there is the additional strategic benefit of building a large network early to decrease later sales of the rival firm. Finally, we see the reciprocal dumping results of Brander (1981) where each firm exports their product at a lower net price than they charge in their domestic market. The reason is that an exported good sold at a lower price only depresses the price on the inframarginal goods of the other firm. Therefore, as long as the price minus marginal cost is greater than the transport cost, the firm exports. The foreign rival makes the same calculation about the home market and the result is reciprocal dumping. Note that the difference in prices of the same good in different markets is never greater than the transport cost, so there is no possibility of international arbitrage.

4 Licensing

In this section the home firm licenses to other domestic firms, both when there is no foreign competition and when there is a foreign competitor, as a strategic move to increase profits by increasing the network of compatible goods. In general, licensing is a commitment to increase the total output of the product being licensed when the licensees engage in symmetric Cournot competition. The amount produced is a positive function of the number of licensees. If there are no network externalities, standard Cournot results show that a monopolist would never license its technology, because monopoly profits are always at least as high as the sum of the profits of two or more licensees engaged in Cournot competition.[2] Therefore, even if the license fee were equal to the net profits of the licensees, the monopolist would not want to license. When there is a foreign rival the home firm would want to license its technology even without the network effects.

In Section 4.1 below it is shown that in a dynamic setting with network externalities licensing can be a profitable strategy even for a firm without foreign competition. Consumer surplus also increases, so total welfare can increase due to licensing. Section 4.2 shows that with a foreign competitor the strategic effects of licensing magnify the welfare benefits shown in Section 4.1.

4.1 Licensing without Foreign Competition

As noted by Katz and Shapiro (1986b), in the presence of network externalities a firm cannot credibly precommit to a high monopoly output in the second period, because of a credibility problem which is the opposite of that of the durable goods monopolist (Coase, 1972). In the durable goods monopolist case, the monopolist cannot credibly convince consumers that it will keep prices high in the second period, resulting in lower first-period sales in anticipation of lower future prices. With network externalities present the monopolist has the problem that it cannot credibly convince first-period consumers that it will keep *output* high in period two. The monopolist would

[2]This is because the best that two or more licensees can do is collude and produce the monopoly level of output, earning the same total profit as a monopolist would earn. If the licensees compete in a non-collusive fashion such as Cournot, the total sales are greater than a monopolist's sales would be, and the total profits are lower.

like to commit to high output in period two in order to convince period one consumers that the ultimate network that they will belong to will be large. However, having convinced period one consumers of this, it may no longer be in the best interest of the monopolist to actually produce a high output in the second period. Consumers with rational expectations will foresee this, and in the first period will not expect the level of future sales that the monopolist claims will be produced.

A credible commitment such as licensing for the second period is needed to convince consumers that there will be a high second-period output. With high enough network externalities this is a profitable strategy for the monopolist. For very high levels of network externalities, it is shown that licensing production for both periods is profitable.

4.1.1 Model

The first case is where the monopolist grants licenses in period zero for second-period production in order to convince first-period consumers that the future network will be large. These licenses cannot be revoked by the monopolist after the first period. In period zero the monopolist will choose and announce the licensing parameters for period two. These parameters are k_2, the number of licensees, and L_2, the license fee, which is a fixed fee instead of a royalty due to the standard monitoring problems. The monopolist will either be one of the k_2 licensees in period two, indistinguishable from the rest in the second-period Cournot competition, or will be acting as an independent lab in period two, not producing but simply collecting license fees. All of the monopolist's first-period output is compatible with the licensees' second-period output and thus is a part of the network.

Licensing by a monopolist is only profitable if there are network externalities and a dynamic setting. If there is only one period, even with network externalities present, profits are greater for a monopolist than the total profit of two or more licensees engaged in Cournot competition. If there are two periods, the presence of network externalities provides an interdependency between the periods. Without network externalities each period is a separate game, and once again a monopoly can do at least as well as two licensees. With the network externalities in a two period game, increased second-period expected sales have a positive effect on first-period sales and overall profits, and licensing can be a profitable strategy for a monopolist.

