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RATIONAL INCOMPATIBILITY WITH INTERNATIONAL PRODUCT STANDARDS

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Abstract: This paper considers the incentives of an import-competing firm and a technology-importing country to conform to an exogenous international standard for a product characterized by network externalities. The domestic firm has an incentive to deviate from the international standard. Moreover, the importing country government has no incentive to enforce the international standard. Indeed, because consumers may also incur switching costs, the government may value deviation from the international standard more than the firm does, thereby creating incentives to adopt and enforce technical barriers to trade. The results highlight the challenge lock-in effects pose to the international standard-setting process.

Rational Incompatibility with International Product Standards

"These days, it is differences in national regulations,
far more than tariffs, that put sand in the wheels of
trade between rich countries."
The Economist, 24 May 1997, p.72

I. Introduction

Technical product standards are becoming key issues, both in corporate global business strategy and in government trade and technology policy. Sharp long-run reduction in average tariff levels, import quotas, and relative international communications and transport costs have led to increased international economic integration. However, international diversity in product standards can lead to technical barriers to trade that threaten to limit further integration (Hillman 1991, Kende 1991, Sykes 1995, Thilmany and Barrett 1997). Internationally accepted product standards can facilitate international trade and foreign direct investment by reducing search and adjustment costs, cutting production costs where there are economies of scale or scope, and facilitating spatial arbitrage. For goods characterized by demand-side network externalities, the incentives to achieve compatibility are especially pronounced (Katz and Shapiro 1985, 1994). Voltage standards for consumer electrical products are a clear example. Considerable effort is therefore being invested currently in developing international standards through intergovernmental bodies — such as the International Organization for Standardization (ISO), Codex Alimentarius (Codex), the International Electrotecnical Comission (IEC), and the Asia Pacific Economic Cooperation (APEC) forum — as well as through private negotiation among firms. Meanwhile, trade treaties (e.g., NAFTA) increasingly incorporate language designed to restrict nations' abilities to introduce technical barriers to trade (Sykes 1995, Wilson 1995).

Some nations and firms nonetheless choose not to adopt international standards. Some telephone systems cannot be linked by direct dialing, some nations use righthand-side-drive vehicles while others use lefthand-side-drive, automotive and machinery parts come in metric and non-metric sizes, railroad tracks and machinery exist in different gauges, and so on. Sometimes idiosyncratic standards become mandatory in a particular economy (e.g., righthand-side-drive vehicles) when governments convert voluntary standards into regulations. This is a primary source of technical barriers to trade, which appear to be increasing, both relative to quotas and tariffs and in absolute terms, as reflected in the quote that opens this paper.

This paper considers why an import-competing firm and an importing nation more generally might choose not to comply with international product standards. If key market participants have incentive to maintain incompatible standards, then efforts to design uniformly agreeable international standards may prove futile. In this paper, we show that incentives to deviate from international standards may be significant in an important class of cases. Our analytical findings are consistent with the dominant international pattern: countries typically do not recognize international standards. For example, the U.S. Congressional Research Service (1989) found that only 17 of approximately 89,000 standards recognized in the United States had international origins.

The literature on networks explains incompatibility[1] as arising either from consumer heterogeneity that gives social value to variety, from stochastic technology quality that creates disincentives to betting everything on one standard of uncertain ultimate quality, or from firm asymmetries that cause one firm to be confident it will win a contest of competing standards (Farrell

[1] We have in mind either two-way (in)compatibility among alternative technologies or one-way incompatibility from the original domestic technology to the two new technologies.

and Saloner 1986, Katz and Shapiro 1986, Matutes and Regibeau 1988, Katz and Shapiro 1994). Without recourse to any of those rationales, we show that international standards incompatibility will generally be a rational choice for import-competing domestic firms and importing country governments. This finding obviously carries significant implications for costly expenditures on international product standardization agreements designed to facilitate trade. Important classes of prospective signatories may never find it in their interest to comply with standards. Our findings also offer some insight as to why governments wishing to maximize social welfare might impose technical barriers to trade.[2] As Matutes and Regibeau's (1996) recent review highlights, these international standardization choices and policies have been largely neglected in the literature to date.[3]

II. International Standards and the Domestic Network Market

Products in network markets generate some of their value through compatibility with others. Fax machines, computer software, and automobile parts are familiar examples. The network value of the good takes the form of an externality which is a function of the volume of the product in use, often referred to as the "installed base" of the network. Markets in goods characterized by network externalities are especially appropriate subjects for the study of international product standards because product standards and resulting compatibility influence the installed base of, and thus consumers' valuation of a product. If production or exchange technologies exhibit nonconstant returns over any range, standards also influence production and transaction costs. Comparative

[2] Hillman (1991), Sykes (1995) and Thilmany and Barrett (1997) discuss the political economy of technical barriers to trade.

[3] Gandal and Shy (1996) tackle related issues.

advantage, international demand patterns, and trade flows in network products are thus affected by product standards.

Sykes (1995) defines a product "standard" as a specification or set of specifications that relate to a product's attributes. Compliance with standards is voluntary and may or may not be formally promulgated by a private or public standard-setting entity. In some cases governments wish to enforce compliance with a standard by means of regulatory controls. Technical barriers to trade are a means by which national governments ensure all imported products are fully compatible with particular specifications.

