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Do safeguard tariffs and antidumping duties open or close technology gaps?

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Abstract

This paper examines how the country-breadth of tariff protection can affect the technology adoption decisions of both domestic import-competing and foreign exporting firms. The contribution of the analysis is to show how firm-level technology adoption changes under tariffs of different country-breadth. I show that a country-specific tariff like an antidumping duty induces both domestic import-competing firms and foreign exporting firms to adopt a new technology earlier than they would under free trade. In contrast, a broadly-applied tariff like a safeguard can accelerate technology adoption by a domestic import-competing firm, but will slow-down technology adoption by foreign exporting firms. Because safeguard tariffs can delay the foreign firm's adoption of new technology, the worldwide welfare costs associated with using them may be larger than is generally believed.

Keywords: Trade theory; Trade policy; Technology adoption; Antidumping; Safeguard measures

JEL classification: F12; F13; O33

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1. Introduction

This paper explores how the country-breadth of tariff protection affects technology adoption decisions. Although protection-seeking industries often claim that they are the victims of "unfair" trade, in many cases, it is clear that a domestic industry's falling market share is due to its technological inferiority relative to its foreign competitors. For example, the US saw steel imports increase from 7.3% of the US market in 1964 to 16.7% in 1968 after European and Japanese steel producers adopted a major technological innovation, the basic oxygen furnace.[1] From 1969 to 1974, the US government responded to this import surge with country-specific import restraints; specifically, voluntary restraint agreements with the EC and Japan. These import restrictions had two notable effects. First, steel imports from countries not covered by the agreement rose.[2] Second, the US industry failed to catch-up technologically. In 1974, when 80.9% of Japanese production and 68.8% of German production utilized the basic oxygen furnace, only 56.0% of US steel production utilized the new technology.[3]

In the 1980s and 1990s, technology in steel production continued to improve with the development of continuous casting, another cost-reducing production technology. The US government again responded to import surges from technological leaders with country-specific antidumping duties and voluntary restraint agreements.[4] The results of protection were the same as before. The US remained technologically behind.

Despite the dismal history of steel, the American experience with trade protection and technology adoption has not been universally bad. In 1983, in the face of rising imports of Japanese motorcycles, the US government temporarily raised its tariff on motorcycles. The goal was to help the American producer, Harley-Davidson, implement its plan to introduce "innovative new management and manufacturing techniques, many of which were learned from [Harley-Davidson's] Japanese competitors."[5] This experiment in using the multi-country "safeguard tariff" to assist a firm in adopting the technology of its foreign rivals turned out to be a success—by 1986 Harley-Davidson had closed the technology gap. It had "revitalized its manufacturing and streamlined its operations"[6] and had reclaimed the top spot in the US superheavyweight motorcycle market. Interestingly, unlike the US experience with steel protection, the comprehensive safeguard tariff did not lead to trade diversion. In fact, under the safeguard tariff, imports of motorcycles from Japan grew 17.6% between 1984 and 1985 while growth of imports from Germany was only 7% and imports from Italy fell 11.0%.[7]

[1] See Moore (1996).

[2] See Prusa (2001) and Moore (1996).

[3] OECD Steel Committee, 1974.

[4] An exception to the general practice of country-specific protection was the use of the Trigger Price Mechanism from 1977 to 1982 that imposed a price floor on imports from all countries.

[5] Harley-Davidson Motor Company (2000, p. 2).

[6] Ibid.

[7] Author's calculation for motorcycles with engines 700 cc's or larger from "US Imports for Consumption and General Imports, TSUSA Commodity by Country of Origin, FT246," Bureau of the Census, Washington, DC 1972–1988. Because the safeguard was imposed in mid-1983, 1984 is the first year for which data on imports under the safeguard are available.

Why were the outcomes of trade protection so different? This paper attempts to explain how differences in the breadth of trade protection could have affected technology adoption by these two industries. Understanding this difference is important because the use of antidumping duties and safeguard measures is spreading around the world. By the end of 2003, 100 members of the WTO had adopted legislation that provided for the use of safeguards and 104 members had adopted legislation that provided for the use of antidumping duties. Interestingly, although safeguard measures may appear to be more effective at closing technology gaps, antidumping duties are greatly preferred— in 2003, 1323 antidumping measures were in force around the world compared to only 44 safeguard measures.[8]

This is the first paper to analyze the relationship between the breadth of trade protection and technology adoption. In exploring how tariffs affect technology adoption, I draw from the technology literature (Reinganum, 1981a,b; Fudenberg and Tirole, 1985) in which ex ante identical firms compete in the dates at which they adopt an existing, widely available technology whose cost of adoption is decreasing with time. My research complements Matsuyama (1990), Tornell (1991) and Miyagiwa and Ohno (1995, 1999) who study how the duration of trade protection can affect the adoption of an existing technology. They show that when the duration of protection is endogenous to the domestic firm's decision of when to adopt the new technology, the new technology is never adopted or, in the case of Tornell, the level of investment is lower. I abstract from this problem by examining permanent protection.[9]

This paper uses a segmented markets model in which three firms in three different countries—one importing country and two exporting countries—compete on quantity. At some time, the firm in one foreign exporting country discovers and adopts a new technology. The import-competing firm and the firm in the second foreign country then decide when to adopt the new technology. When the cost of technology adoption is decreasing with time but is a fixed cost at any moment in time, a firm that faces a large worldwide market has an incentive to adopt the new technology relatively early. I show that when the import-competing firm and the firm in the second foreign country are sufficiently similar in terms of the size of the worldwide market they face, it is indeterminate which country will adopt the new technology first in the pure strategy Nash equilibrium under free trade. If one firm faces a worldwide market that is sufficiently larger than its competitor's, it will adopt the new technology first.

Protection under a multicountry safeguard tariff and a country-specific antidumping duty changes the equilibrium in the technology adoption game. Country-specific antidumping duties advance the date of technology adoption for both the import-competing firm and the second foreign firm. They do this by reducing the market share of

[8] WTO, 2003, 2004.

