# Strategic Interoperability Standards and Trade Policies for Industries with Network Externalities*

Mikhail M. Klimenko
University of California, San Diego
9500 Gilman Drive, La Jolla, CA 92093, USA
mklimenko@ucsd.edu

March 24, 2004

Abstract

The paper considers a country (home) in which domestic and foreign firms produce partially incompatible products while heterogeneous consumers value both variety and a network externality. The presence of the network externality justifies home government intervention by means of a standard requiring the foreign firm to guarantee a minimum level of compatibility between its own product and the product of the domestic rival. However, the home government's unilateral standard is inefficiently stringent from the global perspective. The paper also clarifies the exporting (i.e., foreign) government's incentives for a policy affecting the degree of compatibility between the exported and import-competing products in the home market. Based on the analysis of the governments' incentives, we examine the equilibrium outcome of the non-cooperative game in which the home government uses the compatibility standard and the foreign government uses a subsidy (or a tax) for compatibility-enhancing R&D. We show that the non-cooperative use of the compatibility policies by the countries always results in an inefficient combination of trade volume and compatibility level. The paper also evaluates the existing provisions in the WTO legal system aimed at minimizing the trade-inhibiting impact of technical standards and regulations.

JEL classification numbers: L5; F13

Keywords: Technical Standards; Network Externalities; Trade Policy.

# 1. Introduction

A growing number of international trade disputes concerning domestic standards and regulations reflect declining importance of traditional trade barriers such as tariffs and quotas and the increasing reliance of governments on more subtle instruments of protection against foreign competition. The rising importance of standards in commercial policy matters led to active discussion of their trade-inhibiting implications in the analytical and empirical trade literature.[1] However, the formal economic analysis of standards as tools of trade policy has been focused primarily on quality, environmental, and labor standards. Relatively little attention has been given to the trade policy role of standards and regulations that ensure technical compatibility (or interoperability) among goods and services the consumption of which generates demand-side scale economies or network externalities. The trade policy implications of such technical compatibility standards and regulations are the main focus of this paper.

The international disciplines governing technical compatibility regulations and standards for goods and services are contained in the original General Agreement on Tariffs and Trade (GATT), as well as in the Agreement on Technical Barriers to Trade (TBT) and the General Agreement on Trade in Services (GATS), both of which were concluded during the Uruguay Round of multilateral trade negotiations. While all of these agreements prohibit the discriminatory use of standards, they do not deny any country the right to use standards and regulations to pursue legitimate domestic regulatory objectives. One such legitimate objective is to maintain seamlessness and integrity of national information and communication technology (ICT) networks and infrastructure.[2] The economic theory justification for this objective is associated with the notion of the positive network externality, which is maximized when all products constituting the network are perfectly compatible. Perfect compatibility can be achieved by imposing the standard, which mandates the adoption of a uniform technical design by all producers. However, for many types of networks the desired degree of integrity and seamlessness can be achieved by means of less stringent compatibility standards, which allow heterogeneity among technical designs embodied in the elements of the network and specify an acceptable range of performance characteristics that have to be guaranteed during interoperation of these elements.[3]

---

[1] See, for example, Bagwell and Staiger (2001), Fischer and Serra (2000), Gandal and Shy (2001), and Maskus et al. (2001).

[2] Information technology has been making an important contribution to globalization and economic growth. The share of ICT equipment in world merchandise exports has increased from 9% in 1990 to 13% in 1998. (See OECD, 2001.) Special characteristics of trade in ICT equipment and services are recognized in the WTO Information Technology Agreement (ITA) concluded in 1997. The primary goal of that agreement is the reduction of customs duties to zero on a limited range of information, communication, and broadcasting technologies. One of the goals of the Doha Round of the multilateral trade negotiations is to conclude a follow-up agreement (ITA II), which will expand product coverage and create clear international disciplines for trade-related ICT regulations and standards.

[3] The Organization for Economic Co-operation and Development (OECD) distinguishes four types of these standards for the ICT industry: interoperability, public network integrity, electromagnetic compatibility (EMC), and interference avoidance standards. (See OECD, 2000a, 2001.) While the interoperability and public network integrity standards are directly aimed at improving interconnection among devices constituting the network, the EMC and

*Motivating examples and evidence*

There are a large number of examples of technical compatibility standards imposed for legitimate domestic public policy reasons that have had trade-inhibiting effects. Imports of wireless communication equipment for the licensed spectrum bands are often hindered by strict requirements for interoperability between the imported equipment and the networks already licensed and deployed in the domestic market.[4] Imports of wireless equipment for the unlicensed spectrum bands are sometimes inhibited by strict spectrum sharing, interference avoidance and data security standards, which can be complied with only through costly modifications of the imported equipment.[5]

Another example concerns suppliers of direct broadcasting satellite services and equipment intended for high-definition television (HDTV) in the E.U. and the U.S. These suppliers often complain that the main

---

interference avoidance standards help to improve compatibility by reducing the congestion and signal interference in shared communication channels.

[4] The second- and third-generation digital wireless communication networks in Europe are based on the Global System for Mobile Communications (GSM) and the Universal Mobile Telecommunications System (UMTS), respectively, both of which are sponsored by a group of European telecommunication companies. When a U.S. company, Qualcomm, developed an alternative wireless communications system called Code Division Multiple Access (CDMA), the European Telecommunications Standards Institute (ETSI) responsible for setting the European Union's telecommunications standards did not explicitly ban CDMA networks but imposed prohibitively strict roaming requirements on wireless network operators wishing to use the CDMA technology. These roaming requirements essentially imply that in order to sell their equipment in Europe the CDMA equipment makers will have to supply fully integrated dual-mode (CDMA/GSM) wireless handsets and cell stations that can ensure perfectly smooth roaming between the networks based on the different systems. The high cost of compliance with these requirements has made the exporting of CDMA equipment to Europe economically infeasible. Only very recently the cost of chipsets which enable multimode phones operational over both CDMA and GSM has gone down enough to make production of CDMA/GSM handsets economically feasible. For example, in 2002 Qualcomm announced its dualmode platform MSM6300, which supports CDMA and GSM/GPRS, and platform MSM6500, which supports CDMA 1X and 1XEV-DO along with GSM and GPRS. For a discussion of the trade-inhibiting effects of ETSI's standardization practices see Clarke (1999) and Grindley, Salant, and Waverman (1999).

[5] For wideband Wireless Local Area Networks (WLAN) operating in the 2.4 GHz frequency band, otherwise known as Wi-Fi networks, China has developed its own standard *GB 15629.11-2003*, which is different from the U.S. backed standard specified by the *802.11* committee of the Institute of Electrical and Electronics Engineers (IEEE). The main difference between the two standards is in terms of encryption and quality-of-service specifications. In order to comply with the encryption compatibility requirement for the Chinese market, foreign Wi-Fi chip makers and equipment manufactures have to implement costly modifications of their products in accordance with China's WLAN Authentication and Privacy Infrastructure standard (WAPI). (See Mannion and Clendenin, 2003.) The U.S. government claimed that the WAPI encryption requirement for Wi-Fi equipment imports violates China's WTO commitments with regard to national treatment and market access and threatened to file a complaint against China in the WTO. (See Clendenin, 2004.) For WLAN operating in the 5 GHz frequency band, the E.U. telecom regulator ETSI has developed the High Performance European Radio Local Area Network 2 (HiperLAN2) standard, while most of the U.S. equipment makers support the IEEE 802.11a standard. Both the European and the U.S. equipment vendors acknowledge that it is technically feasible albeit costly to achieve interoperability between the two systems through dual-mode 802.11a/HiperLAN2 solutions based on flexible digital signal processing architectures. What prevents them from selling in each other's markets are the excessively stringent interference avoidance and power emission requirements set by the regulators in the U.S. and the E.U. (See Wong, 2001, and McLean, 2001).

impediment to their entry into these markets are the excessive technical regulatory requirements for the signal conversion to ensure that the HDTV programming can be sent and received between transmitters and receivers based on the European and the U.S. systems. (See European Commission, 2001.)

Finally, with the introduction of Europe's own satellite navigation system, Galileo, the U.S. manufacturers of equipment based on the Global Positioning System (GPS)—and the U.S. airlines using this equipment—fear that the E.U. regulators may impose excessively strict requirements for interoperability between the GPS receivers installed in the aircraft and the Galileo-based transmitters in the European airports. Compliance with these requirements would involve substantial additional costs for the U.S. companies and might erode their competitive positions in Europe. (See O'Neil, 2001.)

A number of sectoral case studies and firm level surveys conducted by the OECD documented the empirical importance of technical compatibility regulations as instruments of commercial policy in network industries. For example, OECD (2000a) presented results of a survey of 20 manufacturers of terminal telecommunications equipment (TTE) in the United States, Japan, the United Kingdom, and Germany. The majority of surveyed telecommunications companies indicated that because of the need to adapt products to meet technical specifications related to interoperability, interference avoidance and public network safety in export markets their production costs were greater than for an equivalent domestic manufacturer in the export market. The estimates of additional production costs ranged from 5 to 10 per cent.[6] 13 out of 20 surveyed telecommunications equipment firms indicated that they had been prevented from exporting products due to the magnitude of costs of compliance with technical compatibility standards in the export markets. (See OECD 2000a, p. 93.)

Another OECD case study focused on trade implications of a specific type of regulation of electrotechnical sector -- electromagnetic compatibility (EMC) standards. (See OECD, 2000b.) EMC standard includes a specification for a method to prevent damage to electricity supply networks from unwanted low-frequency harmonic current emissions produced by electrical products. The study indicated that the cost to industry of enforcing the EMC standard throughout the world could exceed US$50 billion per year.[7]

---

[6] Gandal (2001) provides qualitative evidence that cellular communications equipment firms are likely to dominate in their own domestic markets in which foreign equipment makers are subject to very strict compatibility standards. He notes that 63 per cent of all mobile phones sold in the U.S. are produced domestically while the corresponding shares of the domestic producers in the U.S. markets for audio and video equipment are, respectively, 19 and 26 per cent. One of the reasons for such a difference in the domestic marker shares of the U.S. firms in these industries undoubtedly has to do with greater compatibility compliance costs that foreign importers incur in order to gain access to the U.S. cellular communications equipment market compared to these costs in audio and video equipment markets.

[7] High costs caused by standards-related trade barriers in the area of telecommunications terminal equipment were also reported in the recent OECD (2001) case study of telecommunications sector. The study points out that differences over approaches to technical compatibility regulations across countries arise from different evaluation of types of harmful effects of incompatibility and interference for telecommunications network.

*Main contribution of the paper and the relevant previous literature*

Inspired by these examples and empirical evidence, this paper considers an analytical framework combining elements of well-known models of trade under imperfect competition with the approaches taken in the industrial organization literature in analyzing the role of compatibility-enhancing devices in industries with network externalities.[8] Specifically, we analyze a home-market "half" of the reciprocal-markets model in which a domestic firm and a foreign firm supply imperfectly compatible products while heterogeneous consumers value both variety and compatibility. This framework allows us to highlight three important trade-related aspects of compatibility issues, which were not considered in the earlier international trade literature.

First, we show that, to the extent the imported and the import-competing products are not perfectly compatible, international trade creates a negative externality in the home country. If the home country is closed to international trade, the consumers have no other choice but to adopt the domestic firm's product. Since the products of the same make are perfectly compatible, the advantage of autarky is that it maximizes the positive network externality. Opening the domestic market to international trade brings foreign competition, which directly benefits the consumers by expanding the variety of available products and reducing the prices. However, the adoption of the foreign product by some domestic consumers undermines the integrity of the domestic network because the foreign product is not perfectly compatible with the domestic product. The fact that after opening the market to trade the homogenous domestic network is replaced by partially incompatible rival networks implies that the country loses the positive network externality associated with the single-technology nationwide network.

Second, although the loss of the network externality can be reduced by increasing compatibility between the imported and the import-competing products, any home country compatibility policy (short of ensuring complete compatibility) is insufficient to overcome a distortion in the product adoption pattern among the users. As Farrell and Saloner (1992) demonstrated in the closed economy context, the pattern of adoption of partially incompatible products by users is inefficient because users adopt their most preferred product without taking into account the effect of their adoption decisions on the relative size of the rival networks. Under oligopoly, this inefficiency is aggravated by the distortion caused by the imperfectly competitive pricing behavior of the firms. The socially optimal sorting of the users into the two rival networks strikes a balance

[8]The effects of compatibility-enhancing devices (e.g., converters, adapters, gateways) on technology adoption in a closed economy with network externalities were discussed informally by Braunstein and White (1985), David and Bunn (1988), David and Greenstein (1990), and David and Steinmueller (1994). Formal analyses of the effect of converters on the outcome of the strategic interaction between the rival firms and technology adoption by users were conducted by Katz and Shapiro (1985, 1986), Berg (1988), Economides (1988, 1991), Farrell and Saloner (1992), and Choi (1997).

between the network-related component of the social welfare and the "stand-alone" component, the latter being defined by the user utility derived from the product characteristics independently of the network effect.

The third aspect has to do with the incentives to achieve greater compatibility among the firms competing internationally in the imperfectly competitive environment. In this paper, we assume that the degree of compatibility between rival products can be increased by means of a symmetric compatibility-enhancing technology (i.e., a converter or an adapter), which can be incorporated into the main technical design of either one of the two rival products. Depending upon the allocation of the control rights over the interface between the rival designs, the decision regarding the compatibility enhancement may require a certain degree of cooperation and cost sharing between the rival firms. But regardless of the interface control issues, each of the rival firms has insufficient incentives for enhancing compatibility because some of the enhanced network benefits accrue to consumers and to the rival firm. What makes this problem trade-policy relevant is that as long as some of the cost of attaining greater compatibility is borne by the foreign firm, the home government has the incentive to choose inefficiently stringent (from the global welfare maximization perspective) regulation or standard for compatibility between the rival goods. This creates the possibility of a regulatory sham in trade policy—i.e., the practice of using a legitimate regulatory objective to disguise a protectionist action.

The incentives affecting the optimal trade and industrial policies toward international oligopoly in the domestic market *without* network externalities are well understood in the trade literature (see, for example, Brander and Spencer (1984), Dixit (1984, 1988), Eaton and Grossman (1986, Section 6), Cheng (1988) and Krishna (1989)). This literature demonstrates that trade restrictions against foreign firms involve a trade-off between the negative effect on the domestic consumer surplus and the positive effect on the domestic firms' profits. Despite this trade-off, under fairly typical conditions the optimal trade policy is an import tariff, which allows the home government to shift rents from the foreign firms to the domestic firms and the domestic treasury. Moreover, if the import tariff is the only policy instrument available to the home government, then in the full optimum the government should use it not only for rent shifting but also for targeting the domestic consumption distortion arising from the non-competitive behavior of the domestic firms (see Dixit (1988)).[9]

[9] Brander and Spencer (1984) demonstrated that under homogenous good international Cournot duopoly in the domestic market the import tariff is the optimal policy if it does not reduce the domestic consumer surplus too much relative to the domestic firm's gain in market share. Eaton and Grossman (1986) generalized the Brander and Spencer result by pointing out that domestic firms often choose their actions on the basis of incorrect conjectures about the actions of foreign firms. If the government understands that the domestic firms' beliefs are incorrect and can precommit to tax/subsidy schemes, there is a role for government policy in correcting the distortions arising from the incorrect conjectures of the firms. Using a conjectural variations approach, Dixit (1988) showed that an import tax and a domestic production subsidy are optimal under various assumptions about the substitution between foreign and domestic goods in the domestic demand. Cheng (1988) used a similar approach and showed that for international duopoly in the domestic market an import tax and a domestic production subsidy are optimal under both Cournot and Bertrand conjectures.