This section presents a simple, two-stage model of oligopoly in a domestic market exhibiting network externalities. We draw on the pioneering work of Katz and Shapiro (1985), extending their approach to permit firms nondichotomous choice over standards compatibility. Like Jain (1989) and Shy (1996), we allow for *partial* compatibility in our model, reflecting the common phenomenon that some, but not all, key features are compatible among products providing similar services.[4] Partially compatibile products (partly) contribute to each other's installed network base, thereby influencing market equilibria.

The scenario we model runs as follows. A domestic monopolist[5] offers a product with an original technology potentially incompatible with the subsequently established international

[4] For example, a software package might be able to access another application's format although their other characteristics may be decidedly different (Gandal, 1995).

[5] Alternatively, one can think of our "monopolist" as a cartel that must employ a uniform technology, as in the color television broadcasting case discussed by Pargal (1996), wherein reception and transmission standards must be common to work. Similarly, a nation's vehicle manufacturers must uniformly produce either righthand- or lefthand-side drive vehicles, not both, for local sale. Government regulation sometimes enforces domestic standardization.

technology standard, with which (at least some) foreign producers conform. So at the dawning of a new product standard, there may be two distinct technologies already in use. The potential differences between these two technologies are captured in a compatibility index, β, defined over the unit interval. The international product standard is fully compatible with the original domestic technology if $\beta=1$, they are totally incompatible if $\beta=0$, and they are partially compatible if $\beta\in(0,1)$. The domestic market is in equilibrium when a foreign firm tries to enter the domestic market offering a product conforming to the international standard characterized by β. The domestic firm responds by potentially changing its technology. The index $\alpha\in[0,1]$ captures the compatibility between the firm's new and old technologies. The domestic firm's new and original technologies are totally incompatible if $\alpha=0$, they are perfectly compatible — indeed, the firm may continue to produce the original technology — if $\alpha=1$, and they are partially compatible if $\alpha\in(0,1)$. At the same time, the domestic government decides whether to encourage or enforce the international standard, i.e., to impose the technology standard $\alpha=\beta$ on the firm by regulatory fiat.

The timing of the game is as follows. In the first stage, the domestic firm chooses a technology for its new product, i.e., decides α, given the installed base of both the original domestic technology and the international standard, and the compatibility of the international standard with the original domestic technology, as reflected by β. In the second stage, consumers form expectations about the network sizes of both technologies, given the domestic firm's compatibility decision in stage one. We assume a fulfilled expectations equilibrium, following Katz and Shapiro (1985). Finally, the domestic firm and its foreign competitor(s) set quantities in a Cournot competition. We find that, save for unusual circumstances, neither the domestic firm nor the social welfare-maximizing government have an incentive to adopt the international product standard. This result has obvious implications for negotiations over international product standards agreements.

A. Consumer Behavior

Following Katz and Shapiro (1985), a prospective consumer of type r has a willingness to pay $r+v(N_e)$ for a product with expected network size N_e ,where r represents her intrinsic valuation of the product and $v(N_e)$ reflects the network externality. For simplicity, we assume r is uniformly distributed with density one between minus infinity and A, a positive number. The network externality function, v(.), is assumed to be twice continuously differentiable, with $v(0)=0$, $v' > 0$, $v'' < 0$, and $\lim_{z \to \bar{N}} v'(z) = 0$ where there exists a large network size, $\bar{N}$. We should point out that $\bar{N}$ is not a saturated market, merely one in which the marginal value to consumers of adding another user has vanished; contemporary fax, electronic mail, road, and utility networks are examples that spring immediately to mind.[6] The services provided by the technologies are viewed as homogenous by all consumers, but the technologies may not be perfectly compatible. The only differences are the expectations about the sum of weighted network sizes since the networks might not be perfectly compatible.

In the second stage, consumers form expectations about the weighted size of the new networks associated with the domestic and foreign products based on the known existing network sizes of both the original domestic technology and the international standard and on expected sales

[6] More complex network effects, in which the monotonicity and concavity assumptions on $V(N_e)$ are relaxed, can accomodate network overload or exclusivity effects — with $v'<0$ at very large or very small network sizes, respectively — but do not change the qualitative results of our analysis.

of each, and the technology choice of the new domestic product made by the domestic firm in the first stage.[7] Let q_e and q_e* denote the expected sales of the domestic and foreign new products, respectively. We assume the expected weighted average network size for those who want to buy the new domestic product is then described by

$$N_e = \alpha q_o + q_e + f(\alpha - \beta)(q_e^* + q_o^*) \tag{1}$$

where q_0 and q_0* are the preexisting domestic and foreign network sizes, respectively, and f(α-β) is a concave index function with support [0,1] that measures the compatibility deviation between the new domestic technology and the international standard. If α=β, the two new technologies are fully compatible with each other, although they might not be fully compatible with the original domestic technology (if $\alpha=\beta\neq1$). Without loss of generality, assume f'(.)>0 when α-β<0, f(α-β)=1 and f'(.)=0 when α=β, and f'(.) < 0 when α-β>0. If α=1 consumers fully count the installed base of the original domestic technology since the domestic original and new technologies are fully compatible. Simply put, the more compatible the new domestic technology is with another product — whether the international standard or the original domestic technology — the more weight consumers give to the installed base of other (domestic or foreign) products in forming their expectations of the relevant network size for the new domestic technology.

Consumers similarly form expectations of the weighted average network size for the imported product conforming to the international standard.

$$N_e^* = \beta q_o + f(\alpha - \beta)q_e + q_e^* + q_o^* \tag{2}$$

[7] Consumers care about the installed base in each technology because they may wish to network with others who purchased an earlier technology. This is a common phenomenon in, for example, automobiles, computer software, and facsimile machines.

