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# A Comparative Institutional Analysis of Agreements on Product Standards

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## Abstract

The WTO and the EU have chosen two different agreements on product standards. While the WTO's approach is primarily based on a "National Treatment" (NT) principle, the EU's approach crucially relies on a principle of "Mutual Recognition" (MR). This paper offers a first look at the comparative performance of these two principles. We show that standards are imposed for levels of externalities that are too low under NT and too high under MR. This suggests that NT should be preferred to MR when the amount of trade in goods characterized by high levels of externalities is large.

**Keywords:** Product Standards, Trade Agreements, Incomplete Contracts, National Treatment, Mutual Recognition

**J.E.L. Classification:** F13, F18

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## 1 Introduction

The GATT and its fifty years of success in tariff cuts did not get rid of trade protection. As Baldwin (1970) already put it: “The lowering of tariffs has, in effect, been like draining a swamp. The lower water level has revealed all the snags and stumps of non-tariff barriers that still have to be cleared away”. In particular, Technical Barriers to Trade (TBT), which result from the mandatory characteristics required for a product to be sold in a given market, have become a big concern for today’s WTO. Not surprisingly, the same concern has been experienced in the EU by developers of the common market. However, those two organizations have chosen two very different institutional arrangements to cope with TBT. This paper offers a first look at the comparative performance of these two institutions.

On the one hand, the GATT-WTO’s approach is primarily based on a “National Treatment” (NT) principle. In particular, GATT Article **III** states that “the products of any contracting party [...] shall be accorded treatment no less favorable than that accorded to like products of national origin in respect of all laws, regulations and requirements affecting their internal sale, offering for sale, purchase, transportation, distribution or use”.<sup>3</sup> On the other hand, the EU’s so called “New Approach” crucially relies on a principle of “Mutual Recognition” (MR). If differences between products legally sold in two member countries arise, the presumption is that they both achieve the same legitimate goals. The EU rules require that “any product imported from another Member State must in principle be admitted into the territory of the importing Member State if it has been lawfully produced, that is conforms to rules and processes of manufacture that are customarily and traditionally accepted in the exporting country, and is marketed in the territory of the latter”.<sup>4</sup>

In this paper, we adopt a transaction-cost perspective to the analysis of international institutions. Namely, we assume that governments cannot write complete contracts governing product standards. Instead, they can only commit to NT or MR. Both institutions are “rigid” rules: they apply to all products, independently of their characteristics. But

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<sup>3</sup>GATT Article **I** further implies that these regulations must be applied on a most favored nation basis, but this requirement is logically redundant. As noted by Sykes (1995): “if all imports receive national treatment, they will also be receiving most favored nation treatment”.

<sup>4</sup>“Communication from the Commission Concerning the Consequences of the Judgment Given by the Court of Justice on 20 February 1979 in case 120/78”, taken from Sykes (1995).

they affect the set of governments' available policies in two very different ways. Under NT, the domestic country sets standards on both domestic and foreign products; under MR, control over the latter is transferred to the foreign country. This implies in particular that these two rules are mutually exclusive: one government or the other can decide what will be the regulation faced by an exporting firm (maybe under some constraints), but they cannot both do so. In other words, using a combination of NT and MR as a rigid rule is not feasible.

What is feasible, and what has been done in practice by both organizations, is to augment the agreement on product standards with a set of additional principles. Within the WTO, the two most prominent examples are the "least restrictive means" principle and the "sham" principle of the Tokyo Round "Standards Code" and the Uruguay Round "Technical Barriers to Trade Agreement" and "Sanitary and Phytosanitary Measures Agreement". They state that standards should not be a "disguised restriction" to trade and that they should attain their goals in a way that is the least restrictive for trade. But in practice, both principles may be too vaguely phrased to be easily enforced. To take one famous example, is the stance adopted by the EU in the dispute on hormone-treated beef a legitimate regulatory concern or a protectionist action?<sup>5</sup>

Within the EU, MR is the second step of a two-stage procedure, which sets "essential requirements"<sup>6</sup> first and then, eliminates non-essential TBT through mutual recognition. Clearly, pre-specified requirements might affect the performance of MR in general and its relative performance with respect to NT in particular. In the extreme case where these requirements are a complete description of the good, the choice of MR or NT is irrelevant: the unique version which satisfies all requirements will be sold in every market. However, as long as essential requirements do not *completely* harmonize standards (and by definition, they don't!), both the incentives that we describe and the results that we derive should still be important in practice. As a result, we have chosen to restrict

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<sup>5</sup>In his overview of agreements on product standards, Sykes (1995) concludes: "the sham principle is rarely invoked and, to [his] knowledge, has never been invoked in the GATT system. It does not follow that the sham principle is altogether useless. [...] On the whole, however, its significance is probably minimal, and efforts to police "disguised restrictions" are better concentrated elsewhere."

<sup>6</sup>These requirements briefly describe goals in terms of environmental or consumer protection. For example, the Lifts Directive (95/19/EC) is 15 pages long, see Baldwin (2000). They are set by the European Council of Ministers. Then, the European Court of Justice assesses whether conformity has been achieved, and the European Commission determines whether national measures are equivalent.

attention in this paper to the rigid rules that are at the heart of the alternative institutional arrangements, NT and MR.<sup>7</sup>

We consider an economic environment à la Brander and Krugman (1983). There are two countries, one firm per country and a duopoly in each market. We further assume that firms can produce different versions of the same good. Consumption of this good creates a local externality in each market, whose size depends on the particular versions being sold. Governments can correct the associated distortions by imposing product standards on the two firms. These are the “legitimate” motives for product standards in our model. However, standards also affect the market shares of the two firms, which creates in turn “protectionist” motives.

In our paper, the mechanics of unconstrained standards setting (USS) has a simple prisoner’s dilemma structure. Each government chooses its policy in order to maximize welfare in its country. As a result, it always imposes standards on exporters in order to shift profits from the foreign to the domestic firm. But because both governments do so, welfare is reduced in both countries. In order to understand how the rigid rules affect this strategic interaction, we examine two polar cases: “quality” and “compatibility” standards.

The case of “quality” standards, to which we will also refer as “vertical” standards, corresponds to the situation where there exists a natural ordering over standards. Two major examples are standards for agricultural products and emission standards for cars. In our model, lower standards generate higher levels of a negative consumption externality (e.g. pollution), with both lower costs of production for firms and lower levels of utility for consumers. Under these assumptions, we show that governments will impose higher standards on foreign exporters under USS — “*Discriminatory Green Protectionism*”. Governments discriminate because the greater the wedge between the marginal costs of the domestic and the foreign firm, the greater the market share and profits

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<sup>7</sup>In practice, standards set within the EU or the WTO may also depend on the initiatives of organizations such as the International Organization for Standardization (ISO). However, such initiatives are unlikely to put an end to TBT. As Sykes (1995) notes: “Technical barrier disputes will continue to arise because international standards are lacking, because nations see fit to depart from them, or because national standardizers act or have acted before the existence of an international standard. The question then arises as to whether further discipline can be introduced to police technical barriers that arise despite the best efforts of international standardizing bodies”. This is the question addressed in this paper.

of the domestic producers. When governments commit to NT, they mechanically eliminate discrimination. However, because they still do not take into account the profits made by exporters in their market, they over evaluate the importance of pollution. As a result, vertical standards are too high under NT, leading to “*Green Protectionism*”. Conversely, while MR also mechanically solves inefficiencies related to discrimination, it leads to standards that are too low — “*Race to the Bottom*”. The reason is that governments have incentives to loosen the regulation at home in order to promote exports abroad. And when evaluating the optimal regulation, they do not take into account the externalities generated by the national firm on the export market.