The new profit and output equations at home are:

$$
\begin{aligned}
q_{2h} &= \sum_{i=1}^{k_2} q_{i2h} = k_2 \cdot q_{i2h} \text{ by symmetry} \\
\pi_{i2h} &= q_{i2h}(1 - q_{2h} + nq_{1h} + nq_{2h} - c_o) - L_2 \\
\pi_{2h} &= k_2 \cdot L_2 = q_{2h}(1 - q_{2h} + nq_{1h} + nq_{2h} - c_o) \\
\pi_{1h} &= q_{1h}(1 - q_{1h} + 2nq_{1h} + nq_{2h}^e - c_o) \\
\pi_h &= \pi_{1h} + \pi_{2h} - F
\end{aligned}
$$

where q_{2h} represents the total sales of the good at home in period two, π_{i2h} is the profit of the ith licensee, and π_{th} is the profit of the licensor. The licensor extracts all of the profit from the licensee, i.e. $L_2 = q_{i2h}(1 - q_{2h} + nq_{1h} + nq_{2h} - c_o)$ and thus $\pi_{i2h} = 0$. These equations can be solved for the home market as in the monopoly equilibrium above.

4.1.2 Period 2

In period two each licensee maximizes profit:

$$\begin{aligned}
\text{Max}_{q_{i2h}} \pi_{i2h} &= q_{i2h}(1 - q_{2h} + nq_{1h} + nq_{2h} - c_o) - L_2 \\
\text{FOC}: \frac{\partial \pi_{i2h}}{\partial q_{i2h}} &= 1 - q_{-i2h} - 2q_{i2h} + nq_{1h} + nq_{-i2h} + 2nq_{i2h} - c_o = 0 \text{ where } q_{-i2h} = \sum_{j \neq i}^{k_2} q_{j2h} \\
&= 1 - (k_2+1)q_{i2h} + nq_{1h} + (k_2+1)nq_{i2h} - c_o = 0 \text{ where } q_{j2h} = q_{i2h} \\
q_{i2h}(q_{1h}) &= \frac{1 + nq_{1h} - c_o}{(k_2+1)(1-n)} \\
q_{2h}(q_{1h}) &= k_2 \cdot \frac{1 + nq_{1h} - c_o}{(k_2+1)(1-n)}.
\end{aligned}$$

4.1.3 Period 1

With rational expectations, $q_{2h}^e = q_{2h}(q_{1h})$. In period one the licensor chooses output to maximize its first-period profit as well as the sum of all second-period license fees:

$$\begin{aligned}
\text{Max}_{q_{1h}} \pi_h &= q_{1h}(1 - q_{1h} + 2nq_{1h} + nq_{2h}(q_{1h}) - c_o) + q_{2h}(q_{1h})(1 - q_{2h}(q_{1h}) + nq_{1h} + nq_{2h}(q_{1h}) - c_o) \\
\text{FOC}: \frac{d\pi_h}{dq_{1h}} &= \frac{\partial \pi_{1h}}{\partial q_{1h}} + \frac{\partial \pi_{1h}}{\partial q_{2h}} \frac{dq_{2h}}{dq_{1h}} + \frac{\partial \pi_{2h}}{\partial q_{1h}} + \frac{\partial \pi_{2h}}{\partial q_{2h}} \frac{dq_{2h}}{dq_{1h}} = 0
\end{aligned}$$

The firm solves the first-order condition to determine first-period production, $q_{1h}(n, c_o, k_2)$, and then can solve backwards for $q_{2h}(n, c_o, k_2)$. The firm solves the same game abroad to determine $q_{1h}^*(n, c_o, k_2, \tau)$ and $q_{2h}^*(n, c_o, k_2, \tau)$.