Each consumer maximizes her surplus by purchasing one unit of either the new domestic or foreign product or by declining to purchase either product. In order to focus attention on the decision of whether or not to conform with the international standard, we assume the foreign firm cannot unilaterally change its product's standard; it must satisfy the international standard. The foreign firm can only choose the quantity it exports into the market, q*, in order to maximize its profits in the domestic market. Letting p denote the price of the new domestic product, an agent who purchases the new domestic technology must have

$$r + v(N_e) - SC(\alpha) - p \geq 0 \tag{3}$$

where SC(α) is the nonegative cost of switching from the original domestic technology to the new domestic technology. We assume SC'<0 and SC(1)=SC'(1)=0. In words, consumers' switching costs decrease with the degree of compatibility with the original domestic technology, going to zero when the firm doesn't change its technology.[8] Symmetrically, any agent who purchases the new foreign product must have

$$r + v(N_e^*) - SC^*(\beta) - p^* \geq 0 \tag{4}$$

where SC(β) is the cost of switching from the original domestic technology to the international standard. Those consumers whose reservation prices are less than either p or p* stay out of the network market. Therefore, if $r+v(N_e)-SC(\alpha)-p > r+v(N_e^*)-SC(\beta)-p^*$ for all consumers, no one buys the imported international standard product. Analogously, no one buys the new domestic product if $r+v(N_e)-SC(\alpha)-p < r+v(N_e^*)-SC(\beta)-p^*$ for all consumers. Under those two limiting situations, the domestic market has a single provider, either the domestic firm or foreign producers.

[8] The microeconomic literature on consumer behavior in the presence of switching costs has developed parallel to the literature on network effects over the past decade. Klemperer (1995) offers an excellent survey.

If the domestic and international products are homogenous — i.e., $\alpha = \beta$, whether or not $\alpha = \beta = 1$ — then $SC(\alpha)=SC(\beta)$ and $v(N_e)=v(N_e^*)$, so the low-price producer captures the entire market. This is the textbook example of price-based division of a homogenous good's market, and a special case of our model of potentially heterogeneous (i.e., imperfectly compatible) goods. But in the more general case, the low price competitor does not necessarily capture the market if network effects or switching costs confer an advantage on the producer offering the good at a higher price. In particular, the domestic firm's choice of technologies influences control over the market. The next section describes the firm's optimal technology choice. We will then subsequently revisit the possibility of market exclusion conditional on the firm's optimal technology choice.

Our interest centers on the scenario in which both the imported international standard and the new domestic product exist in the domestic market in the second stage. In equilibrium, two firms both have positive sales only if

$$r + v(N_e) - SC(\alpha) - p = r + v(N_e^*) - SC(\beta) - p^* \tag{5}$$

Equation (5) can be rearranged as follows

$$p - v(N_e) + SC(\alpha) = p^* - v(N_e^*) + SC(\beta) \tag{6}$$

Equation (6) indicates that the expected hedonic prices must be equal if both firms have positive sales in the competitive domestic market. Let ϕ stand for the common value of the hedonic prices, i.e., $\phi = p - v(N_e) + SC(\alpha) = p^* - v(N_e^*) + SC^*(\beta)$. Only those consumers whose intrinsic valuation of the product is greater than the hedonic price ($r \geq \phi$) will buy a new product. Since r is uniformly distributed between minus infinity and A with density one, $A - \phi$ consumers enter the product network. If the total sales of the products from two firms are $(q+q^*)$, then

$$A - \phi = q + q^* \tag{7}$$

Substituting for ϕ yields

$$A - (p - v(N_e) + SC(\alpha)) = q + q^* \tag{8}$$

Rearranging equation (8), we find that the domestic firm faces the downward-sloping inverse demand function

$$p = A + v(N_e) - SC(\alpha) - (q+q^*) \tag{9}$$

Substituting instead $p^* - v(N_e^*) + SC(\beta)$ for ϕ in (7) and rearranging yields the imported price for the product conforming to the international standard

$$p^* = A + v(N_e^*) - SC(\beta) - (q+q^*) \tag{10}$$

B. Firm Behavior

The foreign firm sells a product conforming to the predetermined international standard; it has no unilateral influence to change that standard. The foreign firm enters the game actively only in the second period, as a quantity-setting Cournot competitor. The domestic firm, on the other hand, chooses the degree of compatibility between its new and old products, α, in the first period, knowing the international standard (β), the installed network base under both the original domestic and the international standard technologies (q_0 and q_0^*, respectively), and the way in which consumers form expectations.

The domestic firm offers an upgraded product in response to market entry by foreign firms selling the international standard only if total revenue is larger than the sum of variable, redesign and other fixed costs. The domestic firm's redesign costs are a function of compatibility with its original technology, $R(\alpha)$. Assume $R(\alpha)$ is decreasing in α and $R(1)=R'(1)=0$. In words, sticking with the original technology entails no redesign costs, which increase with the deviation from the original design. Without loss of generality, we assume the domestic firm's other fixed costs have no influence at the margin. For simplicity, we also assume constant marginal cost of production and, without loss of generality, set this equal to zero.