The case of “compatibility” standards, to which we will also refer as “horizontal” standards, corresponds to the situation where different standards are alternative means to achieve the same level of utility for the consumers, but firms have different preferences over those means. Real-world examples include standards on televisions (PAL, SECAM or NTSC), standards on cell-phones (GSM, UMTS or CDMA) or more simply the voltage of any electric device. In our model, each firm has a comparative and absolute advantage in the production of one version. Consumers do not care about the versions that are sold *per se*; but because of “network effects” (positive consumption externality), they care about whether these versions are different or not. A horizontal standard implies a larger network with higher levels of utility for consumers, more sales for both firms, but also higher costs for the firm on which the standard has been imposed. Under these assumptions, we show that governments will always impose a standard on foreign exporters under USS — “*Systematic standardization*”. Even if the costs of standardization are higher than its benefits, the domestic government is concerned only with the benefits because the costs are entirely borne by the foreign firm. Unlike in the vertical case, NT does not improve the unilateral outcome for low levels of externalities. Because there are preexisting technological differences between firms, governments do not need discrimination to increase the market shares of their national producers. Therefore, NT always is equivalent to USS. In contrast, MR leads to “*Under Standardization*”. Like in the vertical case, governments do not take into account the benefits of standardization on both the foreign firm and the foreign consumers. As a result, they weigh excessively the costs of standardization.

While there are some important differences between the vertical and horizontal cases, they yield a common qualitative insight regarding the performance of NT and MR. Irrespective of the nature of externalities,

neither NT nor MR reproduces the optimal complete contract. Instead, standards are imposed for levels of externalities that are too low under NT and too high under MR. Thus, NT tends to perform better for goods characterized by relatively high levels of externalities, and MR for goods characterized by relatively low levels of externalities. As a result, NT should be preferred to MR when the amount of trade in goods characterized by high levels of externalities is large.

The effects of vertical standards on trade have been previously studied by Fisher and Serra (2000). However, they only consider a small-country model in which only one government behaves strategically. As a result, agreements on product standards cannot be discussed. In this paper, we look at how the two rigid rules chosen by the EU and the WTO perform in a symmetric two-country world, where standards are set by opportunistic welfare-maximizing governments in both countries. Closely related to our work is Suwa-Eisenmann and Verdier (2002), who also investigate regulatory protectionism under oligopolistic competition. But their focus is on political solutions as “intra-sectorial bargaining schemes”, which implicitly assume NT, while we think of political solutions as rigid rules whose incentives are evaluated in a non-cooperative environment. Also related to our paper is Sturm (2002) who discusses agreements on product standards when there is delegation to politicians.

The effects of horizontal standards on trade have been previously studied by Gandal and Shy (2001) and Klimenko (2003). They both emphasize how protectionist incentives depend on the trade-off between positive network effects and costly horizontal standards. In this paper, we address the same trade-off but focus on how it is resolved by NT and MR. In the meantime, we propose a unified framework to compare protectionist incentives in the case of compatibility and quality standards.

Like Bagwell and Staiger (1999) and (2001), we investigate the efficiency rationale behind WTO’s principles. However, they emphasize reciprocity in market access in a perfectly competitive economy where externalities between countries are limited to world price effects. While this last assumption fits well the case of production standards (standards that must be satisfied for a good to be produced), we find it more controversial in the case of product standards (standards that must be satisfied for a good to be sold), which are the focus of this paper. Our transaction-cost perspective is closest in spirit to Battigalli and Maggi (2003) who introduce the idea that NT is a rigid rule to which governments may commit in response to some contractual incompleteness. However, they focus on a situation where demand is located in a sin-

gle market and ignore MR. Our analysis of NT also is related to Horn (2006) who analyzes the welfare impact of NT when governments can simultaneously impose domestic taxes and tariffs.

Before we delve into the details of the model, it is worth emphasizing one potential limitation of our approach. Unlike Bagwell and Staiger (2001), we assume that product standards are the only policy instruments available to governments. In particular, we exclude from our analysis the two traditional instruments of the strategic trade literature: import tariffs and export subsidies. This is a very reasonable assumption for one out of two organizations considered in this paper: the EU. Within the EU, these instruments are *not* available, as our model assumes. Hence, if our only concern is to understand whether the EU may be better-off with NT rather than MR, this restriction is irrelevant. Within the WTO, however, these instruments do exist and one should be more careful when reinterpreting our results in this context.

The rest of the paper is organized as follows. Section 2 describes the equilibrium behavior and performance of USS, MR and NT in the case of quality standards. We examine the case of compatibility standards in section 3. Section 4 discusses the robustness of our results. Section 5 offers some concluding remarks. All proofs can be found in the appendix.

## 2 Quality Standards

### 2.1 The Economic Environment

There are two identical countries, one domestic and one foreign, with one firm per country,  $d$  and  $f$ , both producing the same good. This good may come in two versions,  $H$  and  $L$ . Each version is characterized by its amount of pollutants per unit of output,  $\theta \geq 0$  for  $H$  and 0 for  $L$ . The unit costs of the two versions are 0 and  $c > 0$ , respectively. Technology is the same in both countries. By symmetry, we need consider only the domestic country.

There is a continuum of consumers of measure one. Each consumer can buy at most one version and one or zero unit of each version sold in her market. Her associated utility is:

$$U = \begin{cases} u - p - \varphi & \text{if she buys any version at price } p \\ -\varphi & \text{if she does not buy at all} \end{cases} \quad (1)$$

Pollution affects consumers at home through a negative consumption externality  $\varphi$ . If  $d$  and  $f$  sell  $q_d$  and  $q_f$  units respectively in the domestic



market, then  $\varphi$  is given by:

$$\varphi = \theta_d q_d + \theta_f q_f \quad (2)$$

where  $\theta_i \in \{0, \theta\}$  is the concentration of pollutants of firm  $i$ 's version for  $i = d, f$ .<sup>8</sup> Note that (1) implies that demand does not depend on the particular versions sold by  $d$  and  $f$ . Because each consumer has an infinitesimal impact on aggregate pollution, she is indifferent between non-polluting and polluting products. For simplicity, we further assume that individual surpluses,  $u$ , are uniformly distributed over  $[0, 1]$ . Thus, firms charge a common price  $p$  such that:

$$p = 1 - (q_d + q_f) \quad (3)$$

Finally, if both firms decide to serve the domestic market, they compete à la Cournot. In what follows, we restrict our attention to  $c < 1/4$ , which guarantees that: (i) firms always serve both markets; and that: (ii) a duopoly with one firm selling  $H$  and the other  $L$  is never optimal.<sup>9</sup> Analytical expressions for outputs, profits and consumer surplus under a Cournot duopoly are derived in the Appendix.