Krishna (1988) considered a model in which the domestic and foreign markets are linked by a common network, and in which expectations about the size of that network affect the demand. In her model, greater sales in the domestic market of the exporting firm raise marginal revenue in the export market because the exporting firm's foreign and domestic user bases constitute a single international network. The main difference between our model and Krishna's is that we focus on the role of compatibility standards in the importing country rather than on the effect of the exporting country's domestic network on the demand for exports. In our model, exports can be increased by ensuring greater compatibility of the exported product with the product of the rival firm in the export market.[10]

Gandal and Shy (2001) use a three-country model to formally analyze government's incentives to recognize foreign standards when there are potentially both network effects and conversion costs (i.e., costs of attaining compatibility). They show that depending on the relative magnitude of conversion costs and network effects, the countries may agree to mutual standards recognition universally or in a restricted fashion through the formation of a standardization union, which excludes one country. Their approach and ours are similar in that each highlights how government's incentives to use standards as strategic trade policy instruments depend on the inherent tension between costs of attaining greater compatibility and network effects. However, in their analytical framework, unlike ours, governments cannot use traditional instruments of trade policy such as tariffs and subsidies.

The international economics literature recognizes that countries have incentives to use domestic regulations and standards to affect the international competitiveness of their firms not only in imperfectly competitive markets but also in environments in which offer curves are well defined and countries are large enough to affect their terms of trade. For example, Bagwell and Staiger (2001) showed that the government of the importing country has the incentive to impose *unduly lax* standards on the domestic import-competing firms. The government of the exporting country can change the terms of trade to its advantage by imposing *excessively stringent* standards on exporters. If the home firms compete with the foreign firms in a third-country market, the unilaterally optimal home country standard will again be unduly lax in comparison with the home standard. If, in addition to the terms-of-trade driven externalities, there are other types of cross-border externalities, then the regulatory laxity toward exporters may create additional concerns about cross-boundary spillovers, "races to the bottom," and "regulatory chill," which have also been discussed by economists (see Bagwell et al. (2002)).

---

[10] Therefore, in our formulation, the exporting country does not have to have a substantial user base in its own domestic market to be able to promote exports. An example can illustrate the relevance of our formulation. The U.S. was able to promote the adoption of the CDMA wireless equipment abroad when the CDMA network was not dominant in the U.S. By creating incentives for the U.S. CDMA equipment manufacturers to develop interference-reduction chips and protocols for multimode wireless handsets, the U.S. government achieved large sales of the CDMA equipment in countries that had extensive incumbent networks based on non-CDMA digital and analogue technologies.

*Overview of the structure of the paper and the main results*

The basic analytical framework of the paper is introduced is Section 2, where we describe the equilibrium outcome of the price-setting game between the rival firms assuming that the degree of compatibility between their products is given. In Section 3, we examine how government motives for trade policies are affected by the presence of the distortions caused by the imperfect compatibility between the domestic and foreign products. After we clarify the trade policy incentives of the home government, we extend our model by assuming that in addition to the import tariff the home government can set a standard that establishes the minimum degree of compatibility between the foreign and domestic products. The standard reduces the loss of the social network benefit arising from the decision by some domestic users to adopt the foreign product. However, if the costs of compliance fall primarily on the foreign firm, then the home government has the incentive to impose an excessively stringent (from the global perspective) compatibility standard.[11] Section 3 analyzes the combination of the import tariff and the compatibility standard that would be optimal for the home government in this environment, as well as the optimal standard under a free trade agreement restraining the government's ability to use the import tariff.

In Section 4, we analyze the incentives of a foreign government to use a policy affecting the foreign firm's choice of the degree of compatibility between its own product and the home firm's product. The foreign government can use this policy alone or in combination with the export taxes or subsidies. The incentives of the foreign government to conduct a compatibility-suppressing (or compatibility-enhancing) policy are somewhat similar to the incentives to tax (or subsidize) the exporting firm's quality-enhancing investment or cost-reducing R&D, which have been addressed in the strategic trade policy literature (see, for example, Spencer and Brander (1983), Cheng (1988) and Zhou et al. (2002)). However, in our setting the optimum mix of trade and compatibility-enhancing policies of the foreign government is affected by the presence of the

[11] Given the structure of our model, both rival firms prefer greater compatibility and can coordinate on its jointly efficient level for any allocation of the intellectual property rights over the interface. In practical terms, this can be achieved through a cross-licensing arrangement that ensures that costs and benefits of compatibility-enhancement are allocated according to the bargaining powers of the rivals in dividing the joint surplus from greater compatibility. Since we are interested in trade effects of the domestic compatibility standard, we adopted a simplifying assumption under which the entire cost of achieving compatibility is born by the foreign firm. This means that the burden of standard-compliance falls disproportionately on the foreign firm. Therefore, the compatibility standard we consider in this paper is inherently discriminatory.

However, the difference in the standard-compliance costs that arises from the allocation of the intellectual property rights over the interface does not necessarily imply a violation of the national treatment principle. If the firm controlling the interface were domestic, then the burden of compliance with the standard would fall on the domestic firm. What matters is not the fact that the regulatory burden incurred by a firm varies depending upon the extent to which its control over the interface makes it responsible for remedying the targeted problem, but rather the effect of the national identity of the firm bearing the main share of regulatory burden on the stringency of the domestic regulation. This issue is further discussed in the next section. A possible extension of this paper would be a full reciprocal markets model (i.e., with domestic consumption in the home and foreign markets) in which the allocation of control rights over the interface is determined as an outcome of a bargaining game between the foreign and home firms. In that framework, the home government's optimal compatibility standard would take into account the fact that a share of the standard-compliance cost is borne by the home firm.

network externality. Section 4 shows that when compatibility affects the firm's fixed cost but not its marginal cost, the export tax policy interferes with the policy aimed at stimulating greater compatibility of the exported product with the local rival's product in the export market. Although both policies can serve as instruments of rent-shifting by helping to relax price competition between the firms in the export market,[12] the export tax is in conflict with the goal of compatibility enhancement because it reduces the foreign firm's incentives to make its product compatible with the domestic product. To overcome the negative effect of the export tax on the foreign firm's incentive to invest in compatibility, the foreign government has to subsidize the firm's investment. Therefore, to achieve the fully optimal outcome in this setting the foreign government must combine the export tax and the subsidy for compatibility-enhancing investment.[13]

After we clarify the foreign and home governments' incentives for policies affecting the degree of compatibility between the imported and import-competing products, we analyze, in Section 5, the equilibrium outcome of the non-cooperative game in which the home government uses the compatibility standard and the foreign government uses a tax (or a subsidy) linked to the foreign firm's compatibility-enhancing effort. To simplify the analysis and to emphasize the trade-related implications of policies toward compatibility, we assume that a free trade agreement restrains the governments' ability to use trade taxes. In addition, in this section we depart from the assumption that compatibility does not affect the marginal cost of the foreign firm. In this setting, the governments' incentives for using trade taxes are deflected into their compatibility policies. We derive the governments' best response policy functions and analyze some of the properties of the Nash equilibrium of the compatibility policy game.

In Section 6, we examine international agreements on policies toward compatibility. First, we characterize the combination of compatibility policies that is jointly efficient for the two countries. Having identified the globally efficient policy combination, we analyze the inefficiencies that are present in the non-cooperative equilibrium. By comparing the Nash equilibrium outcome with the globally efficient policy combination, we can discern the changes in the countries' policies toward compatibility that should arise as a result of international cooperation in the area of compatibility policies. We show that in the Nash equilibrium the level of compatibility between the rival networks and their relative sizes are always different from the world optimum. Therefore, the strategic use of compatibility policies by the countries always leads them to an

---

[12] Greater compatibility with the rival's product makes the firm's profit less dependent on its own market share. This effect blunts competition for market share between the rival firms and leads to higher prices.

[13] Obviously, the conclusions regarding the sign of the optimal policies are sensitive to the assumption that the firms compete in prices. Had we assumed that the firms hold Cournot conjectures or choose outputs rather than prices, their decision variables would be strategic substitutes, and the sign of the optimal policies would be the opposite of what we have in this paper, at least for the exporting country government. Since the goal of our analysis was to illustrate in principle how government incentives to pursue international trade policy goals using compatibility policy instruments are affected by the presence of the network externality and user preference heterogeneity, we decided to confine our analysis to the setting involving price-competing firms, which is common in the industrial organization literature on compatibility. An analysis of trade policy in an environment in which the firms' choice variables are strategic substitutes can be developed using, for example, the Cournot framework with rational expectations employed by Katz and Shapiro (1985).

inefficient combination of trade volume and compatibility level. Depending upon the strength of the network externality effect, there can be either an excessively high equilibrium level of compatibility (in combination with either too much or too little trade) or very low levels of both compatibility and trade.

In Section 7, we discuss our findings in the context of the existing provisions of the WTO legal system aimed at minimizing the trade-inhibiting impact of domestic technical standards and regulations. In particular we use the results of our formal analysis to evaluate whether the "least-restrictive means" principle of policing technical regulatory barriers to trade is sufficient to enable the WTO member countries to reach global efficiency in the presence of network externalities.

## 2. The basic model: consumer demand and costs

The analysis is conducted within a two-country framework in which a domestic firm A and a foreign firm B supply two products for the home country market.[14] Although domestic users have heterogeneous preferences regarding the products, they also value compatibility between the products they adopt and those adopted by other users because compatibility allows them to experience positive network externality. While users can achieve perfect compatibility if they adopt the product of the same firm, users of different firms' products can enjoy only partial compatibility. The extent of compatibility enjoyed by any two users of the different products is determined by the parameter $\gamma \in [0, 1]$, representing the fraction of the full compatibility benefit that the two users could realize if they adopted the product of the same make.[15]

In modeling the consumer preferences, we follow Farrell and Saloner (1992). Specifically, we consider a unit mass of domestic users, each of which has an inelastic demand for one unit of the products. The users differ in terms of their taste index $s \in [0,1]$, which determines the "stand-alone" value of the product to them (i.e., users' willingness to pay for the product regardless of the network externality). Assuming that users' relative preferences for product A over product B increase in $s$, the stand-alone utility accruing to a user with index $s$ from adopting the products is given by:

[14] By ignoring the domestic market in the foreign country we focus on one of the two national markets of a reciprocal markets framework. A usual caveat about the conditions of market segmentation applies. The results of our analysis can be readily extended to a full reciprocal markets model incorporating the domestic markets of both countries. However, such an extension would involve substantially more notation without generating additional policy-relevant insights.

[15] It is helpful to think about the users as ICT operators providing the services to the unmodeled end consumers. While the end consumers of the ICT services may not appreciate the difference between the alternative technical designs of the substitute technologies underlying the services they purchase, the providers of those services are much more savvy and have clear preferences with regard to both the stand-alone quality of the technology they adopt and compatibility with the rival providers. In that interpretation, the duopolists are suppliers of equipment to the service operators.

$$\begin{cases} a+s \text{ if she adopts product } A; \\ a+(1-s) \text{ if she adopts product } B, \end{cases} \tag{1}$$

where constant $a$ represents the part of the utility that is independent of the underlying product characteristics.[16]

All users share linear preferences for the network benefit. Specifically, if the share of users who adopt product $A$ is $x$ then the network-related component of the user's utility is $nx + n\gamma(1-x)$ if she adopts product $A$ and $n(1–x) + n\gamma x$ if she adopts product $B$ where the parameter $n > 0$ measures the strength of the network externality.[17] Therefore, the consumer surplus of the type $s$ user is:

$$\begin{cases} a+s+nx+n\gamma(1-x)-P_A \text{ if she adopts product } A; \\ a+(1-s)+n(1-x)+n\gamma x-P_B \text{ if she adopts product } B, \end{cases} \tag{2}$$

where $P_A$ and $P_B$ are the prices for products $A$ and $B$.[18]

We assume that the products are incompatible ex ante (i.e., by design) but partial compatibility between them can be achieved by means of an ex post compatibility-enhancing modification, which can be incorporated into the main technical design of one or both rival products. Typically, the amount of control the rival producers have over the degree of compatibility between their products depends upon the allocation of the intellectual property (IP) rights over the technical interfaces. To simplify the analysis, we assume that the degree of compatibility $\gamma$ is controlled by the foreign firm $B$, which can unilaterally undertake

[16] Parameter $a$ captures the reservation price of consumers. We adopt a standard approach employed in applications based on the so-called address models of horizontal product differentiation by assuming that $a$ is sufficiently large to ensure that the reservation price constraint is not binding in the equilibrium with two firms supplying the market. (See Economides (1984) and Neven et. al. (1991)). We also assume that $a$ is large enough to guarantee that no user abstains from purchase even under autarky when the domestic market is supplied by the domestic monopolist producing a single product. Although these assumptions suppress the market-size and market-structure effects, they allow us to highlight the issues related to compatibility in the context of international trade.

[17] More generally, the network-related component of the user's utility is $N(x + \gamma(1-x))$ if she adopts product $H$ and $N((1–x) + \gamma x)$ if she adopts product $F$ where $N(\cdot)$ denotes the network benefit function. $N(\cdot)$ is increasing and concave (convex) if the network externality is characterized by decreasing (increasing) returns to the average level of compatibility attained by the users. Auriol and Benaim (2000) identified the degree of concavity of the network benefit function with the user's tolerance to incompatibility between rival technologies; the more concave the network benefit function the more tolerant is the user to incompatibility. According to Auriol and Benaim's classification, communication networks are neutral to incompatibility, i.e., characterized by the linear network benefit function of the kind considered in this paper. Although we assumed that the network benefit function is linear, the conclusions of our paper remain valid for a nonlinear form of the function, as long as it is not too concave, i.e., the users are not too tolerant to incompatibility.