[9] Miyagiwa and Ohno (1995) show that permanent protection is equivalent to temporary protection with a minimum duration and a termination date that is exogenous to the domestic firm's technology adoption decision. Because the two temporary tariffs authorized by the WTO, the multicountry safeguard tariff and the country-specific antidumping duty, have exogenously set termination dates that are enforced by the threat of retaliation, analyzing permanent protection is a reasonable simplification.

the technologically superior firm and increasing the market shares of both the domestic firm and the second foreign firm. By increasing both firms' market shares, the antidumping duty creates an incentive for both firms to adopt the new technology earlier that they would under free trade. Because the antidumping duty doesn't change the relative market shares of these two firms, it doesn't alter the equilibrium order of technology adoption. In contrast, a multicountry safeguard tariff advances the date of technology adoption by the import-competing firm and delays the date of technology adoption by the second foreign firm. This happens because the safeguard tariff increases the market shares of the domestics firm and reduces the market shares of both foreign firms. Moreover, the safeguard tariff changes the relative market shares of the domestic firm and the foreign firm that does not have the new technology. By changing the relative market shares of these two firms, the safeguard tariff can alter the equilibrium order of adoption. When the safeguard tariff increases the domestic firm's market share above a critical threshold, the domestic firm "leap-frogs" the second foreign firm in the technology adoption race if it would be the last to adopt in free trade.

Section 2 outlines the model. Section 3 presents the technology adoption game and the equilibrium technology adoption dates under different trade policies. Section 4 concludes.

2. The model

There are three countries in the world, two foreign countries (denoted A and B) and one domestic country (called home and indexed H). There is one firm in each country, markets are segmented, and the goods produced in each country are prefect substitutes. To simplify the analysis, I assume the home market is open to imports, but the foreign markets are closed to each other and to the home firm.

Inverse demand in the home country is given by $p(q, m^a, m^b)$ where q is the home firm's output and m^i is imports from firm i into the home country. Inverse demand in each foreign country is given by $p^i(q^i)$ where q^i is firm i's sales in its own market. For simplicity, I assume inverse demand in all countries in linear $p(q, m^a, m^b) = a - (q + m^a + m^b)$ and $p^i(q^i) = a^i - q^i$, for the home and foreign countries, respectively.

The technology level of a firm at any point in time is simply its marginal cost of production at that time, γ^i where $i = a, b, h$. The technology level of the any firm can take on two values, $\gamma^i \in \{\underline{\gamma}, \bar{\gamma}\}$ where $\underline{\gamma}$ is the new or low-cost technology and $\bar{\gamma}$ is the old or high cost technology ($\underline{\gamma} < \bar{\gamma}$). Initially, the three firms have identical, high-cost technologies. At some time denoted $t = 0$, firm A experiences a positive technology shock; its marginal cost of production falls to $\underline{\gamma}$. At any time $t > 0$, the new technology of the firm in country A can be acquired by the home firm and the firm in country B at a cost $C(t)$ that decreases with time $C'(t) < 0$ and $C''(t) \geq 0$.[10] The advent of this new technology induces a technology adoption race between the import-competing firm in the home

[10] For example, cost-reducing process innovations like the basic oxygen furnace, continuous casting, industrial robots, computers and machine vision would satisfy this assumption.

country and the firm in country B. In Section 3, I characterize the Nash equilibrium of the technology adoption game.[11]

At every moment in time, firms choose their quantities simultaneously to maximize profits given their current technology level.[12] Let $\pi^i(\gamma_i, \gamma_j)$ denote the instantaneous equilibrium profits earned by firm $i=h, b, j=h, b, j \neq i$. Firm A's new technology level is given by $\gamma_a = \underline{\gamma}_a$ after $t=0$ and is suppressed for clarity. Thus $\pi^i(\bar{\gamma}_i, \bar{\gamma}_j)$ denotes the instantaneous profits earned by firm $i=h$, b when both firms have the old technology, $\pi^i(\bar{\gamma}_i, \underline{\gamma}_j)$ denotes the profits earned by firm i when firm i has the old technology and firm j has the new technology, $\pi^i(\underline{\gamma}_i, \bar{\gamma}_j)$ denotes the profits earned by firm i when firm i has the new technology and firm j has the old technology, and $\pi^i(\underline{\gamma}_i, \underline{\gamma}_j)$ denotes the profits earned by firm i when both firms have the new technology.

Linear demand and constant marginal cost imply the following relationship about instantaneous profits under different technology levels for any sets of non-prohibitive tariffs (τ^a, τ^b) that are constant over time.[13] First, the profits from being a technological leader exceed the profits earned when both firms have the new technology which, in turn, exceed the profits from being a technological follower. Formally, $\pi^i(\underline{\gamma}_i, \bar{\gamma}_j) > \pi^i(\underline{\gamma}_i, \underline{\gamma}_j) > \pi^i(\bar{\gamma}_i, \underline{\gamma}_j)$. Second, the profits of leading in the technology adoption race exceed the profits earned when both firms have the old technology, which in turn, exceed the profits from being a follower, $\pi^i(\underline{\gamma}_i, \bar{\gamma}_j) > \pi^i(\bar{\gamma}_i, \bar{\gamma}_j) > \pi^i(\bar{\gamma}_i, \underline{\gamma}_j)$. Thirdly, firms earn lower instantaneous profits when they both have the new technology than when they both have the old technology, $\pi^i(\underline{\gamma}_i, \underline{\gamma}_j) - \pi^i(\bar{\gamma}_i, \bar{\gamma}_j) < 0$.

Most importantly, the benefit to a firm of being the leader in adopting the new technology exceeds the benefit to the firm when it is the follower in adopting the new technology.

$$\pi^i(\underline{\gamma}_i, \bar{\gamma}_j) - \pi^i(\bar{\gamma}_i, \bar{\gamma}_j) > \pi^i(\underline{\gamma}_i, \underline{\gamma}_j) - \pi^i(\bar{\gamma}_i, \underline{\gamma}_j) > 0. \tag{1}$$

These conditions ensure that the two firms, home and firm B, will want to adopt the new technology, but they will never want to adopt the new technology at the same moment in time, even if their instantaneous profit functions are identical.