The domestic government can regulate its market by setting standards  $\Sigma_i \subset \{H, L\}$  for  $i = d, f$ . By definition, firm  $i$  can sell in the domestic market if and only if its version  $\sigma_i \in \{H, L\}$  is in  $\Sigma_i$ . If  $\Sigma_i = \{L\}$ , we say that the domestic government imposes a “vertical” standard on firm  $i$ . We interpret both  $\Sigma_i = \{H\}$  or  $\{H, L\}$  as “no standard”. In both cases, firm  $i$  would produce at its minimum marginal cost and so,  $\sigma_i = H$ .<sup>10</sup> Without loss of generality, we assume throughout this section that  $\Sigma_i$  is a singleton.

The domestic government sets its standards in order to maximize a social welfare function  $W(\theta) \equiv S(\sigma_d, \sigma_f; \theta) + \pi(\sigma_d, \sigma_f) + \pi(\sigma_d^*, \sigma_f^*)$ , where  $S(\sigma_d, \sigma_f; \theta)$  is the consumer surplus in the domestic country,  $\pi(\sigma_d, \sigma_f)$  are the profits of the domestic firm in the domestic market, and  $\pi(\sigma_d^*, \sigma_f^*)$  its profits in the foreign market. Asterisks denote all variables relating to the foreign market. In the remainder of this section, we refer to

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<sup>8</sup>For expositional purposes, we assume that each firm can only sell one version per market. This is without loss of generality: in equilibrium, firms would never want to sell two different versions anyway.

<sup>9</sup>It is natural to disregard this situation since it only arises as a consequence of our simplifying assumptions; see proof of lemma 1. Here, a duopoly with two different versions may only be optimal because there are no intermediate concentrations of pollutants available between 0 and  $\theta$ .

<sup>10</sup>Since the demand faced by firm  $i$  does not depend on  $\sigma_i$ , it always prefers to sell  $H$  if it can legally do so.

$w(\sigma_d, \sigma_f; \theta) \equiv S(\sigma_d, \sigma_f; \theta) + \pi(\sigma_d, \sigma_f)$  as the *domestic* component of the welfare function. For a given level of externalities, its value only depends on the *domestic* standards,  $\sigma_d$  and  $\sigma_f$ .

The timing of the non-cooperative standards game without any international agreement is the following:

**Date 1:** Governments simultaneously choose their standards  $(\Sigma_d, \Sigma_f)$  and  $(\Sigma_d^*, \Sigma_f^*)$ .

**Date 2:** After observing governments' standards, firms simultaneously decide which version to sell in each market and in what quantity.

We will refer to this game as the Unconstrained Standards Setting (USS) game. In order to analyze this game, as well as the ones that will follow, we restrict our attention to Pareto-efficient, or “most cooperative”, Subgame Perfect Nash Equilibria (SPNE). If one equilibrium is strictly preferred to any other by both governments, we assume that they have the ability to coordinate on this equilibrium. This is sufficient to allow us to compare the performances of our different institutions.

## 2.2 Institutions

**The Complete Contract Benchmark.** In order to evaluate the inefficiencies that arise in the USS game, we first need to identify what is “efficient”. Suppose that the two countries have the same policy instruments — a regulatory set — at their disposal but can contract *ex ante* — before the game — on the standards to be in place depending on the level of externalities  $\theta$ . How would countries choose the efficient standards  $\{\Sigma_d(\theta), \Sigma_f(\theta), \Sigma_d^*(\theta), \Sigma_f^*(\theta)\}$ ? Let us suppose that they would maximize global welfare:

$$\{\Sigma_d(\theta), \Sigma_f(\theta), \Sigma_d^*(\theta), \Sigma_f^*(\theta)\} = \arg \max_{\{\Sigma_d, \Sigma_f, \Sigma_d^*, \Sigma_f^*\}} \Omega(\theta)$$

where  $\Omega(\theta) \equiv W(\theta) + W^*(\theta)$  is the level of total welfare when firms play date 2's equilibrium, conditional on the regulatory profile being  $\{\Sigma_d, \Sigma_f, \Sigma_d^*, \Sigma_f^*\}$ . We can restrict our analysis of the complete contract to three regimes:

1. *Full Regulation*,  $(\Sigma_d = \{L\}, \Sigma_f = \{L\}, \Sigma_d^* = \{L\}, \Sigma_f^* = \{L\})$ ;
2. *Discrimination*,  $(\Sigma_d = \{H\}, \Sigma_f = \{L\}, \Sigma_d^* = \{L\}, \Sigma_f^* = \{H\})$ ;
3. *No Regulation*,  $(\Sigma_d = \{H\}, \Sigma_f = \{H\}, \Sigma_d^* = \{H\}, \Sigma_f^* = \{H\})$ .

Since the two countries are symmetric, any other regulatory profile would lead to (weakly) lower global welfare than the best of these three regimes. For notational convenience, we refer to the above regulatory profiles as  $(\mathbf{L}, \mathbf{L})$ ,  $(\mathbf{H}, \mathbf{L})$ , and  $(\mathbf{H}, \mathbf{H})$ , respectively. Throughout this paper, we use bold letters when standards apply to both countries, and normal letters when they apply to only one of them.

In the case of quality standards, there are two types of output distortions that go in opposite directions. The first comes from market power and tends to underproduction; the second comes from the existence of negative externalities and tends to overproduction. When the size of externalities is small, the first effect dominates and welfare is higher under regimes which enhance output, those without a standard. Alternatively, as the size of the externality increases, welfare is higher under regimes with lower levels of output. Let us define  $\theta^*$  implicitly by:

$$w(H, H; \theta^*) + \pi(H, H) = w(L, L; \theta^*) + \pi(L, L) \quad (4)$$

By construction, governments would prefer  $(\mathbf{H}, \mathbf{H})$  to  $(\mathbf{L}, \mathbf{L})$  if and only if  $\theta \leq \theta^*$ . In the following lemma, we show that  $(\mathbf{H}, \mathbf{L})$  is never optimal.

**Lemma 1** *For quality standards, the optimal complete contract implies:*

$$\begin{cases} (\mathbf{H}, \mathbf{H}) & \text{for } 0 \leq \theta \leq \theta^* \\ (\mathbf{L}, \mathbf{L}) & \text{for } \theta^* \leq \theta \end{cases}$$

**Rigid Rules.** The complete contract benchmark supposes that governments are able to choose regulations conditional on the level of externalities  $\theta$ . In practice, such an institutional arrangement may be extremely difficult to implement; because some new (and unexpected) products may be created or writing costs may simply be too high; see Battigalli and Maggi (2003). In this paper, we will not delve further into the origins of the contractual incompleteness but simply assume that this incompleteness exists.