[18] Given this specification of preferences, if the user $s$ prefers product $B$, then so does every other user in the interval [0, $s$]. Similarly, if the user $s$ prefers product $A$, then so does every other user in the interval [$s$, 1].

a compatibility-enhancing modification of its product.[19] We follow the existing literature by focusing on the symmetric two-way compatibility-enhancing modification, which requires altering only one of the two rival products but confers the same compatibility benefit on the users of both products (see, for example, the discussion of the two-way converters in Choi (1997)). Although these simplifying assumptions are rather severe in terms of the representation of ownership and control of the interface, they allow this paper to focus on the trade effects of the domestic standard that regulates the foreign supplier's choice of compatibility with the domestic product.[20]

For simplicity, the production costs of the firms under complete incompatibility are assumed to be zero. However, the foreign firm's compatibility-enhancing decision affects its production cost. We consider two alternative cost structures. In this section and the next one, we assume that to achieve the degree of compatibility $\gamma$ the foreign firm has to incur a fixed cost $F(\gamma)$.[21] Moreover, after the compatibility-enhancing modification, the unit cost of the foreign product becomes $C > 0$ regardless of the specific level of $\gamma$ chosen by the foreign firm. The investment cost of compatibility, $F(\gamma)$, and the marginal investment cost of compatibility, $F'(\gamma)$, are assumed to be strictly increasing for all $\gamma \in [0, 1]$. In addition, in order to ensure the existence of the interior equilibrium with positive sales of the foreign product in the domestic market we assume that $F(0) =$

[19] A possible interpretation of this assumption is that the domestic firm's interface-related IP rights have already expired while those of the foreign firm have not because the foreign technology is newer than the domestic. In regard to the asymmetry in the interface control between the producers of the two complementary products, see also MacKie Mason and Netz (2002). They discuss technical design strategies, which allow a firm controlling the IP rights over one of the two complementary technical systems to extend the boundary of its control to include the IP rights over the entire interface through which the two systems can interoperate. According to MacKie Mason and Netz, such strategies are quite common in the information technology industry.

[20] Farrell and Saloner (1992) discuss an alternative structure in which two incompatible products are supplied by a duopoly and the converters are supplied by the independent perfectly competitive firms. The consumers are free to choose whether to buy the products with or without converters. In that framework, there are three pure-strategy equilibria in the product adoption game among the users. The first equilibrium ("full standardization") is the adoption of the same product by all users. There is no need to buy converters in this case because users achieve perfect compatibility by virtue of using the same product. The second equilibrium is "perfect incompatibility," which occurs when the users split into two equal groups according to the product they adopt but no one adopts the converter. The third equilibrium ("conversion") implies imperfect compatibility because the users in the larger group buy one of the products without the converter and the users in the smaller group buy the rival product and the converter. In the third equilibrium, it is either only the users of product A or only the users of product B who buy the converters; there cannot be an equilibrium with both groups of users buying the converters. The identity of the minority group of users (i.e., A-users or B-users) who pay for the converters is indeterminate. In the context of our model, the fact that the foreign firm controls the interface and bears the entire cost of compatibility enhancement implies that the users of the foreign product implicitly pay for the converter embedded in the foreign product.

[21] $(1-\gamma)$ can be interpreted as the loss of the network benefit, which is attributed to product performance degradation due to the imperfections of the compatibility-enhancing technology. For example, in wireless telephony, users of multi-mode wireless phones usually experience a greater number of dropped calls and shorter battery life when these phones are used for roaming in wireless networks based on communication protocols or radio frequencies that are different from the users' "native" networks.

$F'(0) = 0$ and $\lim_{\gamma \to 1} F'(\gamma) = \infty$.[22] In Section 5, we will consider an alternative cost structure in which compatibility enhancement affects the unit cost of the foreign firm but does not involve any fixed cost.[23]

The firms compete on prices after firm *B* has already made an investment ensuring the degree of compatibility $\gamma$. Assuming that both firms have positive sales in the domestic market, the condition identifying the marginal consumer $s_B$, who is indifferent with respect to the domestic product *A* and the foreign product *B*, is given by

$$a + (1 - s_B) + ns_B + n\gamma(1 - s_B) - P_B = a + s_B + n(1 - s_B) - n\gamma s_B - P_A. \tag{3}$$

Rearranging equation (3) gives the demand functions for products *A* and *B*:

$$s_B = \frac{1}{2} - \frac{(P_B - P_A)}{2(1 - n(1-\gamma))} \text{ and } s_A = 1 - s_B = \frac{1}{2} - \frac{(P_A - P_B)}{2(1 - n(1-\gamma))}. \tag{4}$$

The profits of firms *A* and *B*, respectively, are: $\Pi_A = P_A s_A$ and $\Pi_B = (P_B - C)s_B$. The Nash equilibrium prices are determined by solving the problem of profit maximization simultaneously for the two firms:[24]

$$\begin{cases} P_A = 1 - n(1-\gamma) + \dfrac{C}{3} \\ P_B = 1 - n(1-\gamma) + \dfrac{2C}{3}. \end{cases} \tag{5}$$

Therefore, the equilibrium sales and profits of the two firms, respectively, are:

$$s_A = \frac{1}{2} + \frac{C}{6(1 - n(1-\gamma))}; \quad s_B = \frac{1}{2} - \frac{C}{6(1 - n(1-\gamma))} \tag{6}$$

---

[22] An example of the function satisfying these assumptions is $F(\gamma) = \beta\gamma(1 - (1-\gamma)^{\alpha})$, where $1 > \alpha > 0$, $\beta > 0$.

[23] The assumption that the cost of achieving a degree of horizontal or vertical product differentiation is sunk prior to the determination of prices and output is well established in the literature. See, for example, Gabszewicz and Thisse (1979) and Zhou et al. (2002). In our model, the fixed cost can be interpreted of as a cost of the interface-related R&D that must be undertaken in order to increase the compatibility between the two products.

[24] It is easy to verify that the second-order conditions are satisfied. However, d'Aspremont et al. (1979) showed that in the Hotelling-type address models a pure strategy Nash equilibrium in prices may fail to exist for some parameter values because the profit functions are not quasiconcave. To ensure the existence of the equilibrium, the firms' price strategies must be price undercutting-proof. The condition for proofness against price undercutting is $|P_A – P_B| < lc$, where $l$ is the distance between the sellers and $c$ is the linear transportation rate. In the context of our model, the distance between the sellers is equal to one and the transportation rate is $(1 – n(1-\gamma))$, which can be demonstrated by presenting the utility of the user $s_B$ in exhibit (2) in the form $(a + 1 + n - n(1-\gamma)) - (1 - n(1-\gamma))(1 - s_B) - P_B$ for the utility derived from product *B* and the form $(a + 1 + n - n(1-\gamma)) - (1 - n(1-\gamma)) s_B - P_A$ for the utility derived from product *A*. Therefore, the condition for price-undercutting proofness for our model is $|P_A - P_B| < (1 - n(1-\gamma))$. Because it follows from equations (5) that $|P_A - P_B| = C/3$, the price-undercutting proofness condition is equivalent to $C/3 < 1 - n(1-\gamma)$. The latter inequality follows from the assumption that the compatibility-enhancing technology is not too inefficient (see the discussion in footnote 25 below): $C < 1 - 2n(1-\gamma) \Rightarrow C < 1 - n(1-\gamma) \Rightarrow C/3 < 1 - n(1-\gamma)$. As can be seen from equations (6), the condition $C/3 < 1 - n(1-\gamma)$ also ensures that in equilibrium both firms have positive sales.

and

$$\Pi_A = \frac{\left(1 - n(1-\gamma) + \frac{C}{3}\right)^2}{2(1 - n(1-\gamma))}; \quad \Pi_B = \frac{\left(1 - n(1-\gamma) - \frac{C}{3}\right)^2}{2(1 - n(1-\gamma))}. \tag{7}$$

Since enhanced compatibility provides symmetric benefits for users of both products but raises the cost of only the foreign product, the market share of the domestic firm must exceed that of the foreign firm. This can be seen from equations (6). Therefore, we are going to refer to the domestic product as the dominant product and to the foreign product as the minority product.

When the foreign product is not perfectly compatible with the domestic product (i.e., $\gamma < 1$), the introduction of the former into the domestic market undermines the integrity of the domestic network and may have a negative effect on the home country welfare. On the one hand, the availability of product *B* increases the welfare of those users who prefer it to product *A*. On the other hand, since the network of product *B* users is only partially compatible with the dominant network of product *A* users, each user who adopts product *B* would have conferred greater total network externality on the society by adopting product *A*. Since *B* users do not take into account the negative effect of their product adoption decisions on the society, in equilibrium there are more *B* users than is socially optimal. Farrell and Saloner (1992) demonstrated that the problem of overadoption of the minority product occurs regardless of whether the rival technologies are supplied by perfectly competitive firms or by the oligopoly. However, under oligopoly the problem is aggravated by the fact that the producer of the minority product can attract even more users by undercutting the above-cost price of the dominant firm.

Opening the domestic market to trade benefits those domestic consumers who prefer the foreign product. However, the home country welfare is negatively affected by the shift of some of the pure rents abroad and the loss of the network benefits due to the disintegration of the homogenous countrywide domestic network into two partially compatible smaller networks. When the negative welfare effects outweigh the positive one, the availability of the rival foreign product through trade reduces the total domestic welfare. In that case, the home country is better off under autarky than with trade. Since the focus of this paper is on trade policy, we make an assumption to the effect that with a rent-capturing import tariff the home country prefers trade to autarky. Specifically, we assume that the compatibility-enhancing technology is not too inefficient: $C < 1–2n$.[25]

---

[25] In a closed economy, if the compatibility-enhancing technology is not efficient enough to satisfy the inequality $C < 1–2n(1–\gamma)$, then the homogenous network based on a single technology is better than the two partially compatible networks even when the market share of the minority technology is optimized. Therefore, in the open economy context, the violation of this inequality implies that even if the import tax captured all rents of the foreign supplier the homogenous network based on the domestic technology under autarky would still be better than the network

# 3. Optimal trade and standardization policies of the home country.

The home government faces a number of distortions, which it can target by means of an import tariff and a compatibility standard. First, there is the strategic distortion, which creates the rent-shifting incentive for policy intervention (see Brander and Spencer (1984) and Dixit (1988)). Second, there is the consumption distortion.[26] However, because the present model assumes that consumers have inelastic unit demand and that the market is fully covered, the consumption distortion is evident not in the presence of consumers who abstain from purchasing but in the inefficient relative size of the dominant and the minority networks. In other words, the dominant network is too small because too many users buy the minority product. Third, the firms (or only the foreign firm in our case) have insufficient incentives for making their products compatible.

After we clarify the home government's incentives that determine its choice of the import tariff for a given level of compatibility between the foreign and domestic products, we extend our model by assuming that in addition to the import tariff the home government can set a compatibility standard. The standard can be chosen either simultaneously with the import tariff or prior to it.[27] In either case, the standard reduces the welfare loss due to the disintegration of the domestic network and shifts the cost of achieving greater compatibility onto the foreign firm, which controls the interface between the two products.

*Optimal tariff*

With a specific tariff $\tau$, the profit function of the foreign firm becomes: $\Pi_B = (P_B - C - \tau)s_B$. The equilibrium prices are thus

$$P_A = 1 - n(1-\gamma) + \frac{(C+\tau)}{3} \text{ and } P_B = 1 - n(1-\gamma) + \frac{2(C+\tau)}{3}. \tag{8}$$

based on the partially compatible domestic and foreign technologies. In order to make the trade policy analysis in our model meaningful, we assume that the conversion technology is sufficiently efficient that the heterogeneous foreign/domestic network in combination with the rent-capturing import tariff is better than the autarky-induced homogenous network based on the domestic technology. The assumption about the conversion technology's efficiency also guarantees that the model is price undercutting-proof (see the discussion in footnote 24). To ensure that the inequality $C < 1-2n(1-\gamma)$ is valid for all $\gamma \in [0, 1]$, we assume that $C < 1-2n$ and $n < 1/2$.

[26] In the trade policy literature, the consumption distortion that arises from the supplier's market power is commonly targeted with a production subsidy (see Cheng, 1988). However, since it is not very realistic to assume that anti-competitive behavior is rewarded with a subsidy, we assume that the home government does not use the production subsidy.

[27] As we are going to demonstrate below, the standard will always be binding when it is used in combination with the tariff. Therefore, we can ignore the effect of the tariff on the foreign firm's choice of compatibility.

Therefore, the equilibrium sales of the firms in the domestic market are:

$$s_A = \frac{1}{2} + \frac{C+\tau}{6\left(1-n(1-\gamma)\right)} \text{ and } s_B = \frac{1}{2} - \frac{C+\tau}{6\left(1-n(1-\gamma)\right)}. \tag{9}$$

The foreign firm will have positive sales on the domestic market if $C + \tau < 3(1 - n(1 - \gamma))$, which can be interpreted as a condition requiring that the loss of the network benefit due to imperfect compatibility is not too large. If this condition is satisfied, then both firms have positive sales, and the equilibrium profits are then given by

$$\Pi_A = \frac{\left(1-n(1-\gamma)+\frac{C+\tau}{3}\right)^2}{2\left(1-n(1-\gamma)\right)} \text{ and } \Pi_B = \frac{\left(1-n(1-\gamma)-\frac{C+\tau}{3}\right)^2}{2\left(1-n(1-\gamma)\right)}. \tag{10}$$

The choice of the tariff by the home government is affected by a number of incentives. As equations (10) show, the tariff shifts some of the foreign firm's profit to the domestic firm. When no other policy instrument is available to the home government, the level of the optimum tariff also reflects its second-best role in targeting the distortionary overadoption of the imported product.

The welfare of the home country is simply the sum of the consumer surplus, the domestic firm's profit, and the tariff revenue:

$$\begin{aligned} W_H(\tau) &= \int_0^{s_B}(a+1-x)dx + \int_{s_B}^{1}(a+x)dx + n\left(1-2s_B(1-s_B)(1-\gamma)\right) - P_B s_B + \tau s_B \\ &= a + 1/2 + n + \left(1-2n(1-\gamma)\right)s_B(1-s_B) - P_B s_B + \tau s_B \end{aligned} \tag{11}$$

The first two terms on the right-hand side of the first equality in (11) represent the stand-alone benefits of users who adopt either product B (users with the taste parameters $s \in [0,s_B]$) or product A (users with tastes $s \in [s_B,1]$). The third term is the maximum network benefit attainable when all users adopt the same product minus the loss due to imperfect compatibility. The last two terms are the cost of the imported products and the home tariff revenue.

To obtain an expression for the optimal tariff, we differentiate (11) with respect to $\tau$:

$$\frac{\partial W_H}{\partial \tau} = \frac{6-3\tau+n(1-\gamma)\left(C+4(\tau-3)+6n(1-\gamma)\right)}{18(1-n(1-\gamma))^2}. \tag{12}$$

If the loss of the network benefit due to incomplete compatibility, $n(1-\gamma)$, is not too large, the welfare function $W_H(\tau)$ is concave in $\tau$.[28] Setting $\partial W_H(\tau)/\partial\tau$ equal to zero and rearranging the terms, we find that the optimum tariff is positive and is given by the expression:

$$\tau^* = \frac{6+n(1-\gamma)\big(C+6n(1-\gamma)-12\big)}{3-4n(1-\gamma)}. \tag{13}$$

Equation (13) implicitly assumes that the optimal tariff is not prohibitive—i.e., that the foreign firm has positive sales when the tariff is $\tau^*$. However, this need not be the case. The import tariff becomes prohibitive if it reaches the level that sets $s_B$ in equation (9) to zero: $\tau^P = 3(1 - n(1-\gamma)) - C$. It is straightforward to verify that when the condition for sufficient efficiency of the compatibility-increasing technology is satisfied (i.e., $C < 1 - 2n$) the optimal tariff is less than the prohibitive tariff: $\tau^* < \tau^P$. Therefore, although the optimal tariff reduces trade, it does not shut it out completely.