The domestic firm solves its multi-stage profit-maximization problem by backward induction. In the second stage, the domestic firm chooses output volume so as to maximize profit, given consumers' expectations of network size and its prior compatibility decision, α.

$$\underset{q}{\text{Max}}\ \Pi(q^*\alpha,\beta) = q\ (A+v(N_e)-SC(\alpha) - (q + q^*)) - R(\alpha) \tag{11}$$

The foreign firm's objective is likewise to maximize profits given α and consumers' expectations by

$$\underset{q^*}{\text{Max}}\ \Pi^*(q^{**}\alpha,\beta) = q^*\ (A+v(N_e^*)-SC(\beta) - (q + q^*)) \tag{12}$$

Assume a fulfilled expectations Cournot equilibrium in which consumers' expectations about the sizes of the two domestic market product networks are fulfilled in equilibrium, i.e., $(N_e,N_e^*) = (N, N^*)$ and $(q_e, q_e^*) = (q,q^*)$.[9] The second period first-order conditions for both firms' profit maximization are thus

$$\frac{\partial \Pi}{\partial q} = A + v(N) - SC(\alpha) - (2q + q*) = 0 \tag{13}$$

$$\frac{\partial \Pi^*}{\partial q^*} = A + v(N^*) - SC(\beta) - (q + 2q*) = 0 \tag{14}$$

These two equations represent the reaction curves of the two competing firms and can be solved implicitly for the subgame perfect equilibrium quantities, $(\hat{q}(\alpha),\hat{q}^*(\alpha))$, conditional on the optimal first period compatibility choice of α.

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[9] Katz and Shapiro (1985) also demonstrate another case, in which consumers form expectations of network size after firms have selected their output level.

Let us now consider the comparative static effects of the domestic firm's first period choice of α on ($\hat{q}(\alpha),\hat{q}^*(\alpha)$). Differentiating (13) and (14) with respect to α gives the system of equations

$$\begin{pmatrix} \frac{\partial^2 \Pi}{\partial q^2} & \frac{\partial^2 \Pi}{\partial q \partial q^*} \\ \frac{\partial^2 \Pi^*}{\partial q \partial q^*} & \frac{\partial^2 \Pi^*}{\partial (q^*)^2} \end{pmatrix} \begin{pmatrix} \frac{\partial q}{\partial \alpha} \\ \frac{\partial q^*}{\partial \alpha} \end{pmatrix} = \begin{pmatrix} -\frac{\partial^2 \Pi}{\partial q \partial \alpha} \\ -\frac{\partial^2 \Pi^*}{\partial q^* \partial \alpha} \end{pmatrix} \tag{15}$$

Appropriate differentiation and algebra then establishes that

$$\frac{\partial q}{\partial \alpha} = \frac{f'(\alpha-\beta)(2v'(N)(q*+q_0*)-v'(N^*)q)+2v'(N)q_0-2SC'(\alpha)-2R'(\alpha)}{3} \tag{16}$$

We will need this expression to solve the firm's optimal (stage one) technology choice, below. But in addition to that instrumental value, the result in (16) sheds light on the relationship between sales volume and the firm's prior technology choice and in so doing foreshadows the more general results. This relationship can be summarized in two propositions (proofs of which are in the appendix).

Proposition 1: *When α is close to β and the international standard is not the same as the original domestic technology ($b \neq 1$), the domestic firm's sales are increasing in the degree of its product's compatibility with the original domestic technolog, i.e., by deviating from an the international product standard, if and only if there is an installed base in the original domestic technology.*

This proposition captures the essence of the international standards compatibility problem: when the international standard is not the preexisting domestic technology standard, the domestic firm has an incentive not to comply with the international standard. Evaluated locally, around the point

$\alpha=\beta$, the domestic firm can sell more — and thereby earn higher profits — if it positions its new technology between the international standard and the original domestic technology, unless there is no preexisting domestic technology, in which case it cannot increase sales by departure from $\alpha=\beta$, or unless the international standard is the original domestic technology ($\beta=1$).

For immature networks, wherein new sales generate marginal network effects (v'>0), the first term in the numerator of (16) is of indeterminant sign when $\alpha\neq\beta$, so we have only the local result offered in proposition one. However, for mature networks, wherein the marginal value of adding participants vanishes, we can derive somewhat more general results.

Proposition 2: *When the installed base of the foreign technology is large(q_0*=$\bar{N}$, so that v'(N*)=0), then domestic sales are increasing in a over the range [0,b]. Analogously, when the installed base of the original domestic technology is large(q_0=$\bar{N}$, so that v'(N)=0), then domestic sales are increasing in a over the range [b,1]. So, when both networks have large installed bases, then domestic sales are increasing in a over the full range [0,1].*

Intuitively, the domestic firm can increase its sales by increasing the degree of compatibility with a mature technology's network. When both the international standard and the original domestic networks are mature, however, sales are maximized by maintaining the original domestic technology (i.e., at $\alpha=1$) because this minimizes both firm redesign costs and consumer switching costs, enabling the domestic producer to offer a lower price and generate greater sales and profits. As the existing literature on switching costs emphasizes (Klemperer 1995), the friction introduced by nonzero technology switching costs creates lock-in effects. In the present case, this phenomenon is manifest in the domestic firm's incentive to deviate from an international product standard in the direction of a preexisting domestic technology.