As we will see in the next section, the equilibrium of the USS game generally is not efficient. If a complete contract is not available, one way to cope with these inefficiencies may be for the governments to commit *ex ante* to a pre-specified rigid rule. The idea is simple: the governments may choose to limit the set of available strategies at date 2, in order to force a new and hopefully “better” equilibrium. Once the rigid rule has been chosen before the game, we suppose that it can be externally enforced by some international organization (for example, by the WTO or the European Court of Justice). Again, by symmetry, we

consider only the domestic country but it should be clear that the rigid rule applies the same way in both countries.

By definition, a rigid rule must be “good-independent”. This rules out clauses that would make explicit references to the characteristics of the good, including exceptions based on the nature or magnitude of the externalities.<sup>11</sup> Rigid rules can take only two forms:<sup>12</sup> (i) *an ordinal constraint*:  $\Sigma_d =, \subset, \supset, \subseteq$  or  $\supseteq \Sigma_f$ ; or (ii) *a transfer of sovereignty*: control over a regulatory set is transferred from one country to the other. In this paper, we focus on the two rigid rules that are observed in practice: “Mutual Recognition” (MR) and “National Treatment” (NT).

Product standard agreements in the EU are based on MR. This rigid rule includes both a transfer of sovereignty and an ordinal constraint. First, control over  $\Sigma_d^*$  is transferred from the foreign to the domestic country. We can interpret this as a switch from “market standards” to “firm standards”: each country sets the standards of its national firm. Second, the European Commission requires that imported products must be lawful in the exporting country. Therefore, we will assume that under MR, the domestic country sets  $(\Sigma_d, \Sigma_d^*)$  under the constraint  $\Sigma_d = \Sigma_d^*$ . We define the “MR game” as the standards game in which governments have committed to MR *ex ante*.

Product standard agreements in the WTO are based on NT. This rigid rule is a pure ordinal constraint, which corresponds formally to  $\Sigma_d \subseteq \Sigma_f$ . Indeed, GATT Article III states that the treatment of foreign products must be “no less favorable” than that of domestic products. Nevertheless, both in practice and in our model, governments never have incentives to choose a “strictly more favorable” treatment of foreign products. Therefore, we simply assume that under NT, the domestic country sets  $(\Sigma_d, \Sigma_f)$  under the constraint  $\Sigma_d = \Sigma_f$ . We define the “NT game” as the standards game in which governments have committed to NT *ex ante*.

### 2.3 Equilibrium Behavior and Performance

**Unconstrained Standards Setting.** Under USS, the domestic government’s strategic decision is a discrete choice between four regimes: full regulation,  $(\sigma_d = L, \sigma_f = L)$ , no regulation,  $(H, H)$ , negative discrimination,  $(H, L)$ , or positive discrimination,  $(L, H)$ .

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<sup>11</sup>While such exceptions formally exist — Article XX in GATT and Article 36 in the Treaty of Rome — they may be extremely hard to implement in practice. The US-EU dispute over hormone-treated beef offers a perfect illustration.

<sup>12</sup>The obvious exception is “No Standards” which we discuss briefly in section 4.

	$\theta=0$	$\theta^N$	$\theta^*$	$\theta^U$	$\theta^M$	$\theta$
<b>Complete Contract</b>	(H,H)			(L,L)		
<b>USS outcome</b> <i>Discriminatory Green Protectionism</i>	(H,L)				(L,L)	
<b>MR outcome</b> <i>Race to the Bottom</i>	(H,H)				(L,L)	
<b>NT outcome</b> <i>Green Protectionism</i>	(H,H)			(L,L)		

Figure 1: Equilibrium Behavior for Quality Standards

Since export profits depend only on the foreign standards, the domestic government chooses its standards in order to maximize domestic welfare  $w$ . Clearly, it will never choose positive discrimination; pollution is the same under the two discriminatory regimes but  $d$ 's profits are higher under negative discrimination. More interestingly, in the USS game, no regulation can never be an equilibrium either. To see this, note that for  $\theta = 0$ , we have:

$$w(H, H; 0) = \frac{1}{3} < w(H, L; 0) = \frac{1}{3} + \frac{1}{6}c^2 \quad (5)$$

Since pollution is always more damaging under  $(H, H)$  (both output and pollutants per unit of output are larger), this inequality remains true for  $\theta \geq 0$ . This pattern of “*Discriminatory Green Protectionism*” is similar to the one obtained in Battigalli and Maggi (2003) under perfect competition. When  $\theta$  is low, governments will choose to discriminate for profit-shifting reasons à la Brander and Spencer (1985). However, when  $\theta$  becomes large, governments will stop discriminating and start imposing standards on both firms in order to reduce pollution.

Let us define  $\theta^U$  implicitly by:

$$w(H, L; \theta^U) = w(L, L; \theta^U) \quad (6)$$

By construction, governments strictly prefer  $(H, L)$  to  $(L, L)$  if and only if  $\theta < \theta^U$ . The outcome at the equilibrium follows. Our findings are summarized in figure 1.<sup>13</sup>

<sup>13</sup>From (4) and (6), it is easy to check that  $\theta^U > \theta^*$ .

Inefficiencies arise at the equilibrium of the USS game. Because governments do not take into account the profits made by the foreign firm in their markets, they always prefer  $(H, L)$  — where profits are shifted away from exporters toward national producers — to  $(H, H)$ . As a consequence, the efficient outcome never is achieved for  $\theta \leq \theta^*$ . As  $\theta$  increases, governments will eventually impose standards on both firms. However, the threshold  $\theta^U$  at which  $(L, L)$  is imposed is too large compared to what would be optimal:  $\theta^U > \theta^*$ . Indeed, under  $(H, L)$ , the profits of the national firm are higher and pollution is lower than under  $(H, H)$ . Both effects reduce the gains from imposing a standard on the national firm under USS.

**Mutual Recognition.** Under MR, the domestic government only faces a binary choice between imposing a standard,  $\sigma_d = \sigma_d^* = L$ , or not,  $\sigma_d = \sigma_d^* = H$ . Moreover, this standard now applies to the domestic firm, and not to the domestic market. This leads to one important difference, in terms of strategic interactions, between USS and MR. Under USS, foreign standards affect the welfare in the domestic country through  $d$ 's export profits. But, these export profits are independent of the domestic standards. As a result, the domestic country's equilibrium strategy does not depend on the foreign standards. Under MR, foreign standards do have an impact on the domestic government's best response. As we will see, domestic and foreign standards are strategic complements in the MR game. This particular feature of MR creates room (in our setting with discrete policy choices) for multiple equilibria.

Let's start our analysis of the MR game by assuming that the foreign country imposes a standard on  $f$ . What is the domestic country's best response to  $\sigma_f = \sigma_f^* = L$ ? If  $d$  sells  $\sigma \in \{H, L\}$  in the two markets, welfare at home is given by  $w(\sigma, L; \theta) + \pi(\sigma, L)$ . Let us define  $\theta^M$  implicitly by:

$$w(H, L; \theta^M) + \pi(H, L) = w(L, L; \theta^M) + \pi(L, L) \quad (7)$$

By construction, imposing a standard is a best response to a foreign standard if and only if  $\theta > \theta^M$ .