### *The effect of compatibility on the optimal tariff*

It is often suggested that greater compatibility reduces product differentiation, which, in turn, sharpens competition and leads to lower price.[29] In this paper, however, greater compatibility with the rival's product reduces the dependency of the firm's profit on the size of its own network and, therefore, makes the profit less sensitive to the firm's market share. This effect blunts competition for market share and leads to higher prices. Thus, as products become more compatible, the firms exert weaker competitive pressure on each other and their profits increase. This implies that greater compatibility between the rival firms strengthens the home government's incentives for conducting the rent-capturing trade policy. This is confirmed by the sign of the derivative of the optimal tariff with respect to the compatibility parameter $\gamma$:

$$\frac{\partial\tau^*}{\partial\gamma} = \frac{3n\big(4(1-n(1-\gamma))-C\big)\big(1-2n(1-\gamma)\big)}{\big(3-4n(1-\gamma)\big)^2} > 0. \tag{14}$$

It is instructive to compare the import tariff with the production tax the government would impose on the minority firm in a closed economy if both firms were domestic. Assuming that the fixed cost of

---

[28]The exact condition for the concavity of the welfare function in the tariff is $n(1-\gamma) < 3/4$. Note that this inequality is valid under the condition that the compatibility-enhancing technology is efficient (i.e., $C < 1 - 2n$), which we assume throughout this paper.

[29] Greater compatibility between the rival products can make them better complements and substitutes at the same time. By making them better complements, greater compatibility increases consumer willingness to pay for each of the two products. By making the networks based on the two rival technologies better substitutes, greater compatibility can lead to more intense competition between the firms. See Berg (1988) and Economides (1991) on the effects of compatibility on competition between firms in a closed economy with network externalities.

compatibility has already been sunk, the production tax targets only the overadoption of the minority product that is creating the inefficiency in the relative size of the two networks.[30] The optimal production tax $t^D$ can be derived by solving the first-order condition for maximization of welfare of the country with two domestic rivals producing partially compatible products:

$$\max_{t^D}\left(a+1/2+n+\left(1-2n(1-\gamma)\right)s_B(1-s_B)-s_B C\right), \tag{15}$$

where firm B's equilibrium market share is now a function of the production tax: $s_B = \frac{1}{2} - \frac{C+t^D}{6\left(1-n(1-\gamma)\right)}$.

After verifying the second-order condition, simple rearrangement of the first-order condition leads to the following expression for the optimum production tax on the domestic minority duopolist:

$$t^D = \frac{C\left(2-n(1-\gamma)\right)}{1-2n(1-\gamma)}. \tag{16}$$

Because $\partial t^D/\partial\gamma < 0$ while $\partial\tau^*/\partial\gamma > 0$, the difference between the optimal tax on the domestic minority firm in a closed economy and the optimal tariff against the foreign minority firm in an open economy increases as $\gamma$ becomes larger. The reason for this is that the larger the value of $\gamma$ the less severe is the problem of overadoption and the higher is the profit of the foreign firm. Since the production tax on the domestic minority firm only targets the overadoption distortion, while the import tariff targets the overadoption distortion and recaptures the foreign profit, the domestic tax and the import tariff differ the most when the common incentive for their use (i.e., the problem of overadoption) is small.[31]

*Optimal compatibility standard*

We now turn to the characterization of the optimal compatibility standard chosen by the home government. Under the optimum tariff against the foreign firm, the home country welfare is given by:

$$W_H(\tau^*) = a+1/2+n+\frac{\left(C-1-2n(1-\gamma)\right)^2}{4(3-4n(1-\gamma))}. \tag{17}$$

---

[30] The extent of the overadoption distortion can be measured by the wedge between the socially optimal share of the domestic minority firm $\hat{s}_B = \frac{1}{2} - \frac{C}{2\left(1-2n(1-\gamma)\right)}$ and its equilibrium share $s_B = \frac{1}{2} - \frac{C}{6\left(1-n(1-\gamma)\right)}$. The optimal production tax defined by equation (16) pushes the minority firm's equilibrium share to the socially optimal level.

[31] It is worth noting that the optimal tax against the domestic minority firm does not become zero even when the two rival products are perfectly compatible (i.e., $\gamma = 1$). This is because the problem of overadoption of the minority (i.e., the more costly) product is present even when the rival products are perfectly compatible. The main cause of the overadoption problem is not incomplete compatibility, but rather the non-competitive pricing behavior of the firms. When the products are perfectly compatible and supplied by perfectly competitive firms, the problem of overadoption disappears; i.e., under perfect competition and perfect compatibility the equilibrium market shares of the rival technologies are socially optimal.

Because greater compatibility between the rival technologies benefits all domestic consumers and reduces the problem of overadoption of the minority product, the home country welfare under the optimal tariff increases with increases in the degree of compatibility:

$$\frac{\partial W_H(\tau^*)}{\partial\gamma}=\frac{n(1-2n(1-\gamma)-C)(2-2n(1-\gamma)+C)}{(3-4n(1-\gamma))^2}>0. \qquad (18)$$

Does this mean that the home government should require complete compatibility by setting the standard $\gamma^H = 1$? Any standard that exceeds the level of compatibility at which the foreign firm breaks even is exclusionary (i.e., prohibitively stringent) because it prevents the foreign firm's production for the home country market.[32] If the complete compatibility standard is exclusionary, then setting $\gamma^H = 1$ can induce autarky. Since under international oligopoly it is not uncommon that autarky is preferred to trade (e.g., see Fung (1988)), we compare the home country welfare under trade subject to the optimal tariff with the home country welfare under autarky. Under autarky, all consumers belong to the homogenous network based on the product supplied by the domestic firm. Therefore the autarkic welfare is given by

$$W_H^{Au} = \int_0^1 (a+x+n)dx = a+1/2+n. \qquad (19)$$

By comparing (17) and (19), it is easy to see that with the optimal tariff levied on the foreign firm the home country welfare is higher with trade than under autarky if and only if $n(1-\gamma) < 3/4$. This condition is true under the assumption $C < 1 - 2n$, which has been adopted in this paper. The above results can be summarized as:

**Proposition 1:** If the compatibility-enhancing technology is sufficiently efficient to satisfy the condition $C < 1 - 2n$, then the optimal policy of the home country government is to impose the import tariff given by equation (13) and the most stringent non-exclusionary compatibility standard $\gamma^H$.

If the complete compatibility standard is non-exclusionary (i.e., $\Pi_B(1, \tau^*) > F(1)$), the home government will set $\gamma^H = 1$. If the complete compatibility standard is exclusionary (i.e., $\Pi_B(1, \tau^*) < F(1)$), the home government will set the standard just below the lowest exclusionary level of $\gamma$. This is the highest standard under which the foreign firm would enter the home market. If the cost function $F(\gamma)$ satisfies the assumptions introduced in Section 2, the foreign firm's net profit function $\Psi(\gamma) = \Pi_B(\gamma, \tau^*) - F(\gamma)$ is quasi-concave and satisfies the conditions: $\Psi(0) > 0$ and $\partial\Psi(\gamma)/\partial\gamma\big|_{\gamma=0} > 0$. Therefore, the solution to $\Psi(\gamma) = 0$ is well defined and we can determine $\gamma^H$ by finding the level of compatibility under which the foreign firms breaks even:

[32] Given the tax $\tau$, the exclusionary standard exists if $\Pi_B(1, \tau) < F(1)$, where $\Pi_B(\gamma, \tau)$ is defined by (10).

$$\Psi(\gamma)=\frac{(C-1+2q)^2(1-q)}{2(3-4q)^2}-F(\gamma)=0\,, \tag{20}$$

where $q = n(1-\gamma)$.

Is the home country compatibility standard binding? The foreign firm chooses the level of compatibility to maximize its profit net of the fixed cost of achieving compatibility:

$$\gamma^B = \arg\max_{\gamma} \Psi(\gamma)\,. \tag{21}$$

Again, given the properties of the net profit function $\Psi(\gamma)$ (i.e., quasi-concavity, $\Psi(0) > 0$, and $\partial\Psi(\gamma)/\partial\gamma\big|_{\gamma=0} > 0$), it follows that $0 < \gamma^B < \gamma^H$. Therefore, if the government can impose the optimal tariff, it will combine the tariff with the binding but non-exclusionary compatibility standard implicitly defined by (20). Such a combination of policies achieves several goals: (1) it gives the domestic users access to the foreign product, (2) it minimizes the loss of the network externality caused by that access, and (3) it allows the government to recapture some of the profit earned by the foreign product supplier.

When the home government's ability to tax imports is curtailed by a trade agreement, the homogenous network based only on the domestic product is preferred to the heterogeneous network based on the partially compatible foreign and domestic products even if an efficient compatibility-enhancing technology is available. In other words, autarky is preferred to free trade.

**Proposition 2:** Under a free trade agreement, the home government will set the compatibility standard at a prohibitively high level if the exclusionary compatibility standard exists (i.e., if ($\Pi_B(1,0) < F(1,0)$)). If there is no exclusionary standard under the free trade agreement (i.e., if ($\Pi_B(1,0) > F(1,0)$)), then the home country compatibility standard will be ineffectual: $\gamma^H < \gamma^B$.

The possibility that autarky may be preferred to free trade under international oligopoly is a well-known fact in the international trade literature.[33] In the present framework, the home country's welfare is higher under autarky because the profit lost by the domestic firm after opening the home market to free trade exceeds consumer surplus gains.[34] If the home government cannot extract foreign profits through a sufficiently

[33] Fung (1988) compared free trade under international duopoly in the home country market with the domestic monopoly under autarky. He discussed the conditions under which autarky may be better than free trade when the differentiated product duopolists compete in quantities (i.e., in the Cournot-Nash setting). Fischer and Serra (2000) considered a framework in which autarky is induced by a prohibitively high quality standard that applies to the domestic as well as foreign firms. They investigated the conditions under which the standard-induced autarky is welfare superior to free trade without a standard when the firms are homogenous-good quantity competitors.

[34] This result is based on one of the properties of the (Hotelling-type) address models of horizontal product differentiation, which remains valid in our formulation with the network externality. We omit the technical details of this property because it is described elsewhere (see Economides (1984) and Neven et. al. (1991)). Briefly, the property is that the consumer surplus gains from expanding the variety of available differentiated goods is always dominated by the loss of the profit by the incumbent firm due to competition with the firm supplying the additional

high tariff, then autarky ensures greater total welfare for the home country than trade. Therefore, if a trade agreement restrains the use of tariffs but not standards, the home government will use the standardization policy to induce autarky. This can be achieved by choosing any standard above the level of compatibility that sets the foreign firm's net profit to zero:

$$\frac{\left(1-n(1-\gamma)-\frac{C}{3}\right)^2}{2(1-n(1-\gamma))}-F(\gamma)=0\,. \tag{22}$$

Without trade taxes, setting a binding but non-exclusionary standard will only shift a greater share of the total surplus to the foreign firm. The fact that the positive effect of $\gamma$ on the foreign profit dominates its positive effect on the domestic profit and consumer surplus is evident from the sign of the derivative of the home country welfare with respect to $\gamma$ when the tariff is set to zero: $\frac{\partial W_H(0)}{\partial\gamma}=-\frac{C^2 n\left(2-n(1-\gamma)\right)}{18\left(1-n(1-\gamma)\right)^3}<0$.

Therefore, if neither complete exclusion of the foreign firm nor recapturing of the foreign profit through an import tariff is feasible for the home government, it will set a non-binding standard, which will have no effect on the foreign firm's choice of compatibility level.

## 4. Foreign policies when compatibility does not affect the marginal production cost.

Having discussed the policies of the home country government, we now turn to the policies of the foreign government toward the export market. Since the consumer surplus of the foreign citizens is not involved, the foreign government's only motivation for policy intervention is rent shifting. However, unlike the earlier literature on strategic trade policies, this paper considers two distinct commitment mechanisms through which the equilibrium outcome of the game between the firms in the export market can be changed to the advantage of the exporting country. First, the government can use the export tax to commit the exporting firm to a less-aggressive price-setting behavior, helping it to achieve the Stackelberg outcome of the game. Second, the foreign firm's compatibility-enhancing investment acts as a mechanism for self-imposed commitment to less-aggressive price setting.

Although both mechanisms—the export tax and the compatibility-enhancing investment—help to shift rents from the home firm to the foreign firm and the foreign country treasury, the former mechanism interferes

---

variety. Therefore, if the profit of the additional supplier is not part of the country welfare (which is the case in the context of international duopoly in the home market), the country is better off under autarky than under free trade. Also, this property holds even if some of the domestic users abstain from purchase. Although domestic welfare increases by the amount equal to the consumer surplus of users who abstain from purchase under autarky but buy the foreign product under free trade, the reduction of the domestic firm's profit after the foreign entry dominates the consumer surplus gains.

with the latter. The export tax reduces the foreign firm's incentives to invest in greater compatibility with the home firm's technology. To overcome the negative effect of the export tax on the firm's incentive to invest in compatibility, the foreign government has to subsidize the firm's investment. Therefore, to achieve the full optimum the foreign government must combine the export tax with the subsidy for compatibility-enhancing investment. The foreign government's policies in this setting can be compared with other models of government policies toward the imperfectly competitive export market. Spencer and Brander (1983) showed that if the oligopolistic competition is Cournot and the exporting firm can make a marginal cost-reducing investment, the optimal policy is a combination of the export subsidy and the investment tax. If the firms compete in Bertrand fashion, then the optimal policy mix is the export tax and the investment subsidy (see Eaton and Grossman (1986) and Cheng (1988)).[35] While the export tax ensures the firm's commitment to less-aggressive pricing, the investment subsidy induces the firm to choose the investment that maximizes the direct impact of reducing the marginal cost on the profit. In contrast to these models, the imperfectly competitive exporter considered in this section has no own strategic incentives to underinvest because the compatibility-enhancing investment does not affect the firm's marginal cost.[36] It is the government's use of the export tax for relaxing price competition in the export market that runs into conflict with the exporter's incentive to invest in compatibility. Therefore, the export tax needs to be complemented by a subsidy for compatibility-enhancing investment.[37]

This result holds regardless of whether the export tax and the compatibility investment subsidy are applied simultaneously before the investment is in place or in a sequential manner (i.e., the investment subsidy before the investment and the export tax afterward, but before the production stage). However, to fix the ideas,

[35] Under price competition, the exporting firm under-invests in marginal cost reduction because, in addition to the direct positive effect of such an investment on the firm's profit, there is an opposing indirect effect related to the strategic complementarity of price-setting actions. Lower marginal cost makes the exporter more aggressive in lowering the price, which, in turn, triggers a price reduction by the competitors and subsequently lowers the profits of both firms. Because of this negative indirect effect, the exporting firm moderates its investment in marginal cost reduction. To overcome this distortion, the government imposes the policy mix of the export tax and the investment subsidy.