4.1.4 Period 0

In period zero the firm determines the profit-maximizing k_2 given the value of n, c_o, and τ:

$$\text{Max}_{k_2}\pi_h = \pi_{1h}(n, c_o, k_2, \tau) + k_2 \cdot \pi_{i2h}(n, c_o, k_2, \tau)$$

and L_2 equals the profit of the licensee, π_{i2h}.

If the network externalities are high enough, it becomes profitable to license to at least one other firm in the second period. For values of n greater than .188 it is the case that second-period licensing is profitable. The increased expected network size in period two makes the product attractive enough in period one so that first-period profit increases outweigh the second-period profit decreases from having the licensees produce more than the monopolist would. However, licensing is a time-inconsistent policy for the monopolist. Having convinced first-period consumers that sales will be higher in the second period, it is always in the interest of the monopolist to revoke the licenses if possible. This is because in the second period the monopolist would produce less than the licensees would and earn higher profits than the sum of the licensees. Therefore, for high values of n licensing for the second period is only profitable if consumers and the licensees can be convinced that the licenses cannot be revoked.

The monopolist could also commit to licensing to k firms in period zero where the license is now valid for both periods. In this case total first-period sales are $q_{1h} = \sum_{i=1}^{k} q_{i1h}$, and first-period licensor profit is $\pi_{1h} = k \cdot L_1$. The solution to this model is similar to that above. For low values of the network externalities, licensing decreases total profits. The reason is that total profits and first-period profits are concave in first-period output, while second-period profits are increasing in first-period output because of the network effect. At low levels of n, the decrease in first-period profits from increasing first-period output above the profit-maximizing level outweighs the positive effect on second-period profits. As n increases, the increase in second-period profits from higher first-period sales outweighs the negative effects on first-period profits. Only if n is greater than .262 does this happen.

4.1.5 Simulations

The results of simulations are in Table 1. The first group of results is for a level of the network externalities below the .188 cutoff. The second column of this group shows the case of having two licensees in the second period. Note that first-period sales and profits for the licensor go up in both countries because of expectations of higher second-period sales. However, the increase in second-period sales due to licensing lowers second-period profit and total profits for the licensor so that licensing is not profitable. The second group of results in Table 1 are for a level of network externalities above the cutoff. In this case if $k_2 = 2$ the increase in first-period profits outweighs the second-period losses, and total profits are greater than they would be without licensing. Note that consumer surplus is always greater with licensing than it would be without licensing, due to the increased output.

In the third group of Table 1, n is greater than the minimum level required for profitable licensing in both periods. Column 3 of the third group shows that profits increase from first-period licensing at this level of n. However, profits are not as high as with only second-period licensing (Column 2) for these parameter values. The marginal cost was increased to .7 for this example to avoid corner solutions.

4.2 Licensing with Foreign Competition

This section examines the effects of licensing when there is a foreign rival firm. It is assumed that the foreign firm is not a licensee of the home firm in order to show how licensing affects competition. The presence of a foreign competitor means that not only are there direct effects on profits from licensing, there are also strategic effects from licensing. Without network externalities, in Cournot competition, the total output and profits of two licensees competing against another firm is greater than if only the potential licensor is competing against the other firm. Therefore, licensing has a direct effect on current profits.

Due to the presence of network externalities in this dynamic setting, licensing also has strategic effects. Licensing in the first period results in greater first-period output than the licensor would have produced alone. Because of the network externalities an increase in first-period output makes the product more attractive in the second period. This shifts out the reaction curve of the licensed good in the second period, increasing sales and profits at the expense of the rival firm. Therefore, in the taxonomy of Fudenberg and Tirole (1984) first-period licensing is a "top-dog" strategy for the second period. Similarly, credible second-period licensing, announced in period zero, increases the expected network facing first-period consumers. This shifts out the first-period reaction curve of the licensed good and will thus increase first-period profits of the licensor.