The first stage compatibility choice of α reinforces this finding. Given the second-stage fulfilled expectations Cournot equilibrium, reflected in the optimal quantities $(\hat{q}(\alpha),\hat{q}^*(\alpha))$, the firm maximizes profit by choosing α so as to

$$\max_{\alpha} \Pi\,(\hat{q}(\alpha),\hat{q}^*(\alpha),\alpha\,{}^*\beta) = \hat{q}(\alpha)(A + v(N) - SC(\alpha) - (\hat{q}(\alpha)+\hat{q}^*(\alpha))) - R(\alpha) \tag{17}$$

The first-order necessary condition for an optimum is thus

$$\hat{q}\ \{v'(N)[q_0+f'(\alpha-\beta)(\hat{q}^*+q_0^*)] - SC'(\alpha) - (\partial\hat{q}^*/\partial\alpha)\ \} - R'(\alpha)\ \leq (\geq)\ 0 \tag{18}$$

$$\{\text{with} <0 \text{ only if } \alpha = 0 \text{ and } >0 \text{ only if } \alpha = 1\}$$

The first-stage problem thus relates the firm's technology choice, α, to profits in a fashion analogous to the relationship between α and the firm's sales volume, $\hat{q}(\alpha)$, derived earlier through comparative statics analysis of the solution to the firm's second stage problem. The necessary condition for profit maximization in (18) permits us to derive the necessary conditions for the domestic firm to choose the international standard voluntarily.

Proposition 3: *The domestic firm voluntarily produces a good perfectly compatible with the international standard* ($\hat{\alpha}=\beta$) *only if (i) there was no preexisting domestic network* ($q_0=0$)*, or (ii) the international standard is itself perfectly compatible with the domestic original-technology* ($\beta=1$). *Otherwise it chooses a technology more compatible with the original domestic technology than is the international standard.*

Again, the proof is in the appendix. There may be multiple subgame perfect equilibria, since there will not necessarily be a unique profit-maximizing combination ($\hat{\alpha}$, $\hat{q}$). Nonetheless, an established import-competing firm will only conform to an international product standard that is perfectly compatible with the firm's original technology. This is due to the twin considerations of maximizing network size by being compatible with both preexisting technologies and positioning the new technology between the old domestic technology and the international standard so as to secure a price advantage by reducing consumer switching costs. One consequence is that import volume is reduced since, by Proposition 1, the domestic firm's quantity is increasing in α, which implies that the foreign competitor's sales volume is decreasing in α. Where consumer switching costs confer some advantage on incumbent domestic producers, international product standardization would indeed stimulate international trade flows. But firms' noncompliance with standards therefore reduces trade volumes relative to the scenario of full compliance.[10]

Proposition 3 highlights the importance of *ex ante* versus *ex post* standardization, where *ex ante* standardization represents the designation of an international standard, β, before the establishment of a competing domestic technology (i.e., q_0=0), and under *ex post* standardization, β is set after a domestic technology has been installed (i.e., q_0>0). Firms have incentives to comply with *ex ante* standards, but not necessarily with *ex post* standards. The problem with *ex ante* standardization, however, is that if research and development is stochastic, then it is impossible to know the optimal design *ex ante*, so widespread compliance may be gained at the price of a potentially suboptimal standard. On the other hand, once there is an installed base in a particular

[10] This issue will be studied further in the section IIIc.

technology, voluntary firm compliance can only be ensured if the international standard adopted *ex post* is the original domestic technology, β=1. This obviously bodes poorly for *ex post* standardization of technologies developed independently in more than one importing nation, e.g., for mature products subject to intra-industry trade (e.g., vehicles with lefthand- or righthand-side drive and with English or metric sized parts). As a rule of thumb, these results suggest that self-enforcing, technologically desirable international product standards can be achieved only if there is a clear leader, who develops a technology successfully and before anyone else has developed a competing standard. Under such a scenario, international product standards must go hand-in-hand with intellectual property rights.

We earlier considered the conditions under which the domestic and foreign firm share the market. Having now shown that domestic firms will, under fairly general conditions, choose a technology more compatible with the original domestic technology than the international standard (i.e., $\alpha > \beta$), let us return to consider the effect of the preexisting domestic network size, q_0, on the division of the market between the two suppliers. Recalling the earlier expressions of consumer's willingness to pay for the new domestic technology and the international standard (relations 3 and 4, respectively), we can now derive conditions under which the domestic producer will exclude imports in equilibrium.

The necessary condition[11] for the domestic producer to supply the whole market is

$$[v(N) - v(N^*)] + [SC(\beta) - SC(\alpha)] + [p^*-p] \geq 0 \qquad (19)$$

In words, the price differential between the products using domestic and international standards must not exceed the sum of the benefits to consumers from a larger network externality and lower

[11] The sufficient condition is simply a strict inequality.

switching costs.[12] In long-run equilibrium under monopolistic competition, price equals average cost, implying $p=R(\alpha)/q$ and $p^*=0$ under our assumption of zero and constant marginal costs. Conditional on the optimal technology choice, $\alpha > \beta$ for $\beta \neq 1$, the lefthand side of (19) is increasing in the installed base of the original domestic technology, q_0. In simpler terms, the more mature the domestic industry, as manifest in a larger established consumer base for its original technology, the more likely the domestic monopolist can exclude foreign rivals in equilibrium.

Proposition 4: *Conditional on the optimal technology choice, $\alpha > \beta$ for $\beta \neq 1$, the larger the established base of the original domestic technology, q_0, the larger the price markup the domestic firm enjoys relative to the imported international standard, and the more likely it is to exclude the international standard from the domestic market in equilibrium.*

Product standardization enables traditional, price-based international competition. But the existence of firm redesign or consumer switching costs or of network effects creates market frictions that diminish the incentive to standardize if there already exists a different, mature technology in a reasonalby large market. This leads to multi-attribute competition between products and will, generally reduce trade flows.