Similarly, if the foreign government does not impose a standard, welfare at home is  $w(\sigma, H; \theta) + \pi(\sigma, H)$ . We can then define  $\theta^{M'}$  implicitly by:

$$w(H, H; \theta^{M'}) + \pi(H, H) = w(L, H; \theta^{M'}) + \pi(L, H) \quad (8)$$

$\theta^{M'}$  is such that imposing a standard is a best response to no standards if and only if  $\theta > \theta^{M'}$ .

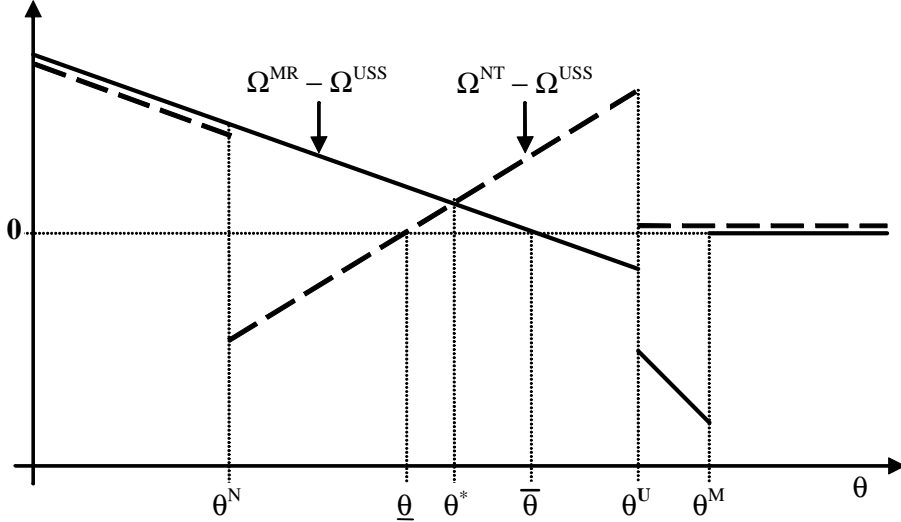


Figure 2: Comparative Performance for Quality Standards

If  $\theta < \min(\theta^M, \theta^{M'})$ , no standards —  $\sigma_d = \sigma_d^* = H$  — is the domestic government’s best response to any choice of the foreign government. Thus by symmetry,  $(\mathbf{H}, \mathbf{H})$  is the unique equilibrium outcome under these conditions. Similarly, if  $\theta > \max(\theta^M, \theta^{M'})$ , imposing a standard —  $\sigma_d = \sigma_d^* = L$  — is always the domestic government’s best response. And by symmetry,  $(\mathbf{L}, \mathbf{L})$  is the unique equilibrium outcome. What happens when  $\theta$  is between  $\min(\theta^M, \theta^{M'})$  and  $\max(\theta^M, \theta^{M'})$ ? For  $c < 1/4$ , we find that  $\theta^M < \theta^{M'}$ . This implies that we have multiple Nash Equilibria over the interval  $[\theta^M, \theta^{M'}]$ . The best response of each government is to impose a standard if and only if the other government has chosen to do so. In other words, vertical standards in the two countries are strategic complements.<sup>14</sup> In order to characterize the outcome, we need to focus on the “most cooperative” equilibrium. From (6) and (7), we immediately get  $\theta^M > \theta^U$ . Since  $\theta^U > \theta^*$ , governments will coordinate on  $(\mathbf{L}, \mathbf{L})$  over  $[\theta^M, \theta^{M'}]$ . See figure 1.

Now that we have characterized the equilibrium outcome under USS and MR, we can compare their performance. Let’s call  $\bar{\theta}$  the level of pollution at which joint welfare is the same under  $(\mathbf{H}, \mathbf{H})$  and  $(\mathbf{H}, \mathbf{L})$ :

$$w(H, H; \bar{\theta}) + \pi(H, H) = w(H, L; \bar{\theta}) + \pi(L, H) \quad (9)$$

<sup>14</sup>Formally, when demand functions are linear, we have for all  $\theta \geq 0$ :  $[w(L, L; \theta) + \pi(L, L)] - [w(H, L; \theta) + \pi(H, L)] > [w(L, H; \theta) + \pi(L, H)] - [w(H, H; \theta) + \pi(H, H)]$ . The incremental gains in domestic welfare associated with a standard increase when the foreign government imposes a standard as well.

From (4), (6) and (9), we find that  $c < 1/4$  implies  $\theta^* < \bar{\theta} < \theta^U$ . Our findings are summarized in figure 2. The dark line represents  $\Omega^{MR}(\theta) - \Omega^{USS}(\theta)$ , where the levels of joint welfare are evaluated at the most cooperative SPNE under MR and USS. For small levels of pollution,  $\theta < \bar{\theta}$ , MR improves upon the USS outcome. Because sovereignty over the standard of the exporters has been transferred to the foreign government, discrimination is no longer possible. For large levels of pollution,  $\theta > \theta^M$ , the two regimes are equivalent. But there always exists an intermediate range,  $\bar{\theta} < \theta < \theta^M$ , for which welfare under MR is strictly lower than under USS.

While the optimal contract would lead governments to impose standards for  $\theta^* < \theta < \theta^M$ , governments still choose no standards for their firms under MR. The reason is that governments have incentives to loosen the regulation at home in order to promote exports abroad. And when evaluating the optimal regulation, they don't take into account the pollution generated by the national firm on the export market. As a consequence, they start imposing standards for levels of externalities that are too high.

One can interpret this result as a “*Race to the Bottom*”. While such arguments are usually used in the case of production standards, the fact that this pattern may also arise for product standards under MR is not new. In Sykes (1995), the (informal) story runs as follows: let's suppose that consumers switch to the less regulated products coming from abroad, then capital may choose to migrate toward the country with the regulation that consumers prefer, and eventually regulators may choose to relax standards in order to preserve their industries. Our result has the same flavor but the rationale is quite different: capital is not mobile but a race to the bottom arises because both countries relax their national standards in order to increase export profits.

**National Treatment.** Like in the MR game, the domestic government's strategic decision in the NT game is a binary choice between imposing a standard,  $\sigma_d = \sigma_f = L$ , or not,  $\sigma_d = \sigma_f = H$ . But like in the USS game, export profits depend only on the foreign standards. As a result, domestic standards will also be chosen to maximize domestic welfare  $w$ . Let us define  $\theta^N$  implicitly by:

$$w(H, H; \theta^N) = w(L, L; \theta^N) \quad (10)$$

By construction, governments strictly prefer to impose a standard if and only if  $\theta > \theta^N$ . The outcome at the equilibrium follows. See figure 1.