4.2.1 The Model

The analysis below is for competition in the home country, which is symmetric to that of the foreign country except for the incidence of the transport cost. The new output variables and profit functions for the home firms at home are as follows:

$$
\begin{aligned}
q_{2h} &= \sum_{i=1}^{k_2} q_{i2h} = k_2 \cdot q_{i2h} \quad \text{by symmetry} \\
\pi_{i2h} &= q_{i2h}(1 - q_{2h} - q_{2f} + nq_{1h} + nq_{2h} - c_o) - L_2 \\
\pi_{2h} &= k_2 \cdot L_2 = q_{2h}(1 - q_{2h} - q_{2f} + nq_{1h} + nq_{2h} - c_o) \\
q_{1h} &= \sum_{i=1}^{k_1} q_{i1h} = k_1 \cdot q_{i1h} \quad \text{by symmetry} \\
\pi_{i1h} &= q_{i1h}(1 - q_{1h} - q_{1f} + 2nq_{1h} + nq_{2h}^e - c_o) - L_1 \\
\pi_{1h} &= k_1 \cdot L_1 = q_{1h}(1 - q_{1h} - q_{1f} + 2nq_{1h} + nq_{2h}^e - c_o) \\
\pi_h &= \pi_{1h} + \pi_{2h} - F.
\end{aligned}
$$

Once again L_t is set equal to the licensees' profits. If there is first-period licensing then $k = k_1 = k_2$, where the number of licensees is assumed constant for both periods. If there is only second-period licensing then $k_1 = 1$.

The analysis for period two is independent of whether or not there is licensing for period one.

4.2.2 Period 2

In the second period, each licensee maximizes:

$$
\begin{aligned}
\mathrm{Max}_{q_{i2h}} \pi_{i2h} &= q_{i2h}(1 - q_{2h} - q_{2f} + nq_{1h} + nq_{2h} - c_o) - L_2 && (21) \\
\mathrm{FOC}: \frac{\partial \pi_{i2h}}{\partial q_{i2h}} &= 1 - q_{-i2h} - 2q_{i2h} - q_{2f} + nq_{1h} + nq_{-i2h} + 2nq_{i2h} - c_o = 0 \quad \text{where } q_{-i2h} = \sum_{j \neq i}^{k_2} q_{j2h} \\
&= 1 - (k_2+1)q_{i2h} - q_{2f} + nq_{1h} + (k_2+1)nq_{i2h} - c_o = 0 \text{ where } q_{j2h} = q_{i2h} \\
q_{i2h}(q_{2f}, q_{1h}) &= \frac{1 + nq_{1h} - q_{2f} - c_o}{(k_2+1)(1-n)} && (22) \\
\text{and } q_{2f}(q_{2h}, q_{1f}) &= \frac{1 + nq_{1f} - q_{2h} - c_o - \tau}{(k_2+1)(1-n)} \text{ by symmetry.} && (23)
\end{aligned}
$$

Then one solves the reaction functions (22) and (23) for $q_{i2h}(q_{1h}, q_{1f})$, $q_{2f}(q_{1h}, q_{1f})$, and $q_{2h}(q_{1h}, q_{1f}) = k_2 \cdot q_{i2h}$.

4.2.3 Period 1

Consumers are rational, so $q_{2h}^e = q_{2h}(q_{1h}, q_{1f})$ and $q_{2f}^e = q_{2f}(q_{1h}, q_{1f})$. Here it matters whether or not there is licensing for the first period.

With first-period licensing, in period one each of the k licensees maximizes their total profit in first-period output:

$$\begin{aligned}
\text{Max}_{q_{i1h}}\pi_{ih} &= q_{i1h}(1 - q_{1h} - q_{1f} + 2nq_{1h} + nq_{2h}(q_{1h}, q_{1f}) - c_o) + \\
& q_{i2h}(q_{1h}, q_{1f})(1 - q_{2h}(q_{1h}, q_{1f}) - q_{2f}(q_{1h}, q_{1f}) + nq_{1h} + nq_{2h}(q_{1h}, q_{1f}) - c_o) \\
\text{FOC} : \frac{\partial \pi_{ih}}{\partial q_{i1h}} &= \frac{\partial \pi_{i1h}}{\partial q_{i1h}} + \frac{\partial \pi_{i1h}}{\partial q_{1h}}\frac{\partial q_{1h}}{\partial q_{i1h}} + \frac{\partial \pi_{i1h}}{\partial q_{2h}}\frac{\partial q_{2h}}{\partial q_{1h}}\frac{\partial q_{1h}}{\partial q_{i1h}} + \\
& \frac{\partial \pi_{i2h}}{\partial q_{i1h}} + \frac{\partial \pi_{i2h}}{\partial q_{1h}}\frac{\partial q_{1h}}{\partial q_{i1h}} + \frac{\partial \pi_{i2h}}{\partial q_{2h}}\frac{\partial q_{2h}}{\partial q_{1h}}\frac{\partial q_{1h}}{\partial q_{i1h}} + \frac{\partial \pi_{i2}}{\partial q_{2f}}\frac{\partial q_{2f}}{\partial q_{1h}}\frac{\partial q_{1h}}{\partial q_{i1h}} = 0
\end{aligned}$$

Now one can solve in the typical fashion for $q_{i1h}(n, k, c_o, \tau)$, $q_{1f}(n, k, c_o, \tau)$, and $q_{1h}(n, k, c_o, \tau) = k \cdot q_{i1h}$. By substitution one can then solve for $q_{i2h}(n, k, c_o, \tau)$, $q_{2f}(n, k, c_o, \tau)$, and $q_{2h}(n, k, c_o, \tau) = k \cdot q_{i2h}$.

For second-period only licensing, where $k_1 = 1$, the licensor performs the following first-period maximization:

$$\begin{aligned}
\text{Max}_{q_{1h}}\pi_{h} &= q_{1h}(1 - q_{1h} - q_{1f} + 2nq_{1h} + nq_{2h}(q_{1h}, q_{1f}) - c_o) + \\
& q_{2h}(q_{1h}, q_{1f})(1 - q_{2h}(q_{1h}, q_{1f}) - q_{2f}(q_{1h}, q_{1f}) + nq_{1h} + nq_{2h}(q_{1h}, q_{1f}) - c_o) \\
\text{FOC} : \frac{\partial \pi_{h}}{\partial q_{1h}} &= \frac{\partial \pi_{1h}}{\partial q_{1h}} + \frac{\partial \pi_{1h}}{\partial q_{2h}}\frac{\partial q_{2h}}{\partial q_{1h}} + \frac{\partial \pi_{2h}}{\partial q_{1h}} + \frac{\partial \pi_{2h}}{\partial q_{2h}}\frac{\partial q_{2h}}{\partial q_{1h}} + \frac{\partial \pi_{2h}}{\partial q_{2f}}\frac{\partial q_{2f}}{\partial q_{1h}} = 0
\end{aligned}$$

Once again the relevant quantity variables can be solved for in the normal fashion. Regardless of which period licensing takes place in, the variables for sales abroad are calculated in the same way as they are at home.

4.2.4 Period 0

In period zero the licensor determines the profit-maximizing number of licensees and the optimal license fees. If there is licensing in both periods then the licensor solves:

$$\mathrm{Max}_k \pi_h = k \cdot \pi_{i1h}(n, c_o, k, \tau) + k \cdot \pi_{i2h}(n, c_o, k, \tau)$$

and L_t equals the profit of licensees, π_{ith}, in each period. If there is only licensing in the second period then the licensor solves:

$$\mathrm{Max}_{k_2} \pi_h = \pi_{1h}(n, c_o, k_2, \tau) + k_2 \cdot \pi_{i2h}(n, c_o, k_2, \tau).$$

and L_2 equals π_{i2h}.