An intriguing prospective extension of this model emerges from the case where there is no original domestic technology, so a start-up firm with market power in a network good (i.e., a firm

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[12] While switching costs will definitely be lower for $\alpha>\beta$, the network externality may not be larger, depending on the shape of f(.) and the quantities q, q^* and q_0^*.

given an exclusive concession by the government, but for which q_0=0) optimally chooses the international standard in order to take advantage of the broader international standard network. The innovation would then be to introduce learning-by-doing dynamics which could lead to the new firm acquiring comparative advantage in this product. This stylized scenario seems to resemble many cases in East Asia in the 1950s and 1960s, where active government industrial policy went hand-in-hand with rapid adoption of foreign technology standards and trade expansion. Contrast this experience with that of several Latin American economies in which incumbent industries secured considerable tariff and regulatory protection against foreign technologies. Extensions of the present model might prove helpful in such comparative analysis.

III. Government Incentives: International Standards Or Regulatory Barriers To Trade?

The preceding model generates clear predictions regarding the incentives faced by the domestic firm not to comply with the international product standard voluntarily. But a powerful government might be able to compel the firm's compliance by regulatory fiat. At the opposite end of the spectrum, an interventionist government might alternatively constrain the firm's ability to modify the original technology by imposing regulatory product standards different from the international standard. This section considers which path a government would more likely follow.[13]

Imagine for the moment that the government maximizes social welfare. The economic surplus enjoyed by a consumer joining a network depends on the network size. By equation (7), a consumer whose intrinsic valuation of the product, r, is greater than the hedonic price, ϕ, joins the network and

[13] The government obviously has a *laissez faire* option which demands no analysis.

derives a surplus of r + q + q* -A from joining a network with sales of Q=q+q*. Integrating over the A-Q consumers who enter the market yields aggregate consumers' surplus

$$S = \int_{A-Q}^{A} (\tau + Q - A)\, d\tau = Q^2/2 \tag{19}$$

Let W denote the aggregate welfare in our fulfilled expectations Cournot equilibrium, i.e., the sum of producer and consumer surplus.

$$W = \Pi + S \tag{20}$$

Suppose initially that α=β. As already established in Proposition 3, producer surplus is increasing locally in α, thereby creating an incentive to deviate from the international product standard, β:

$$\left.\frac{\partial \Pi}{\partial \alpha}\right|_{\alpha=\beta} = \left.\frac{\partial \Pi}{\partial \alpha}\right|_{\alpha=\beta} > 0 \tag{21}$$

Meanwhile, the change in consumers' surplus with respect to α, evaluated in the neighborhood of α=β is

$$\left.\frac{\partial S}{\partial \alpha}\right|_{\alpha=\beta} = \left.\frac{\partial (Q^2/2)}{\partial \alpha}\right|_{\alpha=\beta} = \left. Q \cdot \frac{\partial Q}{\partial \alpha}\right|_{\alpha=\beta} = Q \cdot \frac{\partial (q + q^*)}{\partial \alpha} \tag{22}$$

Using equation (15) and Cramer's rule, and excluding the special cases identified in Proposition 3, wherein α=β (because q_0=0 or β=1),we can rewrite (22) in the following form

$$\left.\frac{\partial S}{\partial \alpha}\right|_{\alpha=\beta} = Q \cdot \left[q_0 \cdot v'(N) \Big|_{\alpha=\beta} - SC'(\alpha) \Big|_{\alpha=\beta} - R'(\alpha) \Big|_{\alpha=\beta} \right] > 0 \tag{23}$$

Consumer surplus is increasing in α when evaluated in the neighborhood of α=β because the network externality function, v(N) is monotonically increasing in N and switching costs are monotonically decreasing in α. Consumers have an interest in maintaining compatibility with the original domestic technology that the private firm does not consider in its profit maximizing calculus. This leads directly to one last proposition.

Proposition 4: *A government concerned exclusively about the welfare of domestic parties will not require compliance with the international product standard. It may even have incentive to impose regulatory barriers to trade limiting domestic and/or foreign firms' abilities to sell products that deviate substantially from the original domestic technology*.

While equations (21) and (23) together prove that social welfare is enhanced by deviating from the international product standard, this proposition does not assume the government maximizes social welfare, merely that it is concerned only about domestic parties' welfare.[14] Equations (21)-(23) demonstrate that both domestic producers and consumers are better off if the new technology, α, lies in the interval $(\beta,1]$, so any political economy model based on votes or contributions that depend on these groups welfare will generate an optimal policy choice of $\alpha>\beta$ unless $q_0=0$ or $\beta=1$. An interventionist government will not compel compliance with the international product standard. Gandal and Shy (1996) study governement choice with respect to the recognition of foreign standards and find the desirability of recognition is inversely related to the conversion costs a firm must incur to comply with a foreign standard. With no conversion costs in the present model, this paper offers analogous results from the consumer side: greater consumer switching costs reduce the government's

[14] In other words, the foreign firm or a foreign government cannot bribe the government to enforce domestic compliance with the international product standard.

incentive to enforce an international product standard. The general inference drawn from both papers is that the greater the frictions in technology conversion — on either the consumer or producer side — the less likely is a government to recognize foreign product standards.

Indeed, a consumer-oriented or social welfare maximizing government would more more likely consider introducing regulatory barriers to trade in an effort to resolve the private technology choice externality evident in (23).[15] This analytical result appears consistent with the casual observation that regulatory barriers to trade invariably arise from pressure by import-competing firms, consumer groups, or both (Hillman 1991, Thilmany and Barrett 1997).