Let's now compare the performance of USS and NT. We call  $\underline{\theta}$  the level of pollution at which joint welfare is the same under  $(\mathbf{H}, \mathbf{L})$  and  $(\mathbf{L}, \mathbf{L})$ :

$$w(H, L; \underline{\theta}) + \pi(L, H) = w(L, L; \underline{\theta}) + \pi(L, L) \quad (11)$$

From (4), (6) and (11), we can easily verify that  $c < 1/4$  implies  $\theta^N < \underline{\theta} < \theta^*$ . Our results are summarized in figure 2. The dashed line represents  $\Omega^{NT}(\theta) - \Omega^{USS}(\theta)$ . For small levels of pollution,  $\theta < \theta^N$ , NT mechanically improves upon the USS outcome. Because discrimination is no longer an option, governments do not impose standards on firms, which is exactly what a complete contract would have prescribed. However, because they don't take into account the profits made by exporters on their market, they over evaluate the importance of externalities. In particular, for  $\theta^N < \theta < \underline{\theta}$ , welfare under NT is strictly lower than under USS. Whereas both countries would like to promote exports by reducing the regulation on their national firm abroad, this regulatory power belongs to the country in which exports are sold and which does not care about these profits. As a result, they start imposing a standard for goods with levels of externalities that are too low:  $\theta^N < \theta^*$ . This pattern of “*Green Protectionism*” is similar to the one derived by Fischer and Serra (2000) in the case of a small open economy (where NT was implicitly assumed). The same type of result is also obtained under perfect competition in Battigalli and Maggi (2003).

From figure 2, it is straightforward to compare the performance of MR and NT. Our results are presented in the following proposition:<sup>15</sup>

**Proposition 1** *In the case of quality standards:*

- (i)  $MR \sim NT$  for  $\theta < \theta^N$  and  $\theta > \theta^M$ ;
- (ii)  $MR \succ NT$  for  $\theta^N < \theta < \theta^*$ ;
- (iii)  $NT \succ MR$  for  $\theta^* < \theta < \theta^M$ .

Standards are too stringent under NT because governments do not take into account exporters' profits; and standards are too loose under MR because they do not take into account pollution in the exports' market. So far, we have assumed that only one good was traded between the two countries. Let us now relax this assumption and think of the set of goods that are traded between the two countries as a probability distribution over  $\theta$ . Broadly speaking, proposition 1 suggests that NT should be preferred to MR when the amount of trade in goods characterized by high levels of externalities is large.

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<sup>15</sup>The preference relation  $\succeq$  over institutions is constructed as follows. We say that  $X \succeq Y$  if and only if  $\Omega^X \geq \Omega^Y$ , where  $\Omega^X$  and  $\Omega^Y$  are the levels of joint welfare at the most cooperative SPNE under institutions  $X$  and  $Y$  respectively.

### 3 Compatibility Standards

#### 3.1 The Economic Environment

The economic environment is identical to the one described in section 2, except for the specification of the two versions of the good. Let's call  $D$  and  $F$  these two versions. We assume that firm  $d$  can either produce  $D$  at zero cost or  $F$  for a unit cost  $c > 0$ . The converse is true for firm  $f$ , which can either produce  $F$  at zero cost or  $D$  for a unit cost  $c > 0$ . In other words, each firm has a comparative and absolute advantage in one horizontally differentiated version. This advantage may either come from exogenous technological differences, licensing fees or the additional cost of an adaptor.<sup>16</sup> The rest of the model is a simplified version of Katz and Shapiro (1985).

Consumers are indifferent between  $D$  and  $F$  *per se*. They only care about the number of individuals who buy the same version as themselves, that is, who become members of the same network. More precisely, each consumer's utility is:

$$U = \begin{cases} u - p_i + \nu_i & \text{if she buys from firm } i \text{ at price } p_i \\ 0 & \text{if she does not buy at all} \end{cases} \quad (12)$$

The size of network  $i$  affects its members through a local positive externality  $\nu_i$  such that:

$$\nu_i = \begin{cases} \gamma(q_d + q_f) & \text{if the two firms sell the same version} \\ \gamma q_i & \text{otherwise} \end{cases} \quad (13)$$

Unlike in the vertical case, (12) and (13) imply that demand does depend on the particular versions sold by  $d$  and  $f$ . When individual surpluses,  $u$ , are uniformly distributed over  $[0, 1]$ , firms thus charge:

$$p_i = 1 + \nu_i - (q_d + q_f) \quad (14)$$

Here, the ‘‘hedonic’’ price  $p_i - \nu_i$ , i.e. the price of  $\sigma_i$  adjusted for the size of network  $i$ , is identical across firms. Like in Katz and Shapiro (1985), we focus on the ‘‘fulfilled expectations Cournot equilibrium’’, which is such that: (i) consumers have rational expectations and (ii) for given consumers' expectations, firms compete à la Cournot.<sup>17</sup> In what follows, we restrict our attention to  $\gamma < 1$ , which guarantees that

<sup>16</sup>The focus on marginal rather than fixed costs does not change the qualitative nature of our results; see section 4.

<sup>17</sup>Formally, this equilibrium concept is equivalent to Nash Equilibrium, as long as firms and consumers play *simultaneously* at date 2.

demand curves are downward-sloping, and maintain  $c < \frac{1}{4}$ . Analytical expressions for outputs, profits and consumer's surplus at the fulfilled expectations Cournot equilibrium are derived in the appendix.

In this section, we say that the domestic government imposes a “horizontal” standard on firm  $d$  (resp.  $f$ ) if and only if  $\Sigma_d = \{F\}$  (resp.  $\Sigma_f = \{D\}$ ). In other words, we say that a firm faces a horizontal standard if and only if it is not allowed to sell the version for which it has a comparative and absolute advantage. Following section 2, we call  $w(\sigma_d, \sigma_f; \gamma)$  and  $\pi(\sigma_d, \sigma_f; \gamma)$  the equilibrium values of domestic welfare and domestic firm's profits, conditional on  $d$  and  $f$  selling versions  $\sigma_d$  and  $\sigma_f$ , respectively. The rest of the standards game is unchanged.

### 3.2 The Complete Contract Benchmark

In this economic environment, global welfare does not depend on the particular versions being sold *per se*. It only depends on whether both firms sell the same version in a given market. By symmetry, we can now restrict our analysis of the complete contract to two regimes:

1. *Standardization*,  $(\Sigma_d = \{D\}, \Sigma_f = \{D\}, \Sigma_d^* = \{F\}, \Sigma_f^* = \{F\})$ ;
2. *Incompatibility*,  $(\Sigma_d = \{D\}, \Sigma_f = \{F\}, \Sigma_d^* = \{D\}, \Sigma_f^* = \{F\})$ .

Like in the case of quality standards, it is easy to check that any other regulatory profile would lead to (weakly) lower global welfare than the best of these two regimes. In line with section 2, we refer to the two previous regulatory profiles as  $(\mathbf{D}, \mathbf{D})$  and  $(\mathbf{D}, \mathbf{F})$ , respectively.