4.2.5 Simulations

The results are that with licensing in either period, for any level of network externalities or transport cost, profits increase from licensing. Tables 2 and 3 show the results of some simulations for different values of n. The first group in each table shows the symmetrical results of neither country having the standard licensed. The second group shows the results of profit-maximizing licensing for the second period only. For all n, home profits and consumer surplus would be greater than without licensing. While foreign consumer surplus would be greater than if the home firm hadn't licensed as a result of increased total sales, the foreign firm's profits would be lower for all levels of n, leading to an overall decrease in foreign welfare resulting from home licensing.

Licensing, while increasing the consumer surplus of foreign countries, is a beggar-thy-neighbor policy with respect to the foreign country's profits. The result of first-period licensing is in the third group of results in each table. Home profits and consumer surplus would be greater than with no licensing or only second-period licensing. Foreign profits would be even lower while foreign consumer surplus would be even greater than with only second-period licensing. For all levels of n, licensing for both periods results in the greatest increases in home welfare and largest decreases in foreign welfare.

It is also interesting to note the effects of licensing and the magnitude of the network externalities effect on the composition of sales. As n increases, the foreign firm's sales in Home decrease to zero due to licensing. The reason is that the foreign firm has more difficulty overcoming the transport cost as home consumers get more and more benefits from being in the larger domestic network. In Foreign, although the foreign firm continues to have sales, licensing can make the home firm's market share larger than the foreign firm's. Licensing helps the home firm overcome the natural protection that the foreign firm enjoys from the transport cost.

Finally, the magnitude of the fixed cost of developing the standard could affect the results of licensing. All of the results given in the tables are gross of F. If F were high enough it is possible that licensing could make the foreign firm not enter the market in period zero. For instance, in Table 3, if F equals 0.15, when the home firm licenses to two firms for both periods the foreign firm could not break even, and would not enter the market. If F were very high it may be that neither firm would enter the market without licensing. If F is greater than 0.30 then in Table 3 a result without licensing is not feasible. Because a single firm facing these costs would have positive profits, as seen in the first column of Table 1, this may result in a "grab the dollar" game which won't be explored here.

Because licensing is a profitable strategy in the face of foreign competition even without the dynamic effects shown here, there is no question of the credibility of licensing. The licensor's profits decrease if the license is revoked immediately preceding second-period competition. Therefore, a pre-commitment to license in period two is credible. However, profits are further increased if the standard is licensed for use in both periods, so this is the preferred strategy of the licensor. This strategy is also credible because in each period profits increase due to licensing.

5 Conclusions

The results above demonstrate that licensing a standard for a homogeneous product from which consumers derive network externalities can increase domestic profits and consumer surplus. Licensing always increases consumer surplus because consumer surplus is an increasing function of the quantity consumed, and licensing always increases output. Without network externalities, licensing would decrease monopoly profits. However, at high enough levels of network externalities, in the dynamic model presented here, licensing can actually increase profits of the licensor. After introducing foreign competition not only does licensing have direct effects on profits, but licensing is also a strategic top-dog strategy. The strategic effect is simply that a credible commitment to increase the size of the network, such as licensing provides, decreases the competitor's output, which improves the licensor's profits. Licensing is profitable at all levels of n for a firm facing foreign competition.

Encouraging domestic firms to license to other firms is in the government's interest due to its positive effect on consumer surplus and profits. In the example of the introduction, MITI chose Fanuc to develop the standard numerical control for the Japanese machine tool industry while in the U.S. antitrust laws were a perceived deterrent to standardization. While the highly interventionist role of government such as that taken by MITI in Japan may not have been desirable in the U.S. context, antitrust laws which discouraged firms from developing common standards were not desirable either. Choosing one firm to be the standard-bearer and license their technology, as MITI did with Fanuc, may not always be feasible and may even lead to rent-seeking. However, allowing and possibly aiding a domestic consortium to develop an industry standard may be more practical and give the same strategic benefits.

The next steps for this line of research are in two directions. First of all, an empirical test of these results on the machine tool industry would be interesting. The goal would be to determine the costs and benefits to Japan and the U.S. of the actions that each country took in regards to standardization of numerical controls. Further theoretical work includes a determination of the effects of both countries attempting to develop a standard and engaging in a licensing war. Finally, the effects of relaxing some of the assumptions in this paper such as an exogenous number of technologies or homogeneity of the goods could be explored.