3. The technology adoption game

The home firm and the firm in country B strategically choose dates at which to adopt the new technology, t^h and t^b, in order to maximize the discounted present value of net

[11] The Nash equilibrium rules out by assumption the possibility of pre-emption in technology adoption. Fudenberg and Tirole (1985) have show that, in a continuous time technology adoption game with two identical firms, allowing for pre-emption causes the equilibrium dates of technology adoption to occur earlier and rents to be equalized between the two firms. When rents are equalized, firms are indifferent between being the leader or follower in technology adoption. In this paper, I analyze what Fudenberg and Tirole call a "precommitment equilibrium." Oster (1982) finds that plant-specific characteristics are important determinants of the dates at which US steel firms adopted the basic oxygen furnace and continuous casting. Thus, plant-specific characteristics may act as pre-commitment devices.

[12] I assume that firms follow Markov strategies in order to restrict my attention to the non-cooperative equilibrium in the repeated quantity-setting game.

[13] In Sections 3.2 and 3.3, I discuss how relaxing the assumption that tariffs are constant over time will alter the results.

profits. The firm in country A, which already has the new technology, has no strategic choice to make regarding technology. It does, however, continue to strategically choose the quantity of output to sell in the home country. The discounted present value of net profits to firm $i=h$, b, $i\neq j$ depends on whether it is a leader or follower in technology adoption and is given by the following:

$$V^i(t^i,t^j)=\begin{cases} g_\ell^i(t^i,t^j) & \text{if } t^i\leq t^j \\ g_\mathrm{f}^i(t^i,t^j) & \text{if } t^i\geq t^j \end{cases} \tag{2}$$

where

$$g_\ell^i(t^i,t^j)=\int_0^{t^i} \mathrm{e}^{-rs}\pi^i(\bar{\gamma}_i,\bar{\gamma}_j)\mathrm{d}s+\int_{t^i}^{t^j} \mathrm{e}^{-rs}\pi^i\left(\underline{\gamma}_i,\bar{\gamma}_j\right)\mathrm{d}s+\int_{t^j}^{\infty} \mathrm{e}^{-rs}\pi^i\left(\underline{\gamma}_i,\underline{\gamma}_j\right)\mathrm{d}s - \mathrm{e}^{-rt^i}C(t^i)$$

$$g_\mathrm{f}^i(t^i,t^j)=\int_0^{t^j} \mathrm{e}^{-rs}\pi^i(\bar{\gamma}_i,\bar{\gamma}_j)\mathrm{d}s+\int_{t^j}^{t^i} \mathrm{e}^{-rs}\pi^i\left(\bar{\gamma}_i,\underline{\gamma}_j\right)\mathrm{d}s+\int_{t^i}^{\infty} \mathrm{e}^{-rs}\pi^i\left(\underline{\gamma}_i,\underline{\gamma}_j\right)\mathrm{d}s - \mathrm{e}^{-rt^i}C(t^i)$$

The function g_ℓ^i represents the discounted present values of net profits to firm i if it adopts the new technology before firm j does. The firm term in g_ℓ^i represents the discounted present value of firm i's profits over the period in which both firm i and firm j have the old technology. The second term represents the discounted present value of firm i's profits over the period in which it has the new low-cost technology and firm j has the old high-cost technology. The third term is the discounted present value of firm i's profits over the period in which both firms have the new technology. Finally, the last term represents the discounted present value of installing the new technology at time t^i. The function g_f^i differs from g_ℓ^i in that the second term in g_f^i represents the discounted present value of profits earned for the period in which firm i lags behind firm j in adopting the new technology.

3.1. Technology adoption under free trade

The discounted present value of net profits to each firm, V^i, is strictly concave and continuous in t^i for a given t^j but is not differentiable at $t^i=t^j$. The strict concavity and continuity of $g_\ell^i(t^i,t^j)$ and $g_\mathrm{f}^i(t^i,t^j)$ imply that each function has a unique maximum in t^i. Moreover, because the cross partials of $g_\ell^i(\cdot)$ and $g_\mathrm{f}^i(\cdot)$ are zero, the unique maximum of each function in its first argument, t^i, is independent of t^j. Let $\hat{t}^i=\arg\max g_\ell^i(t^i,t^j)$ and let $\tilde{t}^i=\arg\max g_\mathrm{f}^i(t^i,t^j)$ for every t^j for $i=h$, b, $i\neq j$.

Each firm's optimal dates for technology adoption have two important features. First, because there are larger gains from being the first to adopt the new technology, see Eq. (1), the optimal dates of adoption for each firm depend only on the order of adoption. If a firm is the leader, its optimal date is strictly earlier than if it's a follower $\hat{t}^i<\tilde{t}^i$ for $i=b$, h.

Second, because the cost of adoption at any point in time is a fixed cost, the firm that serves the larger market(s) and can spread the cost of adoption over more units will have earlier optimal dates for adoption.

Proposition 1. *Optimal adoption dates under free trade. Under free trade, the optimal dates for technology adoption by each firm are (a) diffused over time (i.e.,* $\hat{t}^i < \tilde{t}^i$ *for* $i=h, b$*) and (b) the relationships between the optimal dates of adoption for the firms can be summarized as follows where* $q^b = (1/2)\,(a^b - 1/2(\bar{\gamma} + \underline{\gamma}))$*:*

$$\hat{t}^b < \tilde{t}^b < \hat{t}^h < \tilde{t}^h \qquad \text{if } 0 < \frac{3}{8}\left(\bar{\gamma} - \underline{\gamma}\right) < q^b \tag{3}$$

$$\hat{t}^b < \hat{t}^h < \tilde{t}^b < \tilde{t}^h \qquad \text{if } 0 < q^b < \frac{3}{8}\left(\bar{\gamma} - \underline{\gamma}\right) \tag{4}$$

$$\hat{t}^b = \hat{t}^h < \tilde{t}^b = \tilde{t}^h \qquad \text{if } 0 = q^b \tag{5}$$

See Appendix A for the proof.