In order to compare the levels of joint welfare under  $(\mathbf{D}, \mathbf{D})$  and  $(\mathbf{D}, \mathbf{F})$ , we define  $\gamma^*$  implicitly by:

$$w(D, F; \gamma^*) + \pi(D, F; \gamma^*) = w(D, D; \gamma^*) + \pi(F, F; \gamma^*) \quad (15)$$

By construction, the two governments are indifferent between  $(\mathbf{D}, \mathbf{D})$  and  $(\mathbf{D}, \mathbf{F})$  at  $\gamma = \gamma^*$ . Intuitively, governments should then prefer  $(\mathbf{D}, \mathbf{D})$  to  $(\mathbf{D}, \mathbf{F})$  if and only the size of network effects  $\gamma$  is greater than  $\gamma^*$ . However, the argument is more subtle than in the vertical case. Whereas quality standards always reduce the size of a negative externality, compatibility standards may not increase the size of a positive externality. Switching from *Incompatibility* to *Standardization* increases the size of each firm's network from one firm's output to total output. But, at the same time, it increases production costs, which pushes output downward. In the following lemma, we show that when demand and network effects are linear, the former effect always outweighs the latter. Thus,

an optimal complete contract should impose *Standardization* if and only if network effects are large enough.

**Lemma 2** *For compatibility standards, the optimal complete contract implies:*

$$\begin{cases} (\mathbf{D}, \mathbf{F}) & \text{for } 0 \leq \gamma \leq \gamma^* \\ (\mathbf{D}, \mathbf{D}) & \text{for } \gamma^* \leq \gamma \end{cases}$$

### 3.3 Equilibrium Behavior and Performance

**Unconstrained Standards Setting.** Under USS, we can still focus, without loss of generality, on the case where standards —  $\Sigma_i$  for  $i \in \{d, f\}$  — are singletons.<sup>18</sup> Thus, the domestic government’s strategic decision regarding the home market is a discrete choice between four regimes: *D*-standardization,  $(\sigma_d = D, \sigma_f = D)$ , *F*-standardization,  $(F, F)$ , natural incompatibility,  $(D, F)$ , or artificial incompatibility,  $(F, D)$ .

Like in the vertical case, the domestic firm’s export profits depend only on the foreign standards. As a result, the domestic government chooses its standards in order to maximize  $w$ . Clearly, the domestic government strictly prefers  $(D, D)$  to  $(F, F)$ . Total output and network effects are the same under both regimes, but  $d$ ’s profits are higher under *D*-standardization. Likewise, it strictly prefers  $(D, F)$  to  $(F, D)$ . If there is incompatibility anyway, the best regime is the one that minimizes production costs, and so, increases both consumer surplus and the domestic firm’s profits.

Should we observe  $(D, D)$  or  $(D, F)$  in equilibrium under USS? The answer depends on the sign of  $w(D, D; \gamma) - w(D, F; \gamma)$ . When there are no network effects, it is easy to check that:

$$w(D, F; 0) = \frac{1}{3} < w(D, D; 0) = \frac{1}{3} + \frac{1}{6}c^2 \quad (16)$$

The domestic government strictly prefers *D*-standardization. This last inequality is identical to (5), which is no big surprise. Since there are no externalities, the domestic government is simply interested in shifting profits away from foreigners toward national producers. Whether it does so by imposing a vertical or a horizontal standard is irrelevant in terms of the equilibrium outcome.

As the size of network effects  $\gamma$  increases, the gains from standardization,  $w(D, D; \gamma) - w(D, F; \gamma)$ , increases as well; see appendix. Thus, (16)

<sup>18</sup>If there exists a Nash Equilibrium where  $d$  and  $f$  develop  $\sigma_d$  and  $\sigma_f$  at date 2, there exists also a Nash Equilibrium where  $\Sigma_d = \{\sigma_d\}$  and  $\Sigma_f = \{\sigma_f\}$ .

	$\gamma=0$	$\gamma^*$	$\gamma^M$	$\gamma$
<b>Complete Contract</b>	<b>(D,F)</b>			<b>(D,D)</b>
<b>USS outcome</b> <i>Systematic Standardization</i>		<b>(D,D)</b>		
<b>MR outcome</b> <i>Under Standardization</i>	<b>(D,F)</b>			<b>(D,D)</b>
<b>NT outcome</b> <i>Systematic Standardization</i>		<b>(D,D)</b>		

Figure 3: Equilibrium Behavior for Compatibility Standards

implies that the domestic government still prefers  $(D, D)$ . In the case of compatibility standards, the equilibrium outcome under USS is  $(D, D)$ , independently of the size of externalities. Our findings are summarized in figure 3.

Like in the case of quality standards, the domestic government does not take into account the profits made by the foreign firm on the domestic market. As a result, it always imposes a standard on the foreign firm. Even if the costs of standardization are higher than its benefits,  $\gamma \leq \gamma^*$ , the domestic government is concerned only with its benefits since the costs are entirely borne by the foreign firm. This pattern of excessive standardization is similar to the one obtained in Klimenko (2003). In the case of compatibility standards, USS leads to “*Systematic Standardization*”. Unlike the vertical case, there is only one outcome in equilibrium. In the case of quality standards, the domestic government ultimately imposes a standard on both firms in order to reduce a *negative* externality. Here, the domestic government never has an incentive to reduce a *positive* externality.

**Mutual Recognition.** Under MR, we cannot assume *a priori* that the domestic standards are singletons. In principle, the domestic government may strictly prefer to set  $\Sigma_d = \Sigma_d^* = \{D, F\}$ . The potential benefit of such a regulation (or lack thereof) is that it allows the domestic firm to sell two different versions if it finds it profitable. In the appendix, we show, however, that this never occurs: in any SPNE of the MR game, each firm only sells one version of the good. Therefore, we can still assume, without loss of generality, that standards are singletons.

Like in the vertical case, foreign standards have an impact on the domestic government's best response under MR. Thus, we need to consider separately the cases with and without foreign standards. Let's first suppose that the foreign government imposes a standard on  $f$ , i.e.  $\sigma_f = \sigma_f^* = D$ . In this case, the best response of the domestic government is straightforward: it will not impose a standard for any value of  $\gamma$ . Indeed, if  $f$  is selling  $D$ , imposing a standard on  $d$  —  $\sigma_d = \sigma_d^* = F$  — can only reduce both consumer surplus and  $d$ 's profits.

What happens when the foreign government does not impose a standard, i.e.  $\sigma_f = \sigma_f^* = F$ ? Let us define  $\gamma^M$  implicitly by:

$$w(D, F; \gamma^M) + \pi(D, F; \gamma^M) = w(F, F; \gamma^M) + \pi(F, F; \gamma^M) \quad (17)$$

By construction, the domestic government is indifferent between imposing a standard or not at  $\gamma = \gamma^M$ . In the appendix, we show that  $w(F, F; \gamma) + \pi(F, F; \gamma) - w(D, F; \gamma) - \pi(D, F; \gamma)$  is strictly increasing in  $\gamma$ . Therefore, the domestic government strictly prefers to impose a standard on the domestic firm if and only if  $\gamma > \gamma^M$ .