Table 1: Monopoly results with variations of licensing.

	n=.1, c=.2, τ=.1			n=.2, c=.2, τ=.1			n=.3, c=.7, τ=.1		
	$k_1 = 1$ $k_2 = 1$	$k_1 = 1$ $k_2 = 2$	$k_1 = 2$ $k_2 = 2$	$k_1 = 1$ $k_2 = 1$	$k_1 = 1$ $k_2 = 2$	$k_1 = 2$ $k_2 = 2$	$k_1 = 1$ $k_2 = 1$	$k_1 = 1$ $k_2 = 2$	$k_1 = 2$ $k_2 = 2$
q_{1h}	.56	.57	.74	.89	.92	1.0	.71	.78	.94
q_{2h}	.48	.63	.65	.61	.82	.83	.37	.51	.55
π_{1h}	.22	.23	.20	.35	.38	.37	.09	.11	.09
π_{2h}	.20	.18	.19	.30	.27	.28	.09	.09	.11
q^*_{1h}	.49	.50	.65	.78	.81	1.0	.47	.52	.62
q^*_{2h}	.42	.56	.57	.53	.72	.75	.24	.34	.37
π^*_{1h}	.17	.18	.15	.26	.29	.25	.04	.05	.04
π^*_{2h}	.16	.14	.14	.23	.21	.23	.04	.04	.05
CS_h	.27	.36	.48	.58	.76	.85	.32	.43	.59
CS_f	.21	.28	.37	.45	.58	.78	.14	.19	.26
π_h	.75	.73	.69	1.138	1.144	1.12	.26	.29	.28
W_h	1.03	1.09	.1.17	1.72	1.90	1.97	.58	.72	.87

Table 2: Trade results with low network externalities ($n = .05$).

	$k_1 = 1$ $k_2 = 1$		$k_1 = 1$ $k_2 = 3$		$k_1 = 3$ $k_2 = 3$	
	Home	Foreign	Home	Foreign	Home	Foreign
q_{1c}	.35	.21	.37	.19	.70	.004
q_{2c}	.32	.20	.60	.06	.63	.04
π_{1c}	.10	.04	.11	.03	.14	0
π_{2c}	.10	.04	.11	0	.13	.001
q^*_{1c}	.21	.35	.22	.34	.41	.23
q^*_{2c}	.20	.32	.38	.23	.40	.22
π^*_{1c}	.04	.10	.04	.10	.05	.04
π^*_{2c}	.04	.10	.05	.05	.05	.05
CS_c	.29	.29	.37	.34	.47	.40
π_c	.28	.28	.31	.18	.36	.09
W_c	.57	.57	.69	.52	.83	.49
n=.05, τ=.1, c=.2						

Table 3: Trade results with high network externalities ($n = .10$).

	$k_1 = 1$, $k_2 = 1$		$k_1 = 1$, $k_2 = 3$		$k_1 = 2$, $k_2 = 2$	
	Home	Foreign	Home	Foreign	Home	Foreign
q_{1c}	.43	.20	.52	.11	.75	0
q_{2c}	.36	.20	.71	.001	.61	.05
π_{1c}	.13	.03	.18	.01	.20	0
π_{2c}	.11	.04	.15	0	.17	.002
q^*_{1c}	.20	.43	.24	.40	.36	.32
q^*_{2c}	.20	.36	.40	.24	.34	.27
π^*_{1c}	.03	.13	.04	.11	.04	.07
π^*_{2c}	.04	.11	.05	.05	.05	.07
CS_c	.36	.36	.45	.41	.50	.42
π_c	.30	.30	.41	.17	.46	.13
W_c	.66	.66	.87	.58	.96	.56
n=.1, τ=.1, c=.2						

Appendix

The demand curve is derived following Katz and Shapiro (1985). The example shown below is for second-period home consumers buying either the home or foreign good.