Proposition 1 summarizes the relationship between a firm's optimal dates for technology adoption and the size of the worldwide market it faces. Because country *B*'s market is closed to imports and the home country's market is open, firm *B* will serve a larger market. Intuitively, condition (3) tells us that when the size of country *B*'s market is sufficiently large relative to the cost savings generated by the new technology, its optimal dates for technology adoption precede those of the home firm. As the size of country *B*'s market decreases, as given by (4), the gaps between its optimal dates for adoption and the home firm's optimal dates decrease. Finally, when the market of country *B* is so small that firm *B* sells no output in its own market, the optimal dates for adoption for the two firms are the same.[14]

Given the optimal dates of adoption presented in Proposition 1, the best response function of firm *i* can be written as

$$t^{i\mathrm{R}}\left(t^j\right) = \begin{cases} \hat{t}^i \text{ if } t^j > \bar{t}^j \\ \{\hat{t}^i, \tilde{t}^i\} \text{ if } t^j = \bar{t}^j \\ \tilde{t}^i \text{ if } t^j < \bar{t}^j \end{cases} \tag{6}$$

for $i=h, b$, $i \neq j$ and where $\hat{t}^j$ is defined as the value of t^j such that $g^i_{\ell}(\hat{t}^i, t^j) = g^i_{\mathrm{f}}(\tilde{t}^i, t^j)$. The best response function of each firm $i=h, b$ consist of the two dates ($\hat{t}^i$ and $\tilde{t}^i$) that are the candidates for maximizing the discounted present value of net V^i. For firm *i*, the

[14] Relaxing the assumption that foreign markets are closed to each other and the home firm causes the equilibrium to change in an obvious way. If the home firm and firm *B* have the same access to all markets, the size of their worldwide markets will be identical and their optimal dates for technology adoption will be the same. Consequently, there will be two pure strategy Nash equilibria in which either firm can be the first to adopt the new technology.

benefit of being a leader in technology adoption is just equal to the benefit of being a follower in technology adoption if its opponent chooses to adopt the new technology at a date $\bar{t}^j \in (\hat{t}^i, \tilde{t}^i)$. If firm j chooses to adopt at any time before this cutoff date ($t^j < \bar{t}^j$), then firm i earns a higher discounted present value of net profits when it delays its technology adoption until the relatively late date $\tilde{t}^i$. Hence, firm i's best response to firm j adopting at any date $t^j < \bar{t}^j$ is to choose to adopt the new technology at the later date, $\tilde{t}^i$. Similarly, if firm j adopts the new technology at any date $t^j > \bar{t}^j$, the home firm maximizes its discounted present value of net profits by adopting quickly at date $\hat{t}^i$.

Proposition 2. *Technology Adoption under free trade. In the technology adoption game, there are two pure strategy Nash equilibria* $(\hat{t}^b, \tilde{t}^h)$ *and* $(\hat{t}^h, \tilde{t}^b)$ *in which either firm can be the first to adopt the new technology if* $\hat{t}^b < \hat{t}^h < \bar{t}^h < \tilde{t}^b < \tilde{t}^h$ *and* $\hat{t}^b < \hat{t}^h < \bar{t}^b < \tilde{t}^b < \tilde{t}^b$. *This occurs when the quantity firm B sells in country B is sufficiently small,* $q^b < k^*$. *There is one pure strategy Nash equilibrium* $(\hat{t}^b, \tilde{t}^h)$ *in which the firm in country B always adopts the new technology first if the quantity firm B sells in country B is sufficiently large,* $q^b > k^*$ *where* $k^* \in (0, (3/8)(\bar{\gamma} - \underline{\gamma}))$.

Proof. Consider two cases.

Case 1: Suppose $0 \le q^b < k^*$. Then $\hat{t}^b < \hat{t}^h < \tilde{t}^h < \tilde{t}^h$ by Proposition 1. If $\hat{t}^h < \bar{t}^h$ and $\bar{t}^b < \tilde{t}^b$, then the best response functions intersect at $(\hat{t}^b, \tilde{t}^h)$ and $(\hat{t}^h, \tilde{t}^b)$. By Lemma 3 in Appendix A, for all $q^b < k^*$, $\hat{t}^h < \bar{t}^h$ and $\bar{t}^b < \tilde{t}^b$ so there are two pure strategy Nash equilibria.

Case 2: Suppose $q^b \ge k^*$. If $(3/8)\,(\bar{\gamma} - \underline{\gamma}) > q^b \ge k^*$, then $\hat{t}^b < \hat{t}^h < \tilde{t}^b < \tilde{t}^h$ by Proposition 1 and $\hat{t}^h > \bar{t}^h$ or $\bar{t}^b > \tilde{t}^b$ or both by Lemma 3 in Appendix A. Thus, inspection of the best response functions shows that the only possible intersection is at $(\hat{t}^b, \tilde{t}^h)$. If $q^b \ge (3/8)$ $(\bar{\gamma} - \underline{\gamma})$, then $\tilde{t}^b < \hat{t}^h$ by Proposition 1. Inspection of the best response functions shows that the only possible intersection is at $(\hat{t}^b, \tilde{t}^h)$. □

Two interesting observations can be drawn from Proposition 2. First, the order of technology adoption is indeterminate when the foreign firm's domestic market is sufficiently small or does not exist.[15] This suggests that if a very small country with perfect access to foreign markets keeps its own market completely closed in order to promote an infant industry, it can still lose the technology race. Second, if the foreign firm's closed domestic market is sufficiently large and the home country's market is open, the home firm will always lose the technology race.

3.2. Technology adoption under a safeguard tariff

The home country could respond to the increase in imports from country A that follows firm A's positive technology-shock with a multi-country safeguard tariff.[16] Although the WTO specifies that a safeguard is a temporary tariff that can be imposed

[15] Intuitively, allowing for pre-emption as in Fudenberg and Tirole (1985) would cause the firm with the large worldwide market to always adopt the new technology first in equilibrium. If the two firms are identical in terms of the size of their worldwide markets, the indeterminacy in the order of adoption remains.

[16] The WTO's Agreement on Safeguards, codified in US law under Section 201 of the Trade Act of 1974, allows for the use of temporary tariffs when imports surged as a result of "unforeseen developments" and thus, the necessary circumstances include, but are not limited to, the type of technology shock analyzed here.

for a maximum duration of four years, I simplify the analysis by analyzing a permanent safeguard tariff.[17]

I follow the WTO rules and model the safeguard as a non-prohibitive tariff that is equally applied to imports from country A and country B, $\tau^{sg}=\tau^i$ for $i=a, b$. The instantaneous profit function of the home firm is increasing in the safeguard tariff and the instantaneous profit functions of the foreign firms are decreasing in the safeguard tariff. Let $\hat{t}^{\,i}_{sg}$=arg max $g^i_{\ell}(t^i, t^j, \tau^{sg})$ and let $\tilde{t}^{\,i}_{sg}$=arg max $g^i_{f}(t^i, t^j, \tau^{sg})$ for every t^j for $i=h, b, i\neq j$.