[36] In fact, both the direct and the indirect effects of higher compatibility on the exporting firm's profit are positive. Higher compatibility directly increases the firm's marginal revenue because it raises the network-related quality of the product. Higher compatibility also indirectly helps the foreign firm to earn higher profit because it reduces the intensity of competition between the firms.

[37] Gatsios and Karp (1992) discussed a somewhat similar effect. In their model, the governments move first by choosing investment taxes/subsidies, and then the firms exporting into a third country market choose the levels of marginal cost reducing investments. Next, the governments choose the export taxes/subsidies, and finally the firms choose the outputs. Gatsios and Karp have pointed out that if the firms anticipate that the governments will form a trade block and impose export taxes aimed at improving the terms of trade of the trade block as a whole, they will under-invest in the cost-reducing technology. Therefore, to restore the efficient level of investments by the firms, the governments have to offer them investment subsidies.

we assume that the foreign government chooses the investment subsidy before the firm undertakes the compatibility-enhancing investment and only after that chooses the export tax.[38]

With a specific export tax $\sigma$, the profit function of the foreign firm, which has already undertaken the compatibility-enhancing investment, is given by: $\Pi_B = (P_B - C - \sigma)s_B$. The profit of the home firm is defined as in Section 2. After solving for the Nash equilibrium in prices, we obtain the equilibrium profit and sales of the foreign firm in the market of the home country:

$$\Pi_B(\sigma) = \frac{\left(1 - n(1-\gamma) - \frac{C+\sigma}{3}\right)^2}{2\left(1 - n(1-\gamma)\right)} \text{ and } s_B = \frac{1}{2} - \frac{C+\sigma}{6\left(1-n(1-\gamma)\right)}. \tag{23}$$

To determine the optimal export tax, we maximize the sum of the foreign firm's profit and the export tax revenue with respect to $\sigma$: $\max_{\sigma}\left(\Pi_B(\sigma) + s_B\sigma\right)$. Rearranging the first-order condition for this maximization problem[39] yields the expression for the optimal export tax:

$$\sigma^* = \frac{3(1-n(1-\gamma)) - C}{4}. \tag{24}$$

Under the optimum export tax, the market share of the foreign firm is given by

$$s_B = \frac{3}{8} - \frac{C}{8(1-n(1-\gamma))} = \frac{3(1-n(1-\gamma)) - C}{8(1-n(1-\gamma))}. \tag{25}$$

With the optimum export tax, the foreign firm's profit net of the subsidized investment cost of the converter is given by:

$$\pi_B = \frac{\left(1 - n(1-\gamma) - \frac{C+\sigma^*}{3}\right)^2}{2\left(1-n(1-\gamma)\right)} - (1-\phi)F(\gamma) = \frac{\left(C - 3\left(1-n(1-\gamma)\right)\right)^2}{32\left(1-n(1-\gamma)\right)} - (1-\phi)F(\gamma), \tag{26}$$

where $\phi$ represents the proportion of the cost of the compatibility-enhancing investment covered by a subsidy to the foreign firm. If $\phi$ takes a negative value, we interpret it as an investment tax.

The foreign government chooses the subsidy to maximize the country's welfare, which equals the foreign firm's net profit plus the export tax revenue minus the cost of the investment subsidy:

[38] The sequence of policy decisions might be justified by the fact that the firm's response to the investment subsidy involves changing its investment behavior, which generally takes longer than the production stage response to trade taxes.

[39] Note that the second-order condition is satisfied, as well: $\frac{d^2W_F}{d\sigma^2} = \frac{-2}{9(1-n(1-\gamma))} < 0$.

$$W_F = \pi_B + s_B \cdot \sigma^* - \phi F(\gamma) = 2\left[\frac{(C - 3(1 - n(1-\gamma)))^2}{32(1 - n(1-\gamma))} - \frac{1}{2}F(\gamma)\right], \tag{27}$$

where second equality is obtained by rearrangement using the definitions of the optimum export tax (24) and the foreign firm's market share (25).

A comparison of equations (26) and (27) suggests that to induce the foreign firm to choose the welfare-maximizing level of compatibility of its technology with the rival technology, $\gamma$, the foreign government has to offer the firm a subsidy that covers up to half the cost of investment in compatibility.

> **Proposition 3:** The optimum policy of the foreign government is a combination of the export tax defined in (24) and a subsidy for compatibility-enhancing investment.

So far, we have considered the trade and product compatibility policies of the two governments separately. Now, we must ask: What happens if both countries heed their strategic incentives and commit themselves to using these policies? Specifically, what happens if the policy interaction between the governments involves the import tax and the compatibility standard on the side of the home government and the subsidy for compatibility-enhancing investment and the export tax on the side of the foreign government? To answer this question, we must consider a multi-stage game in which the policies toward compatibility on both sides are applied either prior to the application of trade taxes or simultaneously with them. The analysis of such a model is technically complicated and is not presented here. However, it turns out that regardless of the timing of applying the compatibility-enhancing policies (i.e., prior to or simultaneously with the trade taxes) the *nature* of the desirable policies would be the same as described above, and only the *magnitude* of the chosen instruments would change. The home government would still prefer an import tax in combination with the most stringent non-exclusionary compatibility standard, and the foreign government would prefer an export tax in combination with an investment subsidy.

## 5. Non-cooperative compatibility policies when compatibility affects the marginal production cost.

Thus far, we have examined the case in which achieving compatibility with the domestic product has no effect on the marginal production cost of the exporting firm but requires it to incur a fixed cost. In this section, we consider a framework in which greater compatibility with the rival product affects the foreign exporter's marginal cost. This can happen when enhancing compatibility requires costly modification of each individual unit of the foreign product. For example, it may be that in order to achieve compatibility the foreign firm has to embed a compatibility-enhancing device (i.e., a converter) in each unit of its product. For simplicity, we assume that attaining compatibility does not involve any fixed cost.

Because the level of compatibility between the products affects the foreign firm's marginal cost, the foreign government now has two strategic reasons for trying to influence the firm's compatibility choice. First, as we showed in the previous section, a higher level of compatibility increases the foreign firm's marginal revenue by raising consumer willingness to pay for the products and by relaxing price competition between the firms. Second, more compatibility means higher marginal cost, which makes the firm less aggressive in price setting and also, as a consequence, dampens competition.

As in the previous sections, the home government continues to use the minimum compatibility standard. However, to concentrate on the trade-related implications of policies toward compatibility, we assume in this section that a trade agreement between the two countries prevents them from using traditional trade taxes.[40] Instead, the foreign government now uses a subsidy (or a tax) aimed at the level of compatibility chosen by the foreign firm. Although the compatibility subsidy/tax affects the foreign firm's unit cost, it is different from the export subsidy/tax because it is directly linked to the firm's choice of compatibility with the domestic product.

In telecommunications and information technology, there are a number of examples of government policies targeted at the compatibility of exports with rival products in the export market. Broadly speaking, any policy measure, including but not limited to explicit taxes (or subsidies), that makes it harder (or easier) for an exporter to achieve greater compatibility between its own product and the installed base of the rival firms' products in the export market can be interpreted as a compatibility-suppressing tax (or compatibility-enhancing subsidy). Examples of such compatibility policy measures are taxes (or subsidies) on the interface-related R&D affecting interoperability between the rival technologies and taxes (or subsidies) on the R&D that increases differentiation between the designs of the products.[41] In the latter case, an R&D subsidy leading to greater ex ante differentiation between the rival products (i.e., differentiation by design) will have an effect

---

[40] The artifact of the Hotelling-type framework that autarky is preferred to untaxed trade remains even if a compatibility standard affects the marginal cost of the foreign firm. To make a meaningful analysis of implications of the trade agreement restraining the use of trade taxes but not policies aimed at compatibility, we assume that the available compatibility-enhancing technology is sufficiently efficient that even the complete compatibility standard does not exclude the foreign firm from the home market (i.e., even after choosing $\gamma = 1$ the foreign firm still has a positive market share in the home market).

[41] Such R&D may affect the exporter's compatibility-enhancing decision either by requiring it to incur a sunk cost, which we considered in the previous section, or by affecting its unit cost, as we discuss in this section. Therefore, while we considered in the previous section the compatibility-enhancing subsidy (or compatibility-suppressing tax), which takes the form of an investment subsidy (or tax), in this section we analyze the effect of a unit cost subsidy (or tax).

similar to the compatibility-suppressing tax because it increases the cost of making the products compatible ex post.[42]

## 5.1 Unconstrained optimal policy of the foreign government

Let $C(\gamma)$ be the unit cost of achieving the level of compatibility $\gamma$, where $C(\gamma) \geq 0$, $C'(\gamma) \geq 0$, and $C''(\gamma) \geq 0$. To ensure the existence and uniqueness of equilibrium, we also assume that $C'(\gamma)$ becomes infinite in the limit as $\gamma$ approaches one. In order to make it profitable for the foreign firm to enter, we assume that the total and marginal costs of the "first unit" of compatibility equal zero (i.e., $C(0) = C'(0) = 0$). In summary, we assume:

$$C(0) = C'(0) = 0;\ C'(\gamma) > 0 \text{ and } C''(\gamma) > 0 \text{ for } \gamma > 0;\ \lim_{\gamma \to 1} C'(\gamma) = \infty.$$[43]

Denote by $\theta$ the foreign tax ($\theta > 0$) or subsidy ($\theta < 0$) per unit compatibility cost. Assuming that $\theta > -1$, the foreign firm faces a strictly positive cost of compatibility, and its profit is given by: $\Pi_B(\gamma, \theta) = \left(P_B - (1+\theta)C(\gamma)\right)s_B$. Since the tax (or subsidy) $\theta$ and the compatibility level $\gamma$ are chosen prior to the stage in which the firms compete in prices, the equilibrium prices and the foreign firm's profit and sales are determined in a manner similar to the way they were determined in Section 2:

$$\begin{cases} P_A = 1 - n(1-\gamma) + \dfrac{C(\gamma)(1+\theta)}{3} \\[2ex] P_B = 1 - n(1-\gamma) + \dfrac{2C(\gamma)(1+\theta)}{3}, \end{cases} \tag{28}$$

and

[42] Examples in wireless telecommunications include the subsidies for the R&D related to spectrum-sharing and interference-avoidance technologies embedded in multimode wireless handsets and base stations. Such subsidies are used by the governments of Finland and South Korea. An example of policies stimulating greater design differentiation and, as a result, leading to less compatibility is the Chinese government-funded efforts in developing distinct homegrown technical designs on a wide range of technology from audio/video compression and optical-disk technology to operating systems and mobile-phone network protocols. Such policy recently helped a consortium of Chinese firms to develop a third-generation wireless communications system called Time Division Synchronous Code Division Multiple Access (TD-SCDMA). If the state-run China Telecomm adopts TD-SCDMA as a technology for the next generation of wireless networks, China's wireless telephone networks will be compatible neither with the European wideband-CDMA (WCDMA) equipment nor with the U.S.-backed CDMA2000 equipment.

[43] These assumptions greatly simplify the analysis by ensuring the existence of the interior equilibrium with partial compatibility and positive sales of the foreign product in the domestic market. An example of a function satisfying these assumptions is $C(\gamma) = \gamma(1 - (1-\gamma)^{\alpha})$ where $0 < \alpha < 1$.

$$\Pi_B = \frac{\left(1 - n(1-\gamma) - \frac{C(\gamma)(1+\theta)}{3}\right)^2}{2\left(1 - n(1-\gamma)\right)} \text{ and } s_B = \frac{1}{2} - \frac{C(\gamma)(1+\theta)}{6\left(1 - n(1-\gamma)\right)}. \tag{29}$$

The level of compatibility chosen by the foreign firm for a given tax $\theta$ satisfies the following first-order condition for maximization of $\Pi_B$ with respect to $\gamma$:

$$\frac{\partial \Pi_B}{\partial \gamma} = \frac{\left(3(1-q) - (1+\theta)C(\gamma)\right)\left(n(1+\theta)C(\gamma) + (1-q)\left(3n - 2(1+\theta)C'(\gamma)\right)\right)}{18(1-q)^2} = 0, \tag{30}$$

where $q = n(1 - \gamma)$. Given the assumption about the efficiency of the compatibility-enhancing technology, the first-order condition (30) is equivalent to[44]

$$n(1+\theta)C(\gamma) + (1-q)\left(3n - 2(1+\theta)C'(\gamma)\right) = 0. \tag{31}$$

Totally differentiating (31) and solving for the foreign firm's choice of the compatibility level shows: [45]

$$\gamma = f(\theta, n), \tag{32}$$

where the function $f(\theta, n)$ is characterized by $f_1 < 0$, $f_{11} > 0$, $f_2 > 0$, $f_{12} > 0$.

As expected, the higher the compatibility tax the lower the level of compatibility chosen by the firm. The negative effect of the tax on compatibility suggests that the foreign government experiences conflicting motives in its choice of policy toward compatibility. On one hand, the government's inability to use trade taxes deflects the strategic rent-shifting motive into the compatibility policy. Under price competition, this motive dictates that the government should increase the firm's marginal cost by imposing a compatibility tax. The tax commits the firm to a less-aggressive price-setting strategy and thereby moves the outcome of price competition between the firms to the Stackelberg equilibrium of the game in which the foreign firm is a leader. On the other hand, the tax also induces the firm to choose a lower level of $\gamma$, which leads to a reduction in the

[44] The condition ensuring that the compatibility-enhancing technology is sufficiently efficient that a prohibitive standard does not exist (for a given $\theta$) is $C(1)(1 + \theta) < 3(1 - n(1 - \gamma))$, where $C(1)$ is the unit cost of achieving full compatibility. More precisely, for a given $\gamma$ the no-autarky condition is $s_B > 0$, which is equivalent to $C(\gamma)(1+ \theta) < 3(1 - n(1 - \gamma))$. Because of the convexity of $C(\gamma)$, this inequality is harder to satisfy when $\gamma$ is higher. To ensure that the condition is satisfied for any $\gamma \in [0, 1]$, we assume that $C(1)(1+ \theta) < 3(1 - n(1 -\gamma))$. Note that this assumption implies that we again limit our analysis to the relatively efficient compatibility-enhancing technologies.
[45] The second-order condition for profit maximization is satisfied because, given our assumptions about the cost function $C(\gamma)$, the foreign firm's profit is concave in $\gamma$.

firm's profit. Therefore, the government's strategic trade motive for using the compatibility tax is moderated by the positive effect of compatibility on the firm's profit.[46]

The foreign government chooses the compatibility tax/subsidy to maximize the country's welfare, which is equal to the sum of the foreign firm's profit and tax revenues:

$$W_F(\theta) = \Pi_B(f(\theta,n),\theta)) + \theta C(f(\theta,n))s_B(f(\theta,n)) = \left(P_B(f(\theta,n)) - C(f(\theta,n))\right)s_B(f(\theta,n)).$$

The solution to this maximization problem defines the optimal compatibility tax/subsidy:

$$\theta^* = \arg\max_{\theta}\left[\left(P_B(f(\theta,n)) - C(f(\theta,n))\right)s_B(f(\theta,n))\right] \tag{33}$$

**Proposition 4:** The unconstrained optimal policy of the foreign government is the compatibility tax: $\theta^* > 0$. The weaker the network externality effect and the more efficient the conversion technology, the larger is the tax.