The utility that a consumer derives from buying a good in the second period is $r + nq_{1c} + nq_{2c}$, where the first term is the basic willingness to pay for the good, the second term is the consumer's network benefits derived from the existing network, and the third term measures the network benefits from the second-period sales. Let the basic willingness to pay for the good, r, be distributed uniformly from zero to one.

Consumers try to maximize the net benefits from buying a good, $r + nq_{1c} + nq_{2c} - p_{2c}$, or $r - \phi_2$, where the hedonic price is $\phi_2 = p_{2c} - nq_{1c} - nq_{2c}$ from equation (5). If both the home and foreign firms have positive second-period sales their hedonic prices must be equal, i.e. $\phi_2 = \phi_{2h} = \phi_{2f}$. Consumers only buy if their willingness to pay is greater than the hedonic price, $r \geq \phi_2$. From the distribution assumption on r, $\mathrm{P}(r \geq \phi_2) = 1 - \mathrm{F}(\phi_2) = 1 - \phi_2$. Because the number of consumers at home is normalized to one, there are $1 - \phi_2$ consumers willing to buy the good. If each consumer has unit demand, the total quantity of sales is therefore:

$$
\begin{aligned}
Q_2 &= 1 - \phi_2 \quad \text{where } Q_2 = q_{2h} + q_{2f} \\
Q_2 &= 1 - p_{2c} + nq_{1c} + nq_{2c} \\
p_{2c} &= 1 - Q_2 + nq_{1c} + nq_{2c}.
\end{aligned}
$$

The second-period demand for home products at home is therefore:

$$p_{2h} = 1 - q_{2h} - q_{2f} + nq_{1h} + nq_{2h}$$

and for foreign products it is:

$$p_{2f} = 1 - q_{2h} - q_{2f} + nq_{1f} + nq_{2f}.$$

These equations are similar to equation (2) above.

The main difference with Katz and Shapiro is the distribution of the basic willingness to pay, r. They have r distributed uniformly from minus infinity to a positive A. They explain negative values of r by defining r to be the excess of the basic willingness to pay over the constant marginal cost of production. They assume that there is no finite lower bound to avoid corner solutions where all consumers enter the market. A corner solution would occur where ϕ equals the lower bound of the distribution of r, which they implicitly assume could not happen if the lower bound is $-\infty$.

There are three problems with having the lower support of r be $-\infty$. First of all, this makes the density of r equal zero:

$$f(\rho) = \frac{1}{A - (-\infty)} = \frac{1}{\infty}.$$

Second of all, since the basic willingness to pay itself cannot be negative, for the adjusted basic willingness to pay to equal $-\infty$ implies a marginal cost of infinity. Finally, their assumption implies that ϕ_t could be negative, otherwise there would be a corner solution where all A consumers with non-negative basic willingness to pay would buy, and the rest with negative willingness to pay would not buy. From equation (5), $\phi_2 < 0$ implies that $p_{2c} < nq_{1c} + nq_{2c}$, which would seem to imply infinite demand, except for the fact that their basic willingness to pay is net of marginal cost and could be negative.

For clarity, I include marginal cost explicitly in the firm's profit function. Therefore, the basic willingness to pay r is always non-negative, as is ϕ_t. Here $r \sim \mathrm{U}(0,1)$, so that corner solutions are possible. In simulations I choose levels of the parameters which don't allow for corner solutions.

Another difference with Katz and Shapiro is that they assumed that network externalities were a concave function $v(\cdot)$ of the network size, whereas here the network externalities are assumed to be linear for simplicity. Finally, Katz and Shapiro assume that fixed costs are zero, but the cost of becoming compatible is F_i for each firm i. This would make licensing more costly for the firms than incompatibility. I assume that creating a standard costs F, but the cost of a licensee adopting this standard is zero. Therefore, there are economies of scale resulting from licensing in addition to the strategic benefits derived in this paper.

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