Together, Propositions 3 and 4 raise a serious challenge to the international standard-setting process. Incumbent producers in importing nations have no incentive to comply with an international product standard that deviates from their extant technology, and the host nation government has no incentive to force the firm to comply with the international standard, indeed, it may even wish to restrict the firm's ability to approach the international standard. A government from a country that imports network products can thus credibly insist that prospective foreign suppliers conform to the preexisting domestic technology standard, else it will refuse to use regulatory powers to enforce the international product standard and might even, in the interests of consumer welfare, obstruct entry of the international standard. While there is only one importing country in our model, the suggestion is clear that if multiple standards exist, stalemates over *ex post* standardization and reciprocal regulatory barriers to trade would be likely. This seems consistent with experience to date.

[15] Such regulatory barriers may cause foreign firms to incur extra conversion, testing or certification costs in order to meet the differential standard, thus having an effect equivalent to a specific tariff. An unusual characteristic of this quasi-protectionism is that, as the present model shows, it might be desired by consumers more than by producers.

IV. Conclusions

There is widespread belief that harmonized international product standards promote trade and economic welfare globally. Considerable government and corporate human and financial resources are thus committed to the process of negotiating and enforcing international standards. However, the diversity of original technologies among potential trading firms and countries makes standards-setting a difficult process.

The simple model presented in this paper suggests that establishing an international standard that governments and firms will honor may be formidable for an important class of goods, those characterized by network externalities, for which compatibility is central to market performance. First, if an importing country already has a significant network size under its original domestic technology, the domestic producer has an incentive to deviate from any international product standard that is not fully compatible with its own original technology. This clearly suggests a problem of path-dependence or lock-in effects, whereby a technology persists whether or not it is technically superior to other available technologies. Second, the social welfare maximizing government of an importing country has no incentive to force its producer to comply with the international standard. Indeed, the firm's profit maximizing choice to deviate from the international product standard generates additional domestic consumer surplus because it reduces consumers' switching costs. Knowing this, governments from economies not possessing comparative advantage in a product (i.e., prospective importers) have incentives to credibly resist product standardization, thereby potentially frustrating multilateral efforts to negotiate technologically superior standards. Moreover, heterogeneity in standards gives rise to technical barriers to trade.

Our generally pessimistic conclusions about the prospects for global harmonization in network product standards should nonetheless be interpreted carefully. Ours is a parsimonious model that does not include the dynamic evolution of international standards, uncertainty about emerging technologies, strategic interaction among the parties negotiating standards, or the potential for market power exercised by exporting firms. The rapidly advancing literature on networks suggests uncertainty and strategic interaction can be of considerable importance. It would also be fruitful to establish explicitly exporting firms' and governments' incentives to adopt international product standards. This paper neverheless offers an intruiging first look at the economics of international product standardization.

REFERENCES

Farrell, Joseph and Garth Saloner, "Standardization and Variety," *Economics Letters*, 1986, 20, 71-74.

Gandal, Neil, "Competing Compatibility Standards And Network Externalities in The PC Software Market," *Review of Economics and Statistics*, November 1995, LXXVII, 599-608.

Gandal, Neil and Oz Shy, "Standardization Policy and International Trade," mimeo, 1996.

Hillman, Jimmye S., *Technical Barriers to Agricultural Trade*. Boulder, CO: Westview Press, 1991.

Jain, Subhash C., "Standardization of International Marketing Strategy: Some Research Hypotheses," *Journal of Marketing*, January 1989, 53, 70-9.

Katz, Michael L., and Carl Shapiro, "Network Externalities, Competition, and Compatibility," *American Economic Review*, June 1985, 75, 424-40.

Katz, Michael L. and Carl Shapiro, "Product Compatibility Choice in a Market with Technological Progress," *Oxford Economic Papers*, November 1986,

Katz, Michael L. and Carl Shapiro, "Systems Competition and Network Effects," *Journal of Economic Perspectives*, Spring 1994, 8, 93-115.

Kende, Michael, "Strategic Standardization in Trade with Network Externalities," mimeo, 1991.

Klemperer, Paul, "Competition When Consumers Have Switching Costs: An Overview With Applications to Industrial Organization, Macroeconomics and International Trade," *Review of Economic Studies*, 1995, 62, 515-539.

Matutes, Carmen and Pierre Regibeau, "Mix and Match: Product Compatibility Without Network Externalities," *Rand Journal of Economics*, Summer 1988, 19, 221-234.

Matutes, Carmen and Pierre Regibeau, "A Selective Review of the Economics of Standardization: Entry Deterrence, Technological Progress and International Competition," *European Journal of Political Economy*, 1996, 12, 183-209.

Pargal, Sheoli, "Do Incompatible Network Standards Lead To Domestic Benefits? The Case of Color Television," *Information Economics and Policy*, 1996, 8, 205-227.

Shy, Oz, "Technology Revolutions in the Presence of Network Externalities," *International Journal of Industrial Organization*, October 1996, 14, 785-800.

Sykes, Alan O., *Product Standards for Internationally integrated Goods Markets*, Washington: Brookings Institution, 1995.

Thilmany, Dawn D., and Christopher B. Barrett, "Regulatory Barriers In An Integrating World Food Market," *Review of Agricultural Economics*, Spring/Summer 1997, 19, 91-107.

Wilson, John S., Standards and APEC; An Aciton Agenda, Washington: Institute for International Economics, 1995.