*Proof:* See Appendix.

Changes in the strength of the network externality effect (i.e., the parameter $n$) and in the efficiency of the compatibility technology lead to changes in the magnitude of the unconstrained optimal policy but not in its sign, because the optimal policy is always a compatibility tax rather than a subsidy. The government uses the compatibility-suppressing tax for rent-shifting purposes more aggressively if this policy is less costly in terms of the network externality benefit forgone due to imperfect compatibility, $n(1-\gamma)$. This loss is smaller when the network externality effect is weak (i.e., $n$ is small) and/or the compatibility technology is efficient enough to allow the firm to choose a high $\gamma$ despite the tax.

## 5.2 Foreign best response compatibility policy

We are now ready to examine the best response compatibility policy of the foreign country. The function $f(\theta)$, which represents the level of compatibility chosen by the foreign firm in response to $\theta$, is depicted by the thin curve in Figure 1. The foreign unconstrained optimal compatibility tax $\theta^*$ and the corresponding choice of compatibility level by the foreign firm, $\gamma^* = f(\theta^*)$, is represented by point $F_2$. A home compatibility standard more lax than $\gamma^*$ (i.e., $\gamma < \gamma^*$) will not be binding on the foreign firm. Denoting the best

[46] Since $f_{1,2} > 0$, a greater network externality effect mitigates the foreign firm's negative response to the compatibility tax. Therefore, the foreign government will be more careful in heeding its rent-shifting incentive by means of the compatibility tax when the network externality effect is strong.

response compatibility tax of the foreign country by $\theta^F(\gamma)$, we have $\theta^F(\gamma) = \theta^*$ for all $\gamma < \gamma^*$. In other words, when the home standard is not binding, the foreign government is free to choose its unconstrained optimal compatibility tax. This tax optimally balances the effects it has on price competition in the export market through its imposition of higher production cost on the foreign firm and through its influence on the firm's choice of compatibility between the products. The corresponding part of the foreign best response function is represented by the segment $F_1F_2$ of the thick dark curve in Figure 1.

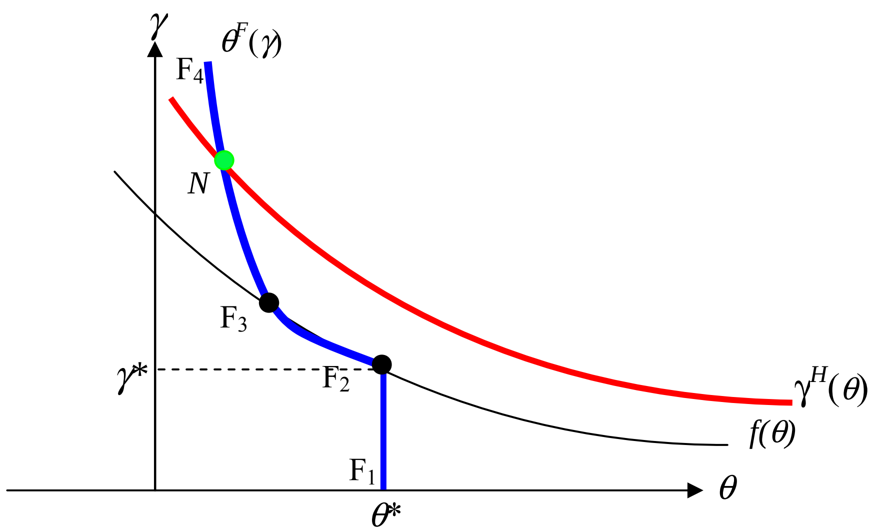


Figure 1.

For a home compatibility standard tighter than $\gamma^*$ (i.e., $\gamma > \gamma^*$), the foreign government has two options. It can either impose a tax that will induce the foreign firm to choose the level of compatibility exactly equal to the compatibility standard or it can choose a tax that will not have any effect upon the foreign firm's choice of compatibility. If it does the former, the best response tax is given by the inverse function of $f(\theta)$— i.e., $\theta^F(\gamma) = f^{-1}(\gamma)$.

When the home country compatibility standard is binding and sufficiently tight, the foreign government does not need to be concerned that its compatibility policy reduces the foreign firm's incentives for making its technology compatible with the home firm's technology. Therefore, for a sufficiently tight compatibility standard in the export market the foreign government does not have to moderate its tax on compatibility. Instead, the government uses the tax $\theta$ only as an instrument for increasing the foreign firm's production cost and, thus, committing it to a more relaxed price-setting behavior in the home market. Thus, the foreign government chooses a compatibility tax different from $f^{-1}(\gamma)$. In Figure 1, the foreign best response curve $\theta^F(\gamma)$ deviates from the curve defined by $\theta = f^{-1}(\gamma)$. Specifically, the government chooses $\theta$ in such a way that the unit tax $\theta\cdot C(\gamma)$ is equal to the optimal export tax given by equation (24) in Section 4:

$$\theta \cdot C(\gamma) = \frac{3(1-n(1-\gamma)) - C(\gamma)}{4}. \tag{34}$$

The result is that when the standard imposed by the home government is sufficiently tight the foreign government's optimum rent-capturing compatibility tax $\theta^F(\gamma)$ is given by:

$$\theta = \frac{1}{4}\left(\frac{3(1-n(1-\gamma))}{C(\gamma)} - 1\right). \tag{35}$$

When the compatibility standard is not too tight (but tighter than $\gamma^*$) the foreign government will choose to follow $\theta^F(\gamma) = f^{-1}(\gamma)$ over (35). As $\gamma$ approaches $\gamma^*$ from above, $f^{-1}(\gamma)$ becomes arbitrarily close to the unconstrained optimal compatibility tax $\theta^*$; whereas the right-hand side of (35) does not. Because the foreign welfare function is continuous, the convergence of $f^{-1}(\gamma)$ to $\theta^*$ as $\gamma$ approaches $\gamma^*$ implies that for some (perhaps small) range of compatibility standards the foreign government will set the tax inducing the firm to choose $\gamma$, which is exactly equal to the minimum level of compatibility required by the home country standard. The corresponding part of the foreign best response function is represented by the segment $F_2F_3$ in Figure 1.

The location of the intersection of the curves defined by (35) and $\theta = f^{-1}(\gamma)$ depends upon the strength of the network externality and the degree of convexity of the cost function $C(\gamma)$. In Figure 1, we depict a case in which the intersection of the curves is at point $F_3$, which is to the left of the point representing the unconstrained optimal tax $\theta^*$. However, the curves may intersect to the right of the point $\theta^*$. In that case, the graph will look like the one shown in Figure 2. In the figure, the discontinuity in the foreign country's best response function $\theta^F(\gamma)$ occurs at a value of $\gamma$ at which the foreign country's welfare function has two local maxima yielding the same level of welfare. In both Figures 1 and 2, the section of the foreign best response function corresponding to (35) is depicted by the segment $F_3F_4$.

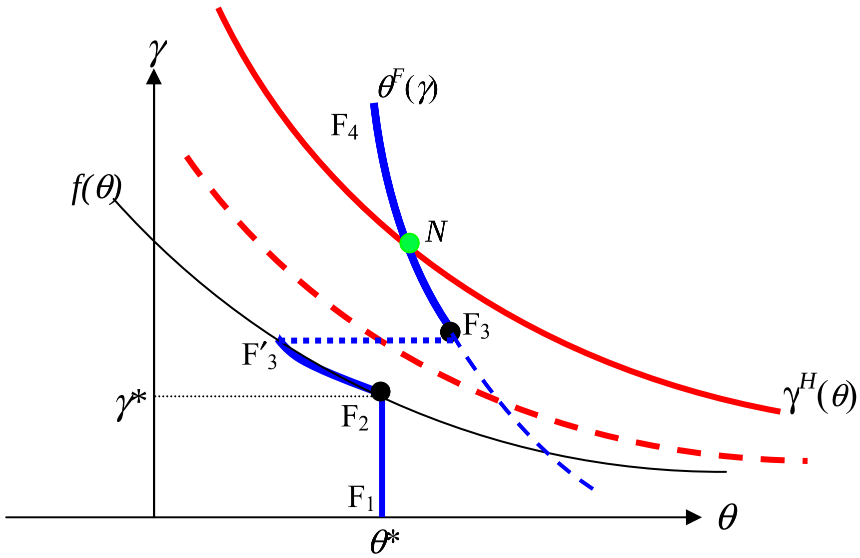


Figure 2.

### 5.3 The home country best response standard and the Nash equilibrium of the compatibility policy game

As we demonstrated in Section 3, if the home government's ability to tax imports is curtailed by a trade agreement it would prefer autarky to untaxed trade. When $\gamma$ does not affect the foreign firm's marginal cost and there is no prohibitive (i.e., autarky-inducing) level of $\gamma$, then the minimum compatibility standard is ineffective as a policy instrument because the home government prefers less compatibility than the firm controlling the interface. However, this is not the case when compatibility affects the marginal cost of the foreign firm. When the cost function $C(\gamma)$ is increasing and convex, the compatibility standard can help the domestic firm to capture a greater share of pure profits in the imperfectly competitive market. Therefore, in this section, unlike the situation considered in Section 3, the compatibility standard allows the home government to shift rents in the "right" direction—i.e., to the home firm. In this setting, it is appropriate to say that the free trade agreement deflects the government's rent-shifting motivation into the standardization policy.

The best response function for the home country represents the level of compatibility standard, which maximizes the home country's welfare given the foreign country's compatibility-suppressing policy variable $\theta$. The home country welfare is given by $W_{\mathrm{H}} = a + 1/2 + n + (1 - 2\,n(1 - \gamma))s_B\,(1 - s_B) - s_B P_B$, where $s_B$ and $P_B$ are given, respectively, by (28) and (29).

The home government's best response compatibility standard will be binding for any compatibility policy chosen by the foreign government. To see this, note that given $\theta$, a non-binding standard $\gamma^{\mathrm{H}} < f(\theta)$ has no effect on the foreign firm's compatibility decision. By raising the standard above the level $f(\theta)$, the home government can achieve two goals. First, it can increase the value of the network based on the partially compatible technologies for the domestic users, and, second, it can reduce the pure rents earned by the foreign firm. Therefore the home government's best response standard will be above the level of compatibility preferred by the foreign firm: $\gamma^H \geq f(\theta)$. This can be verified by checking that $\partial W_H/\partial\gamma > 0$, when evaluated at $\gamma = f(\theta)$.

However, because compliance with the standard increases the marginal cost of the minority product relative to the dominant product, tightening the standard exacerbates the overadoption distortion. For sufficiently high $\gamma$, the negative welfare effect from tightening the standard dominates the positive welfare effect. This follows from the fact that $\partial W_H/\partial\gamma < 0$ when evaluated at $\gamma$ sufficiently close to one. Therefore, the home government will not mandate full compatibility by setting the standard $\gamma^H = 1$. Instead, it will set the standard $\gamma^H$ in such a way that $f(\theta) < \gamma^H < 1$.

For $\gamma^H > f(\theta)$, the best response function for the home country can be derived from the first-order condition for the home country welfare maximization: $\partial W_H/\partial\gamma = 0$. The home country's marginal welfare benefit from tightening the standard reflects an increase in the consumer surplus due to greater compatibility between the domestic and foreign products and an increase in the profit of the home firm due to less intense competition with the foreign firm. The marginal social cost of tightening the compatibility standard is reflected in the negative effect on the consumer surplus exerted by higher prices. Because the price difference between the rival products increases as the standard becomes tighter, some consumers switch to the less-preferred but cheaper domestic product, and those who continue to buy the foreign product pay a higher price. The welfare-maximizing standard sets the marginal social benefit of greater compatibility equal to the marginal social cost. The first-order condition for home welfare maximization is:[47]

$$\gamma = 1 - \frac{2}{3n} + \frac{(1+\theta)CC'(3-2q)(1-q) - 3C'(1-q)^3}{3n^2(1+\theta)C^2}, \tag{36}$$

where, as before, $q = n(1 - \gamma)$. Equation (36) implicitly defines the home country's best response compatibility standard $\gamma^H(\theta)$. By totally differentiating (36), we verify that $\gamma^H(\theta)$ is decreasing and convex: $d\gamma^H/d\theta < 0$, $d^2\gamma^H/d\theta^2 > 0$. In Figures 1 and 2, $\gamma^H(\theta)$ is represented by the lighter solid curve.

When the pure-strategy Nash equilibrium in the compatibility policy game exists, the best response curves $\gamma^H(\theta)$ and $\theta^F(\gamma)$ intersect. Such equilibrium is stable if at the intersection point the absolute value of the slope of the curve corresponding to $\theta^F(\gamma)$ exceeds the absolute value of the slope of $\gamma^H(\theta)$.[48] However, it is possible that the curves $\gamma^H(\theta)$ and $\theta^F(\gamma)$ do not intersect. For example, referring to Figure 2, if the home

---

[47] Equation (36) is the reduced form of the first-order condition: $\partial W_H/\partial\gamma = 0$. Note that the second-order condition for home welfare maximization is satisfied because, given our assumptions about the cost function $C(\gamma)$, $W_H$ is concave in $\gamma$.

[48] Whether the stability condition is satisfied depends upon the degree of the curvature of the cost function and the strength of the network externality. We are more likely to observe a stable Nash equilibrium when $n$ is larger and the convexity of $C(\gamma)$ is greater.

country's best response curve $\gamma^{H}(\theta)$ is located very close to the curve $f(\theta)$, then $\gamma^{H}(\theta)$ might pass through the discontinuity in the foreign country's best response curve. This possibility is illustrated by the dashed curve $\gamma^{H}(\theta)$ drawn close to $f(\theta)$. In that case, there are no pure-strategy Nash equilibria in the compatibility policy game.

## 6. International coordination of policies toward compatibility.

This section examines international agreements on policies toward compatibility. We begin by characterizing the combination of the compatibility policies that is jointly efficient for the two countries. Having identified the globally efficient policy combination, we analyze the inefficiencies that are present in the non-cooperative equilibrium. By comparing the Nash equilibrium outcome with the globally efficient policy combination, we can discern the changes in the countries' policies toward compatibility that should arise as a result of an international treaty.

### 6.1 Jointly efficient compatibility policies

The jointly efficient policy combination maximizes the aggregate welfare of the two countries:

$$W_W = a + 1/2 + n + (1 - 2\,n(1 - \gamma))s_B\,(1 - s_B) - s_B C.$$

When foreign consumers are not involved, the problem of the two-country joint welfare maximization under international duopoly is equivalent to the welfare maximization problem for a closed economy with a domestic duopoly.