Lemma 1. *The home firm's optimal dates for technology adoption under a safeguard tariff are earlier than under free trade, $\hat{t}^{\,h}_{sg}<\hat{t}^h$ and $\tilde{t}^{\,h}_{sg}<\tilde{t}^h$. Firm B's optimal dates for adopting the new technology are later under the safeguard tariff than they are under free trade $\hat{t}^{\,b}_{sg}>\hat{t}^b$ and $\tilde{t}^{\,b}_{sg}>\tilde{t}^b$.*

See Appendix A for the proof. Intuitively, the benefit to the home firm of adopting the new technology is larger under a safeguard tariff than it is under free trade both when it's a leader in adopting and when it's a follower, $\pi^h(\underline{\gamma}_h, \gamma_b, \tau^{sg}) - \pi^h(\bar{\gamma}_h, \gamma_b, \tau^{sg}) > \pi^h(\underline{\gamma}_h, \gamma_b, \tau=0) - \pi^h(\bar{\gamma}_h, \gamma_b, \tau=0)$. The safeguard tariff raises the marginal cost of exporting to the home country for firms A and B. For the home firm, under Cournot competition, the marginal benefit of reducing its costs is larger when its competitors' costs are higher. For the firm in country B, the safeguard tariff has the opposite effect. The safeguard tariff leads firm B to export less and, consequently, produce less. Because the fixed cost of technology adoption must now be spread over a smaller quantity of output, firm B's optimal dates for technology adoption are later than they would be under free trade.

Proposition 3. *Optimal dates under a safeguard tariff. Under a safeguard tariff, the relationships among the optimal dates of adoption for the two firms and the relative magnitudes of the home country's safeguard tariff, τ^{sg}, the cost savings generated by the new technology (3/8) $(\bar{\gamma}-\underline{\gamma})$, and the relative size of country B's market, $q^b=(1/2)(a^b-(1/2)(\bar{\gamma}+\underline{\gamma}))$ are as follows:*

$$\hat{t}^b_{sg}<\tilde{t}^b_{sg}<\hat{t}^h_{sg}<\tilde{t}^h_{sg} \qquad \text{if } \tau^{sg}<\frac{2}{3}\left(q^b-\frac{3}{8}\left(\bar{\gamma}-\underline{\gamma}\right)\right) \tag{7}$$

$$\hat{t}^b_{sg}<\hat{t}^h_{sg}<\tilde{t}^b_{sg}<\tilde{t}^h_{sg} \qquad \text{if } \frac{2}{3}\left(q^b-\frac{3}{8}\left(\bar{\gamma}-\underline{\gamma}\right)\right)<\tau^{sg}<\frac{2}{3}q^b \tag{8}$$

$$\hat{t}^b_{sg}=\hat{t}^h_{sg}<\tilde{t}^b_{sg}=\tilde{t}^h_{sg} \qquad \text{if } \tau^{sg}=\frac{2}{3}q^b \tag{9}$$

[17] Miyagiwa and Ohno (1995) show that temporary protection with an exogenous termination date is equivalent to permanent protection. If safeguards protection is continuously renewed for firms that delay technology adoption, then, as in Matsuyama (1990), firms will never adopt the new technology. In practice, under the Agreement on Safeguards, safeguards protection can be renewed once, for a maximum duration of protection of eight years. However, if an importing country tried to extend protection beyond the eight year maximum, it would be subject to severe WTO sanctions.

$$\hat{t}^h_{\mathrm{sg}} < \hat{t}^b_{\mathrm{sg}} < \tilde{t}^h_{\mathrm{sg}} < \tilde{t}^b_{\mathrm{sg}} \qquad \text{if } \frac{2}{3}q^b < \tau^{\mathrm{sg}} < \frac{2}{3}\left(q^b + \frac{3}{8}\left(\bar{\gamma} - \underline{\gamma}\right)\right) \tag{10}$$

$$\hat{t}^h_{\mathrm{sg}} < \tilde{t}^h_{\mathrm{sg}} < \hat{t}^b_{\mathrm{sg}} < \tilde{t}^b_{\mathrm{sg}} \qquad \text{if } \frac{2}{3}\left(q^b + \frac{3}{8}\left(\bar{\gamma} - \underline{\gamma}\right)\right) < \tau^{\mathrm{sg}} \tag{11}$$

The proof is similar to the Proof of Proposition 1 and is omitted. The full proof is presented in Crowley (2003).

Overall, expression (7)–(11) show that when the safeguard tariff is relatively small, firm B's optimal dates are earlier; when the safeguard tariff is relatively large, the home firm's optimal dates are earlier. Although the safeguard tariff increase the home firm's domestic market share and decreases firm B's market share, if country B's own market is sufficiently large, it will have an incentive to adopt relatively early. Eq. (9) provides the breakeven tariff that makes the two firms identical in terms of their worldwide market share. As the magnitude of the safeguard tariff increases beyond this breakeven tariff, the home firm's market share increases to the point that its optimal dates precede firm B's.

As in the case of free trade, the best response function of firm i is given by (6) with the optimal dates for technology adoption under a safeguard tariff given by Proposition 3.