APPENDIX

Proof of Proposition 1

When evaluated around the point $\alpha=\beta$, $f'(\alpha-\beta) = 0$, and thus equation (16) becomes

$$\partial q/\partial\alpha = 2/3[v'(N)q_0 - SC'(\alpha)\text{-}R'(\alpha)] > 0 \quad \text{(A1)}$$

But since SC'=R'=0 when q_0=0, then $\partial q/\partial\alpha *_{\alpha=\beta}$ =0 if and only if q0 = 0.

Proof of Proposition 2

There are three parts to the proof of this proposition.

(a) When v'(N*)=0, equation (16) reduces to

$$\frac{\partial\hat{q}}{\partial\alpha} = 1/3\Big[f'(\alpha-\beta)[2v'(N)(q* + q_0*)] + 2v'(N)q_0 - 2SC'(\alpha) - 2R'(\alpha)\Big] \quad \text{(A2)}$$

If $\alpha \leq \beta$, then all terms on the right-hand side of (A2) are positive because $f'(\alpha\text{-}\beta) \geq 0$, but (A2) cannot be signed for $\alpha > \beta$.

(b)When v'(N)=0, equation (16) reduces to

$$\frac{\partial q}{\partial\alpha} = 1/3\Big[f'(\alpha-\beta)(-v'(N^*)q) - 2SC'(\alpha) - 2R'(\alpha)\Big] \quad \text{(A3)}$$

If $\alpha \geq \beta$, then all terms on the right-hand side of (A3) are positive because $f'(\alpha-\beta) \leq 0$, but (A3) cannot be signed for $\alpha < \beta$.

(c) When v'(N)=v'(N*)=0, equation (16) reduces to

$$\frac{\partial q}{\partial\alpha} = -\frac{2}{3}\Big[SC'(\alpha) + R'(\alpha)\Big] \quad \text{(A4)}$$

which is positive for all $\alpha < 1$. Q.E.D.

Proof of Proposition 3

There are three parts to the proof of this proposition.

(a) If q_0=0, then (18) reduces to $\hat{q}\, v'(N)\, f'(\hat{\alpha}\text{-}\beta)\, (\hat{q}^* + q_0^*)$ which equals zero if and only if $f'(\hat{\alpha}\text{-}\beta) = 0$, i.e., $\hat{\alpha}=\beta$. [Note, if q_0=0, then v'(N)>0.]

(b) If not q_0=0, then when equation (18) is evaluated around $\alpha=\beta$, it becomes

$$\frac{\partial\Pi}{\partial\alpha} = q\left[v'(N)(q_0) - SC'(\alpha) - R'(\alpha) - \frac{\partial\hat{q}^*}{\partial\alpha}\right] > 0 \quad \text{(A2)}$$

This is necessarily positive because Proposition 1 tells us that $\partial\hat{q}/\partial\alpha>0$,which implies the final term, $\partial\hat{q}^*/\partial\alpha$, is negative, while all the other terms are nonegative. Therefore, if $q_0\neq 0$, profits are increasing in α, leaving only a boundary solution, $\alpha=\beta=1$, as an optimal choice where $\hat{\alpha}=\beta$.

(c) If $\beta=1$ and either the international or the original domestic network is mature (q_0 or $q_0^*=\bar{N}$, so that $v'(N^*)=0$ or $v'(N)=0$), then (18) is everywhere positive because $\partial\hat{q}/\partial\alpha>0$ by the proof of proposition 2 , implying $\partial\hat{q}^*/\partial\alpha<0$ in a Cournot game, thus $\hat{\alpha}=\beta=1$ is the only solution (by the complementary slackness condition).

Hence the necessity of $q_0=0$ or $\beta=1$ for $\hat{\alpha}=\beta$. Q.E.D.

Proof of Proposition 4

Proposition 4 cannot be proved without imposing considerable, arbitrary structure on f(.) and v(.), but we can prove that it holds for both infant and mature technologies. Given that we are relying on a sequence of sufficient conditions, the unproven suggestion is that the relation holds more generally. Call the lefthand side of (19) Λ. Assume long-run equilibrium under monopolistic competition, i.e., $p^*-p = -R(\alpha)/q$. Then partial differentiation of Λ with respect to q_0 yields:

$$\partial\Lambda/\partial q_0 = \alpha - \beta + R(\alpha)/q^2 \cdot \partial q/\partial q_0$$

Since the first term is positive given the optimal technology choice ($\alpha>\beta$) and $R(\alpha)/q^2>0$, a sufficient condition for $\partial\Lambda/\partial q_0 > 0$ is

$$\partial q/\partial q_0 \geq 0$$

Comparative static analysis of (13) and (14) reveals that

$$\partial q/\partial q_0 = [2v'(N)\alpha - v'(N^*)\beta]/3$$

Without imposing specific functional forms on f() and v(.), this expression cannot be signed unambiguously. But the sufficient condition is satisfied at either end of the continuum relevant to v(.), i.e., for large or small q_0 . For large q_0, or more precisely $\partial q/\partial q_0|_{q0=\bar{N}/\beta} = 0$, since both $v'(N)$ and $v'(N^*)\rightarrow 0$. For small q_0, $\partial q/\partial q_0|_{q0=0} \geq 0$ if $q< q^* + q_0^*$. This can be seen by rearranging the righthand side above so that the sufficient condition is $v'(N)/v'(N^*)\geq \beta/(2\alpha)$, for which a sufficient condition is that $N<N^*$. Using (1) and (2), with $q_0=0$, we find that $q< q^* + q_0^*$ is a sufficient condition, i.e., if the installed base in the international standard technology is relatively large.