With the increasing unit cost of compatibility, raising $\gamma$ leads to a greater marginal cost difference between the firms. As a result, enhancing compatibility has a mixed effect on the aggregate welfare. While the increase of $\gamma$ raises the network-related component of the consumer utility, the increase in the unit cost of compatibility, $C(\gamma)$, worsens the inefficiency due to overadoption of the minority technology.

If the compatibility tax (or subsidy) were the only policy instrument available to the governments for joint welfare maximization, its optimal level would reflect the opposing welfare effects of compatibility. On one hand, the problem of overadoption of the minority technology by users suggests that the policy should be a tax ($\theta \geq 0$). On the other hand, the minority firm's socially insufficient incentive for making its product compatible with the rival's product calls for a compatibility-enhancing subsidy ($\theta < 0$). A high enough tax $\theta$ can completely eliminate the problem of overadoption but will also suppress the minority firm's incentive to invest in compatibility. Therefore, if the countries use both policy instruments (i.e., the compatibility tax and the standard), it would be optimal for them to target the overadoption distortion with a *positive* tax and induce the firm to select the socially optimal level of compatibility by means of a binding standard.[49]

For a given value of $\gamma$, the jointly optimal *unit* compatibility tax, $\theta^W \cdot C(\gamma)$, is equal to the closed economy optimal production tax on the minority duopolist defined by equation (16) in Section 3. Therefore, the jointly optimal compatibility tax is given by:

$$\theta^W(\gamma) = \frac{2 - n(1-\gamma)}{1 - 2n(1-\gamma)}. \tag{37}$$

The jointly optimal compatibility standard, $\gamma^W(\theta)$, can be derived from the first-order condition for the maximization of the aggregate world welfare with respect to $\gamma$. The condition equates the marginal social benefit of tightening the standard to the marginal social cost:

$$\frac{\partial\big((1-2n(1-\gamma))s(1-s)\big)}{\partial\gamma} = \frac{\partial(sC)}{\partial\gamma}.$$

Rearranging the first-order condition, we find that $\gamma^W(\theta)$ is given implicitly by

$$\gamma = 1 - \frac{1}{n} + \frac{9(1-q)^3(C'-n) + nC^2(1+\theta)\big(3-q(\theta-2)\big)}{nCC'(1+\theta)\big(5-2q(\theta-2)-\theta\big)}, \tag{38}$$

where, as before, $q = n(1-\gamma)$.[50]

Totally differentiating (38) shows that the function $\gamma^W(\theta)$ is characterized by $d\gamma^W/d\theta < 0$ and $d^2\gamma^W/d\theta^2 > 0$. Comparing the levels of compatibility jointly preferred by the governments with the level preferred by the foreign firm, we confirm that for any tax $\theta > 0$ the jointly optimal standard is binding on the firm: $f(\theta) < \gamma^W(\theta)$. Moreover, since the rent-shifting motive is not present under joint welfare maximization, the jointly optimal compatibility standard will be lower than the best response standard of the home government: $\gamma^W(\theta) < \gamma^H(\theta)$. Therefore, we find that for $\theta > 0$: $f(\theta) < \gamma^W(\theta) < \gamma^H(\theta)$.

In Figures 3 (a, b, c) the jointly optimal standard $\gamma^W(\theta)$ and tax $\theta^W(\gamma)$ are depicted by thin curves. The intersection of the curves corresponding to $\theta^W(\gamma)$ and $\gamma^W(\theta)$ gives us the efficient combination of the tax and the standard: $(\theta^W, \gamma^W)$. Depending upon the parameter values, this combination can be represented by the points *W, W*,* and *W*** in the figures.

[49] In a closed economy context, the fully optimal social outcome could be achieved if the government could impose the consumption tax on the minority technology users and give the compatibility-enhancing subsidy to the minority technology producer. Although we abstract from such policies in our open economy model, if they were feasible they would allow the countries to achieve a higher level of welfare.

[50] The second-order conditions for the maximization of $W_W$ with respect to $\gamma$ and $\theta$ require $W_{\gamma\gamma}, W_{\theta\theta} < 0$, and $W_{\gamma\gamma}W_{\theta\theta} - W_{\gamma\theta}^2 > 0$. These conditions are satisfied if the cost function $C(\gamma)$ is characterized by a sufficient degree of curvature (or convexity). We assume that this is the case in our model.

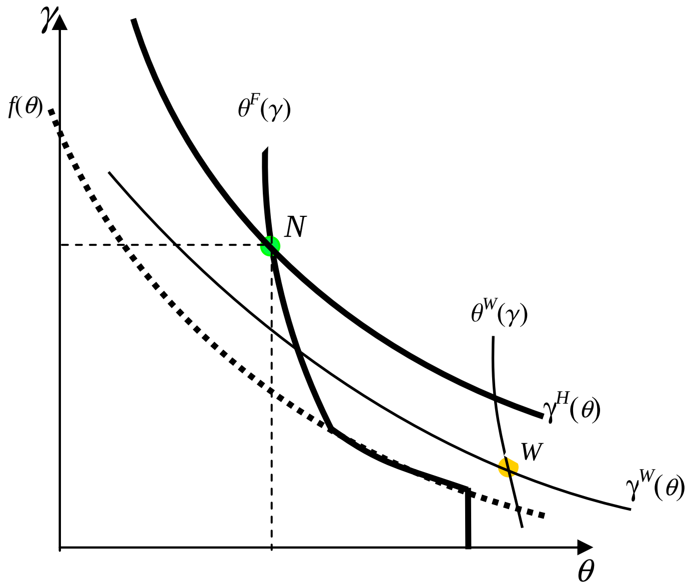


Figure 3a.

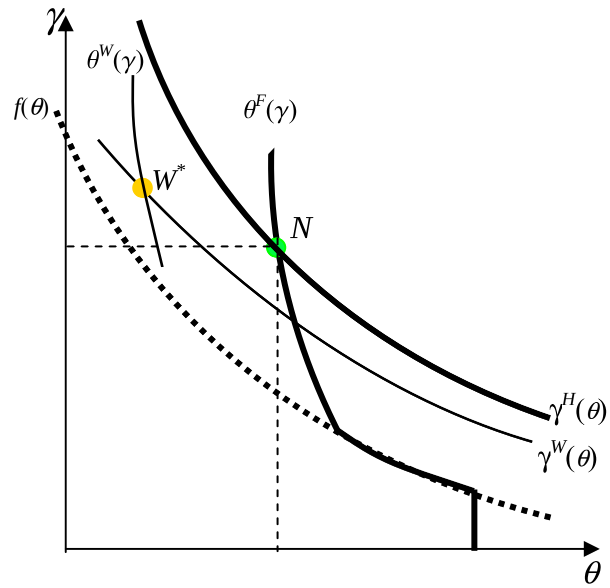


Figure 3b.

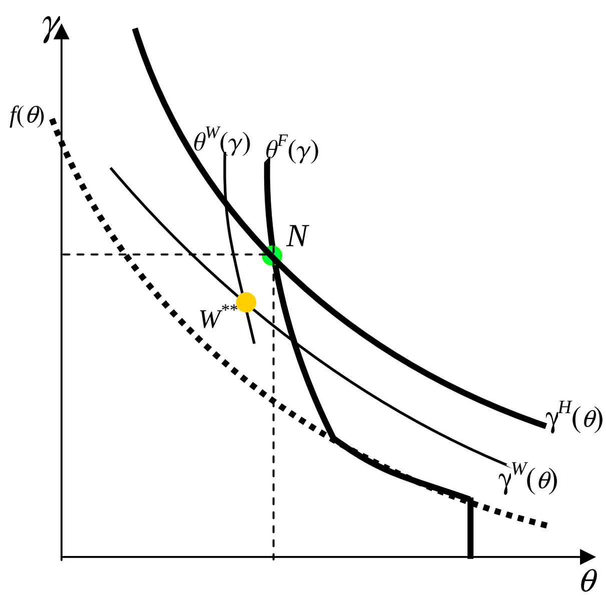


Figure 3c.

## 6.2 Pareto-improving agreements on compatibility

By comparing the efficient policy combination with the policies emerging in a non-cooperative equilibrium, we can determine the likely features of a negotiated agreement on compatibility. As Figures 3 (a, b, c) illustrate, the exact magnitude of the jointly efficient policies relative to the Nash equilibrium policies can vary depending upon the parameters of the model. However, regardless of the "disagreement" levels of welfare, which countries can guarantee themselves without policy cooperation, an agreement based on an efficient policy combination can always be reached in an international negotiation, assuming that the countries can make welfare transfers to one another as part of the agreement. The assumption that countries are able to make such welfare transfers can be motivated by the fact that trade negotiations frequently involve cross-country linkages among a large number of issues. Therefore, it is appropriate to assume that countries use these linkages to effectively make transfers.[51]

Comparing equations (35) and (37), we observe that for any $\gamma$ the size of the jointly optimal compatibility tax relative to the non-cooperative compatibility tax of the foreign country depends upon the strength of the network externality, $n$.[52] Two qualitatively distinct examples are shown in Figures 3 (a, b). When the network externality is strong (i.e., $n$ is large), the overadoption distortion is more severe. Therefore, the jointly optimal compatibility tax targeting this distortion tends to be larger than the best response tax of the foreign country. This possibility is illustrated in Figures 3 (a) in which the point $W$ corresponding to the jointly optimal policy combination is located to the right and below the point $N$, which represents the Nash equilibrium policy outcome. By contrast, when the network externality is weak (i.e., $n$ is small) the overadoption distortion is less severe and the jointly optimal tax tends to be smaller than the foreign best response tax. This situation is depicted in Figure 3 (b), in which the curve corresponding to $\theta^W(\gamma)$ is drawn closer to the vertical axis of the graph than the curve representing $\theta^F(\gamma)$. As a result, the jointly optimal policy combination point $W^*$ is located to the left and above the Nash equilibrium point $N$.

Figures 3 (a, b) illustrate two principal ways in which the governments can use the compatibility factor to raise the component of their joint welfare associated with a network externality effect. First, they can increase compatibility *between* the two rival networks by tightening the standard. Second, they can take the advantage of perfect compatibility *within* the dominant network by expanding its size. However, as we discussed above, under the increasing unit cost of compatibility there is a conflict between the two ways of increasing the network benefits. When $\gamma$ affects the marginal cost difference between the rival firms, increasing compatibility between the networks worsens the overadoption distortion, which by definition means

[51] Hoekman (1993), for example, pointed out that negotiating countries exchange concessions both within and across issues. Cross-issue linkages may allow agreement even if within-issue exchange of concessions proves insufficient to generate an improvement on the status quo for all concerned.

[52] By rearranging the inequality $\theta^W(\gamma) > \theta^F(\gamma)$, we obtain: $C > (1-q)(1-2q)/(3-2q)$. When the cost function is sufficiently convex and satisfies this paper's assumptions regarding $C(\gamma)$, this inequality holds for large values of $n$ but is reversed when $n$ is small.

worsening the inefficiency of the dominant network's size. The optimal size of the dominant network can be restored by means of the tax aimed at the overadoption of the minority technology. But the drawback of the tax is that it increases the cost of achieving greater compatibility between the rival networks.

When the network externality is strong, it is more efficient to emphasize the benefits of perfect compatibility within the dominant network than to achieve a higher (but still imperfect) compatibility between the rival networks. Therefore, when $n$ is large we may be able to observe the situation depicted in Figure 3 (a). The figure illustrates the example in which the lack of policy cooperation in the area of compatibility leads to excessive compatibility between the rival networks at the cost of overadoption of the minority technology. The latter results in the sub-optimal size of the dominant network within which the users enjoy perfect compatibility. Therefore, without policy cooperation, too much of the imperfect inter-network compatibility is substituted for the perfect compatibility within the dominant network.

When the network externality is weak (small $n$), raising compatibility between the rival networks has a greater positive impact on the countries' joint welfare than the expansion of the dominant network. This is the case illustrated in Figure 3 (b), in which the jointly optimal policy combination has a tighter standard and a smaller tax than the non-cooperative policy combination. To understand why this is so, note that the weakness of the network externality implies that the overadoption distortion is small even for high values of $\gamma$. Therefore, a smaller tax is needed to target this distortion. As a result, the governments have a stronger joint incentive to increase compatibility between the minority network and the dominant networks.

One notable feature of the examples illustrated in Figures 3 (b, c) is the fact that the jointly optimal tax, which targets only the overadoption distortion, is less than the unilateral rent-capturing tax of the foreign country. As a result, the standard adopted by the countries under the agreement maximizing their joint welfare may be tighter than even the protectionist unilateral standard of the home country (as shown in Figure 3 (b)).

## 7. Discussion and Conclusion

In the Introduction, we mentioned the disciplines for policing technical regulatory barriers that exist within the legal system of the WTO. Similar disciplines exist within the legal systems of the European Union and NAFTA. Reduced to bare essentials, all of these disciplines are based on the requirement that regulatory policy objectives be achieved in the manner that minimizes impediments to commerce and open markets. This requirement in the international law is referred to as the *least restrictive means principle*.[53]

[53] Other important principles of the internal law designed to prevent regulatory protectionism are non-discrimination, obligation to give reasons and advance notice, transparency, precedence of performance regulations over design regulations, mutual recognition, reliance on international standards, and the 'sham' principle. Alan Sykes (1995) provided a thorough overview of these principles and suggested that all of them may be considered as corollaries of the least restrictive means principle.

The exact language used to formulate this principle in the international trade agreements varies. The original GATT agreement (Article XX) states that domestic regulatory measures should not constitute a means of "arbitrary or unjustifiable discrimination between countries" or "a disguised restriction on international trade." Article 2.1 of the Standards Code adopted during the Tokyo Round says that governments should not adopt standards and regulations "with a view of creating obstacles to international trade" or with " the effect of creating unnecessary obstacles to international trade". The Uruguay Round Agreement on Technical Barriers to Trade (TBT) proposes a balancing test, which requires measuring negative trade effects against the putative benefits of regulation. As stated in Article 2.2 of the TBT Agreement, "technical regulations shall not be more trade-restrictive than necessary to fulfill a legitimate objective, taking account of the risks non-fulfillment would create." Article VI (4) (b) of the General Agreement on Trade in Services (GATS) introduced the *necessity test*, which invalidates domestic standards and regulations that are "more burdensome than necessary to ensure the quality of the service." In the context of standards and regulations governing the supply of services characterized by network externalities, quality-of-service standards include standards aimed at ensuring the integrity of the networks.

Legal scholars identify the rationale behind the least trade restrictive means principle with the goal of maximizing "the sum of net gains from trade and net gains from regulation" or "the net benefits of domestic consumers and producers as well as foreign producers" (Trachtman, 1998). Most economists agree that the appropriate economics interpretation of the least restrictive measure is one that identifies it with the global welfare-maximizing measure, or the measure that a welfare-maximizing government would choose if all producers supplying the domestic market were domestic by origin (see, for example, Baldwin (1970), Engel (2000), and Fischer and Serra (2000)).