Proposition 4. *Technology adoption under a safeguard tariff. In the technology adoption game, if the home country's tariff is sufficiently small relative to the size of country B's market and the cost savings generated by the new technology ($\tau^{sg} < \tau_1^*$ where $\tau_1^* \in \left(\frac{2}{3}\left(q^b - \frac{3}{8}\left(\bar{\gamma} - \underline{\gamma}\right)\right), \frac{2}{3}q^b\right)$), then the firm in country B adopts the new technology first in the pure strategy Nash equilibrium ($\hat{t}^b_{sg}$, $\tilde{t}^h_{sg}$). Over an intermediate range of tariffs ($\tau_1^* < \tau^{sg} < \tau_2^*$),there are two pure strategy Nash equilibria in which either firm can be the first to adopt the new technology ($\hat{t}^h_{sg}$, $\tilde{t}^b_{sg}$) or ($\hat{t}^b_{sg}$, $\tilde{t}^h_{sg}$). If the home country's government imposes a safeguard tariff that is sufficiently large relative to the size of country B's market (τ^{sg})$>\tau_2^*$ where $\tau_2^* \in \left(\frac{2}{3}q^b, \frac{2}{3}\left(q^b + \frac{3}{8}\left(\bar{\gamma} - \underline{\gamma}\right)\right)\right)$, then the home firm adopts the new technology first in the pure strategy Nash equilibrium ($\hat{t}^h_{sg}$, $\tilde{t}^b_{sg}$).*

The proof is similar to the proof of Proposition 2. The full proof is presented in Crowley (2003). Proposition 4 indicates how increasing the tariff above threshold values (τ_1^* and τ_2^*) can alter the equilibrium order of adoption. Of particular interest is an increase in the size of the tariff from a value just below τ_2^* to a value just above this cutoff. For values of $\tau^{\mathrm{sg}} < \tau_2^*$, there are two pure-strategy Nash equilibria. Although the sizes of the worldwide markets served by the two firms are not identical, the tariff is sufficiently large relative to the size of the market in country B that the two firms' total market shares are similar. This means the benefit of technology adoption is almost the same for the two firms and implies that in equilibrium, either firm can lead in technology adoption. Interestingly, the home country's government can eliminate this indeterminacy by raising the tariff above τ_2^* and, thus, increasing the home firm's total market share. For tariffs in the range $\tau^{\mathrm{sg}} > \tau_2^*$, the home firm's market share is so much larger than that of the total market share of firm B that the home firm will always adopt the new technology first.

3.3. Technology adoption under an antidumping duty

Lastly, consider what would happen if the home country imposed a permanent country-specific tariff, similar to an antidumping duty, on imports from country A, but imposed no tariff on imports from country B.[18] A permanent, country-specific tariff on imports from A raises the cost to firm A of exporting to the home country and increases the instantaneous profits of the home firm and firm B regardless of their technology levels. For both the home firm and firm B, the marginal benefit of adopting the new technology is larger under an antidumping duty than it is under free trade. Let $\hat{t}_{\mathrm{ad}}^{\,i}$=arg max $g_{\ell}^{i}\ (t^{i}, t^{j}, \tau^{\mathrm{ad}})$ and let $\tilde{t}^{i,\mathrm{ad}}$=arg max $g_{\mathrm{f}}^{i}\ (t^{i},\ t^{j},\ \tau^{\mathrm{ad}})$ for every t^{j} for $i=h,\ b,\ i \neq j$.

Lemma 2. *The optimal dates for technology adoption of the home firm and firm B are earlier under a antidumping duty than they are under free trade,* $\hat{t}_{ad}^{\,i} < \hat{t}^{i}$ *and* $\tilde{t}_{ad}^{\,i} < \tilde{t}^{i}$.

The proof is similar to that Lemma 1 and is omitted.

Intuitively, the profits earned by the home firm and firm B from sales in the home country are identical under an antidumping duty against country A. By targeting its tariff protection against the import surge from country A, the home country inadvertently helps firm B. The antidumping duty generates some (static) rents for the home firm and provides an incentive for the home firm to acquire the new technology earlier than it would under free trade. However, whereas the safeguard tariff conferred a dynamic gain to the home firm by slowing down firm B's technology adoption, the antidumping duty creates a dynamic cost to the home firm by speeding up its rival's technology adoption.

Proposition 5. *Optimal dates under an antidumping duty. Under an antidumping duty, the optimal dates for technology adoption by each firm are (a) earlier than they are under free trade but (b) the relative ordering of the optimal dates is the same as that under free trade.*

Proof. The proof is identical to the proof of Proposition 1 except that the instantaneous profits under an antidumping duty $\pi^{i}(\gamma_i, \gamma_j, \tau^{\mathrm{ad}})$ replace the instantaneous profits under free trade. Under an antidumping duty, the marginal benefit of technology adoption, $\pi^{i}(\underline{\gamma}_i, \bar{\gamma}_j, \tau^{\mathrm{ad}}) - \pi^{i}(\bar{\gamma}_i, \bar{\gamma}_j, \tau^{\mathrm{ad}})$ increases by the same amount for the home firm and firm B $\left(\frac{\partial\left(\pi^{i}\left(\underline{\gamma}_i, \gamma_j, \tau^{\mathrm{ad}}\right) - \pi^{i}\left(\bar{\gamma}_i, \gamma_j, \tau^{\mathrm{ad}}\right)\right)}{\partial \tau^{\mathrm{ad}}}\right) = \frac{3}{8}\left(\bar{\gamma} - \underline{\gamma}\right) > 0$ for $i=h,\ b$. Because the

[18] Under the WTO's Agreement on Implementation of Article VI of the GATT 1994 (Antidumping) and Section 731 of the Tariff Act of 1930, an antidumping duty could be imposed because the low price that would prevail in the home country immediately after the introduction of the new technology in country A could be compared to firm A's historical data on the costs of producing under the old technology in such a way as to show that firm A was pricing below its average historical costs. In the majority of antidumping cases in the US and EU, the margin of dumping used is the difference between the long run average cost of production and the price in the importing country's market. See Clarida (1996); Macrory (1989); and Messerlin (1989). Further, increased imports from country A after the advent of the new technology would reduce the home firm's profits and market share, thus satisfying the injury criteria.

antidumping duty provides the same incentive for early adoption to each firm, it doesn't alter the ordering of the optimal dates, even though it does cause the optimal dates to be earlier than they are under free trade. □

As in the case of free trade, the best response function of firm i is given by (6) with the optimal dates for technology adoption under an antidumping duty described by Lemma 2.

Proposition 6. *Technology adoption under an untidumping duty. In the technology adoption game, there is one pure strategy Nash equilibrium* $(\hat{t}_{ad}^{b}, \tilde{t}_{ad}^{h})$ *in which the firm in country B always adopts the new technology first if the quantity firm B sells in country B is sufficiently large,* $q^{b}>k^{*}$ *where* $k^{*}\in\left(0,\frac{3}{8}\left(\bar{\gamma}-\underline{\gamma}\right)\right)$. *There are two pure strategy Nash equilibria* $(\hat{t}_{ad}^{b}, \tilde{t}_{ad}^{h})$ *and* $(\hat{t}_{ad}^{h}, \tilde{t}_{ad}^{b})$ *in which either firm can be the first to adopt the new technology if the quantity firm B sells in country B is sufficiently small,* $q^{b}\leq k^{*}$.

Proof. The proof is identical to the proof of Proposition 2. □

Although the idea that antidumping duties could accelerate technology adoption may appear surprising, it is consistent with the empirical evidence. It is well-known that US steel firms have often large behind their foreign competitors in adopting new technologies. Proposition 6 could explain this as either (1) the foreign competitors had larger worldwide markets shares and therefore adopted first or (2) the foreign and US firms had similar worldwide market shares, but although either firm could have been the first to adopt the new technology, the foreign firm adopted first and thus, it was an optimal strategy for the US firm to postpone adoption until the price of the new equipment or technology fell further.

Proposition 6 relies on the assumption that the duration of the antidumping duty is independent of the home firm's behavior. Earlier work by Matsuyama (1990) and Miyagiwa and Ohno (1995) has shown that a temporary tariff whose termination date is endogenous, i.e., will be removed as soon as the domestic firm adopts the new technology, delays technology adoption. In practice, the duration of antidumping protection is supposed to depend on the behavior of foreign exporting firms, not domestic import-competing ones. However, the output and pricing decisions of domestic firms might play a role in the magnitude and duration of antidumping duties (Fischer, 1992; Prusa, 1994). If the duration of antidumping duties depends on domestic firm behavior, Matsuyama's (1990) analysis is applicable and may be that domestic firms delay technology adoption to maintain protection.

4. Conclusion

In summary, tariffs of different country-breadth have different effects on technology adoption. The safeguard tariff closes one technology gap—that between the domestic import-competing firm and the foreign firm that precedes it in technology adoption—but, it also opens a second technology gap by delaying the second foreign firm's technology adoption. In contrast, if an importing country imposes an antidumping duty against a technologically superior foreign firm, this closes the technology gap between the initial foreign innovator and the firms in all other countries that are technologically behind it. By showing that different tariff policies affects the timing of technology adoption in different ways, this paper suggest that any comparative welfare analysis of the two policies should include not only an analysis of the static costs and benefits, but also an analysis of the dynamic costs and benefits associated with technology adoption.

Thus, this paper questions a conventional wisdom that has arisen among some economists and trade policy makers. Previous research has emphasized that antidumping duties impose a high welfare cost on consumers (see Gallaway et al., 2000; Staiger and Wolak, 1994; Prusa, 2001) and are a tax that addresses no fundamental market failure.[19] Gruenspecht (1998), Anderson (1992), and Clarida (1993) suggest that dumping is a profit-maximizing strategy for a foreign firm and imply that antidumping duties are welfare-reducing. However, empirical analyses of the static costs and benefits of safeguard tariffs have shown that they are relatively less costly to consumers (Baldwin, 1985; Finger et al., 1982; Hansen and Prusa, 1995) and less distortionary to worldwide trade flows. Some dynamic theoretical models suggest that safeguard tariffs may be beneficial to importing countries because they allow governments some flexibility in setting policy (Bagwell and Staiger, 1999; Ethier, 1998; Fischer and Prusa, 1999). This paper highlights that conclusions about the relative merits of the two policies should be based on a complete analysis of their static and dynamic costs and benefits.

This paper takes a first step in examining how the country-breadth of tariff protection affects technology adoption by laggard firms in multicountry world. Future research is needed to examine how the breadth of tariff protection affects the incentives to invest in new technologies for innovative cutting-edge firms.

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[19] An exception to this general rule is Hartigan (1996) which examines predatory dumping arising from a capital market imperfection.

Appendix A. Proofs

Proof of Proposition 1. Part (a): Diffusion over time. For all $t^j, \frac{\partial g^{fi}(\hat{t}^i,t^j)}{\partial t^i} > \frac{\partial g^{\ell i}(\hat{t}^i,t^j)}{\partial t^i} = 0$ by the definition of $\hat{t}^i$ and by (1). Since $\frac{\partial g^{fi}(\tilde{t}^i,t^j)}{\partial t^i} = 0$ and $g^{fi}(t^i,t^j)$ is strictly concave, then $\hat{t}^i < \tilde{t}^i$ for $i=h,\ b$.

Part (b): Ordering of optimal dates. The partial derivatives of $g^{\ell i}$ with respect to t^i and of g^{fi} with respect to t^i are as follows:

$$\frac{\partial g^{\ell i}}{\partial t^i} = e^{-rt^i}\left[\pi^i(\bar{\gamma}_i,\bar{\gamma}_j) - \pi^i\left(\underline{\gamma}_i,\bar{\gamma}_j\right) - C'\left(t^i\right) + rC\left(t^i\right)\right] \tag{12}$$

$$\frac{\partial g^{fi}}{\partial t^i} = e^{-rt^i}\left[\pi^i\left(\bar{\gamma}_i,\underline{\gamma}_j\right) - \pi^i\left(\underline{\gamma}_i,\underline{\gamma}_j\right) - C'\left(t^i\right) + rC\left(t^i\right)\right] \tag{13}$$

From the proof of part (a), $\hat{t}^i < \tilde{t}^i$ for $i=h,\ b$ in expressions (3)–(5). Consider expression (3). I need to show $\tilde{t}^b < \hat{t}^h$. Evaluating (13) for $i=b$ at is optimal value $\tilde{t}^b$ implies $-C'(\tilde{t}^b)+rC(\tilde{t}^b)=\pi^b(\underline{\gamma}_b,\underline{\gamma}_h)-\pi^b(\bar{\gamma}_b,\underline{\gamma}_h)$. Thus, evaluating (12) for $i=h$ at $\tilde{t}^b$ yields, $\frac{\partial g^{\ell h}}{\partial t^h}|_{\tilde{t}^b} = e^{-r\tilde{t}^b}\left[\left(\pi^h(\bar{\gamma}_h,\bar{\gamma}_b) - \pi^h\left(\underline{\gamma}_h,\bar{\gamma}_b\right)\right) + \left(\pi^b\left(\underline{\gamma}_b,\underline{\gamma}_h\right) - \pi^b\left(\bar{\gamma}_b,\underline{\gamma}_h\right)\right)\right] > 0$ for $q^b > (3/8)(\bar{\gamma}-\underline{\gamma})$. By the strict concavity of $g^{\ell h}$, it follows that $\tilde{t}^b < \hat{t}^h$.