Our model suggests that the unilaterally optimal compatibility standard of the importing country is "more burdensome than necessary," in that it does not maximize the joint welfare of the importing and the exporting countries. However, as should be apparent from the preceding formal analysis, an exchange of commitments between countries to use the least restrictive measures in their own domestic markets is necessary but not sufficient to ensure the globally efficient levels of trade and compatibility, regardless of whether international welfare transfers are feasible or not. Although such commitments guarantee access to the markets of the importing countries, they do not restrain the compatibility policies of the exporting countries. The latter are important because global efficiency requires an agreement specifying not only the relative size of the networks based on the imported and the import-competing products (which can be pinned down by the reciprocal market access agreement alone) but also the level of compatibility between the rival products within each domestic market. Only such an agreement can guarantee that exporting as well as importing countries internalize the costs that their compatibility policies impose on trade partners.

To achieve the globally optimal agreement, the countries have to exchange commitments regarding (1) market access (which also defines the relative size of the rival networks in each country), and (2) the level of inter-network compatibility within each market. Since the least restrictive means principle restrains the compatibility policy of the importing country but imposes no restrictions on the exporting country's policy toward compatibility, the application of this principle alone does not allow the countries to reach the jointly efficient volume of trade and level of compatibility. In order to maximize global efficiency, the exporting and the importing countries must enter into an agreement linking their compatibility policies toward imported and import-competing products. Such a linkage offers a feasible means of achieving the globally efficient combination of the degree of compatibility between rival products and the relative size of the partially incompatible rival networks.

This point is related to the conclusion reached by Bagwell et al. (2002), who suggest that if the only type of the negative externality the countries can exert on each other is associated with the terms-of-trade effect, then the global efficiency can be attained through a reciprocal market access agreement setting the world prices at the efficient level.[54] They also note that if, in addition to the terms-of-trade driven externalities, countries exert other types of cross-border externalities on their trade partners, then the reciprocal exchange of commitments regarding market access alone will be insufficient to achieve global efficiency.

In our model, the compatibility policy in the exporting country exerts negative externality on the importing country not only through the price charged by the exporting firm but also through the exporting firm's choice of the degree of compatibility with the import-competing product.[55] The latter type of cross-border externality arises because incomplete compatibility of the foreign product with the domestic product undermines the integrity of the domestic network. When the exporter's choice of compatibility level affects its unit cost, the exporting government's compatibility policy has implications for both the relative size of the rival networks in the export markets and the level of compatibility between them. In this situation, an agreement on market access can ensure the optimal relative size of the networks but will not ensure the optimal level of inter-network compatibility. Therefore, in the context of our model, the globally efficient trade agreement should incorporate commitments not only with regard to market access but also with regard to the level of compatibility between the products.

Specifically, if the governments can use trade taxes and subsidies as well as national policies toward compatibility of the kind we have described in this paper, the optimal trade agreement between them must include both reciprocal market access commitments that pin down the relative size of the rival networks within

---

[54] There is no need to agree on the specific levels of domestic regulatory policies as long as the governments have access to an array of sufficiently flexible trade policies. Having fixed the globally efficient terms of trade through reciprocal commitments with regard to market access, countries can then choose their preferred domestic regulations and offset any market-access effects of these regulations through trade policies. The need to supplement market access commitments with a cross-country linkage of specific regulatory and trade policies arises only if the countries are not free to choose the necessary trade policy instruments for offsetting the terms-of-trade effects of domestic regulations. For example, when export subsidies are ruled out, a cross-country linkage between national standards and import taxes enables countries to tighten their export industry standards to the efficient levels while preserving exporters' access to the importing country's market.

[55] The effect of the rent-shifting policies on the prices set by the imperfectly competitive exporters is similar to the effect on world prices of the trade policies aimed at improving the exporting country's terms of trade. Both types of policies lead to higher export prices.

each national market and commitments regarding the level of compatibility between the rival products.[56] After that, the countries can choose their preferred trade taxes and compatibility regulations only to the extent that their choices do not alter their market-access commitments and their commitments on inter-network compatibility.

# Appendix

**Proof of Proposition 4**:

Omitting the subscript denoting the foreign firm's variables, the first-order condition for welfare maximization is given by

$$P_\gamma f_\theta s + s_\gamma f_\theta P - C' f_\theta s - s_\gamma f_\theta C = (P_\gamma - C')\, f_\theta s + (P - C) s_\gamma f_\theta = 0,$$

which is equivalent to

$$(P_\gamma - C')s + (P - C)s_\gamma = 0. \tag{A1}$$

Given our assumptions about the cost function $C(\gamma)$, the welfare function $W_F$ is concave in $\theta$, and the second-order condition is satisfied.

Differentiating the foreign firm's market share (29) with respect to $\gamma$ gives:

$$s_\gamma = \frac{(1+\theta)\big(Cn - C'(1-n(1-\gamma))\big)}{6(1-n(1-\gamma))^2}. \tag{A2}$$

Because we are concerned with $\theta > -1$, the sign of $s_\gamma$ is the same as the sign of $Cn - C'(1-n(1-\gamma))$. Notice that, given the assumptions about the cost function (i.e., $C'>0$, $C''>0$, $\lim_{\gamma\to 1} C'(\gamma) = \infty$ and $C(0)= C'(0) = 0$), we have $C(\gamma) < \gamma C'(\gamma)$, $\forall \gamma \in [0, 1]$. Therefore, $C(\gamma) < C'(\gamma)$, $\forall \gamma \in [0, 1]$. Because our assumption about the efficiency of the converter (see footnote 21) implies that $n \in (0, ½)$, it follows that $Cn < C'(1-n(1-\gamma))$. Therefore, for $\theta > -1$, we have $s_\gamma < 0$.

Under imperfect competition, the mark-up of the foreign firm is positive. Hence, we have $(P - C)s_\gamma < 0$. Therefore, any $\theta^*$ (greater than minus one) that solves equation (A1) and under which the foreign firm has a positive market share ($s(\theta^*) > 0$) must satisfy $P_\gamma(\theta^*) - C'(\theta^*) > 0$, $\forall \gamma \in [0, 1]$. This condition is equivalent to $C'(2\theta^* - 1) > -3n$, $\forall \gamma \in [0, 1]$. It follows that $\theta^* > 1/2$. ■

[56] Although we reached this conclusion based on the analysis of only the home market, the same conclusion can be reached using a full reciprocal markets model incorporating the domestic markets of both countries.

# References


1. Auriol, E. and M. Benaim, (2000), "Standardization in Decentralized Economies," *American Economic Review* 90, 550-570.
2. D'Aspremont, C, J. J. Gabszewics and J.-F. Thisse (1979), "On Hotelling's "Stability in Competition," *Econometrica* 47, 1145-1150.
3. Bagwell, Kyle, Mavroidis, Petros C., and Robert W. Staiger (2002) "It's a Question of Market Access," *The American Journal of International Law* 96, 56-76.
4. Bagwell, Kyle, and Robert W. Staiger, (2001) "Domestic Policies, National Sovereignty and International Economic Institutions," *Quarterly Journal of Economics* 116, 519-562.
5. Baldwin, Richard E. (1970), *Nontariff Distortions of International Trade*, Washington, D.C.: Brookings Institution.
6. Berg, S. V., (1988), "Duopoly Compatibility Standards with Partial Cooperation and Standards Leadership," *Information Economics and Policy* 3, 35-53.
7. Brander, J. A., and B. J. Spencer (1984), "Tariff Protection and Imperfect Competition," in H. Kierzkowski (ed.), *Monopolistic Competition and International Trade*. Clarendon Press, Oxford. pp. 194-206.
8. Braunstein, Y., and L. White, (1985), "Setting Technical Compatibility Standards: An Economic Analysis," *The Antitrust Bulletin* 30, 337-355.
9. Cheng, Leonard K. (1988), "Assisting Domestic Industries under International Oligopoly: The Relevance of the Nature of Competition to Optimal Policies," *American Economic Review* 78, 746-58
10. Choi, Jay Pil (1997), "The Provision of (Two-Way) Converters in the Transition Process to a New Incompatible Technology," *Journal of Industrial Economics* 45, 139-53.
11. Clarke, P., (1999), "U.S. warns Europe to open 3G standards," *Electronic Engineering Times,* Manhasset, July 19, 1.
12. Clendenin, M., (2004) "Intel balks at China's Wi-Fi security spec -- Government pressured to reconsider WAPI scheme," *Electronic Engineering Times*, March 15, 1.
13. Dixit, A. K. (1984), "International Trade Policy for Oligopolistic Industries," *Economic Journal* 94, 1-16.
14. Dixit, A. K. (1988), "Anti-Dumping and Countervailing Duties under Oligopoly," *European Economic Review* 32, 55-68.
15. David, P. A., and J. A. Bunn, (1988), "The Economics of Gateway Technologies and Network Evolution: Lessons from Electricity Supply History," *Information Economics and Policy* 3, 165-202.
16. David, P. A. and S. Greenstein, (1990), "The economics of compatibility standards: An introduction to recent research," *Economics of Innovation and New Technology* 1, 3-41.

17. David, P. A and W. E. Steinmueller, (1994), "Economics of Compatibility Standards and Competition in Telecommunication Networks," *Information Economics and Policy* 6, 217-242.
18. Eaton, J. and Grossman, G. (1986): “Optimal Trade and Industrial Policy under Oligopoly,” *Quarterly Journal of Economics* 101, 383-406.
19. Economides, N. (1984), “The Principle of Minimum Differentiation Revisited,” *European Economic Review* 24, pp. 345-368.
20. Economides, N., (1988), "Variable Compatibility without Network Externalities," Discussion Paper No. 145, Studies in Industry Economics, Stanford University.
21. Economides, N., (1991), "Compatibility and the Creation of Shared Networks," in *Electronic Services Networks: A Business and Public Policy Challeng*e, edited by Margaret Guerrin-Calvert and Steven Wildman, Praeger Publishing Inc., New York: 1991.
22. Engel, E., (2000), “Poisoned Grapes, Mad Cows and Protectionism,” *Journal of Policy Reform* 4, 91–111.
23. European Commission, (2001), *Report on United States Barriers to Trade and Investment.* Brussels, July 2001.
24. Farrell, J., and G. Saloner, (1992), "Converters, Compatibility, and the Interfaces," *Journal of Industrial Economics* 40, 9-36.
25. Fischer, R. and Serra P., (2000), “Standards and Protection,” *Journal of International Economics* 52, 377-400.
26. Fung, K. C. (1988), “Strategic Trade Policies, Differentiated Duopoly and Intra-industry Trade,” *International Economic Journal* 2, 19-34.
27. Gabszewicz, J.J. and Thisse, J.F., (1979), “Price competition, quality and income disparities,” *Journal of Economic Theory* 2, 340–359.
28. Gandal, Neil, (2001), “Quantifying the Trade Impact of Compatibility Standards and Barriers: An Industrial Organization Perspective,” in Keith E. Maskus and John S. Wilson, editors, *Quantifying the Impact of Technical Barriers to Trade: Can It Be Done?* (Ann Arbor: University of Michigan Press), pp. 137-153.
29. Gandal, N., and O. Shy, (2001), “Standardization Policy and International Trade," *Journal of International Economic*s 53, 363-383.
30. Gatsios, K., and L. Karp (1995), “The Welfare Effects of Imperfect Harmonization of Trade and Industrial Policy,” *Economic Journal* 102, 107-116.
31. Grindley, P., Salant, D. and L. Waverman (1999), “Standards Wars: The Use of Standard Setting as a Means of Facilitating Cartels – Third Generation Wireless Telecommunications Standard Setting,” *International Journal of Communications Law and Policy* (IJCLP), Issue 3, Summer, [IJCLP Web-Doc 2-3-1999; http://www.ijclp.org],

32. Hoekman, Bernard (1993), "Multilateral Trade Negotiations and Coordination of Commercial Policies," in Stern, R. (ed.), *The Multilateral Trading System: Analysis and Options for Change.* Ann Arbor: University of Michigan Press.
33. Katz, M. and C. Shapiro, (1985), "Network Externalities, Competition and Compatibility," *American Economic Review* 75, 424-440.
34. Katz, M. and C. Shapiro, (1986), "Product Compatibility Choice in a Market with Technological Progress," *Oxford Economic Papers* 38, 146-165.
35. Krishna, Kala, (1988), "High-Tech Trade Policy," in R. Baldwin, C. Hamilton and A. Sapir, eds. *Issues in US-EC Trade Relations*. Chicago: University of Chicago Press, 285-311.
36. Krishna, Kala, (1989), "Trade Restrictions as Facilitating Practices," *Journal of International Economics* 26, 251-270.
37. MacKie Mason, Jeffrey and Janet S. Netz, (2002), "Manipulating Interface Standards as an Anti-Competitive Strategy," Mimeo, presented at 2002 Telecommunications Policy Research Conference.
38. Mannion, P. and M. Clendenin, (2003) "China throws Wi-Fi a curve -- Mandatory security scheme incompatible with 802.11," *Electronic Engineering Times*, December 22, 1.
39. Maskus, Keith, Otsuki, Tsunehiro and John S. Wilson, (2001), "An Empirical Framework for Analyzing Technical Regulations and Trade," in Keith E. Maskus and John S. Wilson, editors, *Quantifying the Impact of Technical Barriers to Trade: Can It Be Done?* (Ann Arbor: University of Michigan Press), pp. 29-58.
40. McLean, Heather, (2001), "Intel WLAN can forget about Europe," accessed at www.silicon.com/a47267 on September 10, 2001.
41. Neven, D., Norman, G. and J.-F., Thisse, (1991) "Attitudes towards foreign products and international price competition," *Canadian Journal of Economics* 24, 1-11.
42. Organization for Economic Development and Cooperation (2000a), *An Assessment of the Costs for International Trade in Meeting Regulatory Requirement*s. TD/TC/WP(99)8/FINAL, Paris: OECD.
43. Organization for Economic Development and Cooperation (2000b), *Standardization and Regulatory Reform: Selected Cases.* TD/TC/WP(99)47/FINAL, Paris: OECD.
44. Organization for Economic Development and Cooperation (2001), *Standards-Related Barriers and Trade Liberalization: Telecommunications Sector Study – Interim Report.* TD/TC/WP(2001)11/REV1, Paris: OECD.
45. O'Neil, Kim (2001), "Galileo - European Satellite Navigation System," Advanced Aviation Technology Ltd. accessed at http://www.aatl.net/publications/galileo.htm on September 26, 2001.
46. Spencer B. and J. Brander, (1983), "International R & D Rivalry and Industrial Strategy", *Review of Economic Studies* 50, 707-722.
47. Sykes, A.O. (1995), *Product Standards for Internationally Integrated Goods Markets.* Brookings, Washington.

48. Trachtman, J., (1998) "Trade and . . .. Problems, Cost-Benefit Analysis and Subsidiarity," *European Journal of International Law* 9 (1), 32-85.
49. Wong, W., (2001), "Wireless networking wars hit speed bump," CNET News.com at http://news.cnet.com/news/0-1004-200-4952376.html accessed on February 26, 2001.
50. Zhou D., Spencer B., and I. Vertinsky, (2002), "Strategic trade policy with endogenous choice of quality and asymmetric costs," *Journal of International Economics* 56, 205–232.