Turning to expression (4), it is necessary to show (i) $\hat{t}^b < \hat{t}^h$, (ii) $\hat{t}^h < \tilde{t}^b$, and (iii) $\tilde{t}^b < \tilde{t}^h$. From the proof of expression (3), it follows that (ii) is true for $q^b < (3/8)(\bar{\gamma}-\underline{\gamma})$. For (i), evaluating (12) for $i=b$ at $\hat{t}^b$ implies $-C'(\hat{t}^b)+rC(\hat{t}^b)=\pi^b(\underline{\gamma}_b,\bar{\gamma})-\pi^b(\bar{\gamma},\bar{\gamma})$. Substituting this into (12) for $i=h$ yields $\frac{\partial g^{\ell h}}{\partial t^h}|_{\hat{t}^b}>0$ for $q^b > (3/8)(\bar{\gamma}-\underline{\gamma})$. By the strict concavity of $g^{\ell h}$, it follows that $\hat{t}^b < \hat{t}^h$. For (iii), evaluating (13) for $i=b$ at $\tilde{t}^b$ and substituting this expression into (13) for $i=h$ yields $\frac{\partial g^{fh}}{\partial t^h}|_{\tilde{t}^b}>0$ for $q^b > (3/8)(\bar{\gamma}-\underline{\gamma})$. By the strict concavity of g^{fh}, $\tilde{t}^b < \tilde{t}^h$.

For expression (5), if $q^b=0$, then $g^{\ell h}=g^{\ell b}$ and $g^{fh}=g^{fb}$. Thus, the value of $\hat{t}$ that maximizes $g^{\ell h}$ and $g^{\ell b}$ and the value of $\tilde{t}$ that maximizes g^{fh} and g^{fb} must be the same. □

Lemma 3. *There exists a* $k* \in \left(0, \frac{3}{8}\left(\bar{\gamma}-\underline{\gamma}\right)\right)$ *such that* $\bar{t}^h < \hat{t}^h$ *and* $\tilde{t}^b < \bar{t}^b$ *if* $q^b < k*$.

Proof. Define $k^* = \min[k^{1*}, k^{2*}]$. The instantaneous profit function of firm B and the first order conditions for $g^{\ell b}$ and g^{fb} imply that $\frac{\partial \hat{t}^b}{\partial q^b}<0$ and $\frac{\partial \tilde{t}^b}{\partial q^b}<0$. Thus, by definition $\bar{t}^h$ is a decreasing function of q^b. For all $q^b \in \left(0, \frac{3}{8}\left(\bar{\gamma}-\underline{\gamma}\right)\right)$, $\hat{t}^b < \hat{t}^h < \tilde{t}^b$. By the definition of V^h, the definition of optimal dates, and the definition of $\bar{t}^b$, $\frac{\partial \hat{t}^h}{\partial q^b} = 0$ and $\frac{\partial \bar{t}^h}{\partial q^b} = 0$. By the continuity and monotonicity of $\bar{t}^h$, it follows that there exists some $q^b = k^{1*} - \epsilon$ such that $\hat{t}^h = \bar{t}^h$. Thus for $q^b > k^{1*}$, $\hat{t}^h > \bar{t}^h$. By the continuity and monotonicity of $\tilde{t}^b$, it follows that there exists some $q^b = k^{2*} - \epsilon$ such that $\tilde{t}^b = \bar{t}^b$. Thus, for $q^b = k^{2*}$, $\bar{t}^b > \tilde{t}^b$. □

Proof of Lemma 1. From (12), the first order condition of $g^{\ell i}$ with respect to t^i can be written $\pi^i(\underline{\gamma}_i,\bar{\gamma}_j)-\pi^i(\bar{\gamma}_i,\bar{\gamma}_j)=rC(t^i)-C'(t^i)$. By definition, $\hat{t}^i$=arg max $g^{\ell i}$ under free trade for $i=h,\ b$ and $\hat{t}^{isg}$=arg max $g^{\ell i}(t^i,t^j,\tau^{sg})$ under a safeguard tariff for $i=h,\ b$. For all non-prohibitive safeguard tariffs, $0<\tau^{sg}<\frac{1}{2}\left(a-3\gamma^h+\gamma^a+\gamma^b\right)$, the marginal bebefit of the new technology is higher under the safeguard tariff for the home firm, $\pi^h(\underline{\gamma}_h,\bar{\gamma}_b,\tau^{sg})-\pi^h$

$(\bar{\gamma}_h, \bar{\gamma}_b, \tau^{sg}) > \pi^h\ (\underline{\gamma}_h, \bar{\gamma}_b, \tau=0) - \pi^h\ (\bar{\gamma}_h, \bar{\gamma}_b, \tau=0)$ and lower under the safeguard tariff for firm B, $\pi^b\ (\underline{\gamma}_b, \bar{\gamma}_h, \tau^{sg}) - \pi^b\ (\bar{\gamma}_b, \bar{\gamma}_h, \tau^{sg}) < \pi^b\ (\underline{\gamma}_b, \bar{\gamma}_h, \tau=0) - \pi^b\ (\bar{\gamma}_b, \bar{\gamma}_h, \tau=0)$. Thus, $\hat{t}^{h,sg} < \hat{t}^h$ and $\hat{t}^{b,sg} > \hat{t}^b$. From the first order condition of g^{fi} with respect to t^i, it can be shown that $\tilde{t}^{h,sg} < \tilde{t}^h$ and $\tilde{t}^{b,sg} > \tilde{t}^b$. □

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