If  $\gamma < \gamma^M$ , the domestic government strictly prefers no standard, independently of the foreign government's strategy. Thus by symmetry, the equilibrium outcome is *Incompatibility*,  $(\mathbf{D}, \mathbf{F})$ . If  $\gamma > \gamma^M$ , the domestic government imposes a standard if and only if the foreign government does not; and by symmetry, exactly one government imposes a standard in equilibrium. The associated outcome is *Standardization*,  $(\mathbf{D}, \mathbf{D})$ . Our findings are summarized in figure 3.

Now, we can compare the performance of USS and MR. From (15) and (17), we know that:

$$\begin{cases} w(D, F; \gamma^*) + \pi(D, F; \gamma^*) - w(D, D; \gamma^*) - \pi(F, F; \gamma^*) = 0 \\ w(D, F; \gamma^M) + \pi(D, F; \gamma^M) - w(D, D; \gamma^M) - \pi(F, F; \gamma^M) < 0 \end{cases}$$

Since  $w(D, F; \cdot) + \pi(D, F; \cdot) - w(D, D; \cdot) - \pi(F, F; \cdot)$  is strictly decreasing (see proof of lemma 2), it implies that  $\gamma^M > \gamma^*$ . Our results are represented in figure 4. The dark line represents  $\Omega^{MR}(\gamma) - \Omega^{USS}(\gamma)$ . For small network effects such that  $\gamma < \gamma^*$ , MR strictly improves upon the USS outcome; for large network effects such that  $\gamma > \gamma^M$ , the two regimes are equivalent; but there always exists an intermediate range,  $\gamma^* < \gamma < \gamma^M$ , for which welfare under MR is strictly lower than under USS.

Like in the optimal complete contract, the outcome under MR is  $(\mathbf{D}, \mathbf{F})$  for small network effects and  $(\mathbf{D}, \mathbf{D})$  for large network effects.

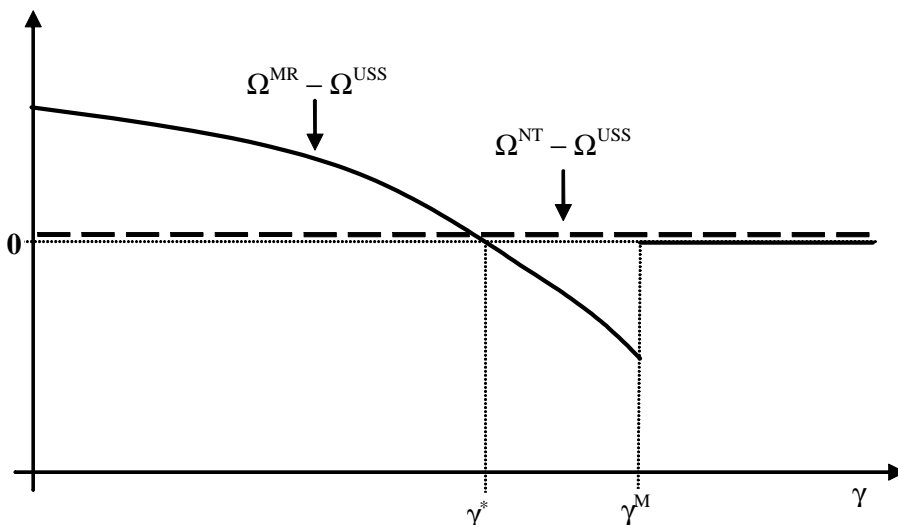


Figure 4: Comparative Performance for Compatibility Standards

However, the threshold at which a standard is imposed is too high. We have “*Under Standardization*”. The logic is the same as in the “*Race to the Bottom*” of section 2. Under MR, governments do not take into account the benefits of standardization on both the foreign firm and the foreign consumers. As a result, they weigh excessively the costs of standardization and for  $\gamma^* < \gamma < \gamma^M$ , *Standardization*, though optimal, is not achieved.

**National Treatment.** Under NT, the domestic government can still impose *D*-standardization,  $(\sigma_d = D, \sigma_f = D)$ , and *F*-standardization,  $(F, F)$ . But compared to USS, it can no longer impose incompatibility arbitrarily, either natural,  $(D, F)$ , or artificial,  $(F, D)$ . In the NT game, setting  $\Sigma_d = \Sigma_f = \{D, F\}$  is the only way for the domestic government to achieve incompatibility on its market. In this case, the two firms are free to choose *Standardization* or *Incompatibility*. Does this affect the equilibrium outcome? The answer is no and the reason is simple.

Starting from the USS game, NT reduces the set of available strategies, but it does not affect protectionist incentives. Under both USS and NT, export profits depend only on the foreign standards. Thus, in both cases, the domestic government chooses its standards in order to maximize domestic welfare,  $w$ . The equilibrium behavior of governments under NT follows. From our analysis of the USS game, we already know that *D*-standardization maximizes  $w$  when governments are unconstrained. So *a fortiori*, it maximizes  $w$  when governments are con-

strained by NT. As a result, the outcome under NT is still “*Systematic Standardization*”,  $(\mathbf{D}, \mathbf{D})$  for all levels of externalities; see figure 3.

Unlike in the case of quality standards, NT is completely ineffective. For compatibility standards, the equilibrium under NT is the same as under USS. Although two strategies,  $(D, F)$  and  $(F, D)$ , can no longer be played in the NT game, these strategies were not played at the equilibrium of the USS game anyway. Because there are preexisting technological differences between firms, governments do not need discrimination to increase the market shares of their national producers. In particular, NT is inefficient when there are no network effects. Each government always adopts the characteristics of the national version as its standard, which creates reciprocal trade barriers. This corresponds to the definition of horizontal standards in Baldwin (2000).<sup>19</sup>

From figure 4, it is straightforward to compare the performance of MR and NT. Our results are presented in the following proposition:

**Proposition 2** *In the case of compatibility standards:*

- (i)  $MR \sim NT$  for  $\gamma > \gamma^M$ ;
- (ii)  $MR \succ NT$  for  $\gamma < \gamma^*$ ;
- (iii)  $NT \succ MR$  for  $\gamma^* < \gamma < \gamma^M$ .

Neither NT nor MR reproduces the optimal complete contract. Instead, there is either “*Systematic Standardization*” or “*Under Standardization*”. Under NT, governments do not take into account losses in exporters’ profits and thus, under evaluate the costs of standardization. Under MR, governments do not take into account increases in welfare abroad and thus, under evaluate the gains of standardization.

These patterns echo the inefficiencies that arise in the case of quality standards, namely “*Green Protectionism*” and “*Race to the bottom*”. Irrespective of the nature of the externalities, standards are imposed for levels of externalities that are too low under NT and too high under MR. Broadly speaking, our model suggests that for a given structure of trade — now defined as a probability distribution over  $(\theta, \gamma)$  — NT should be preferred to MR when the amount of trade in goods characterized by high levels of externalities is large.

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<sup>19</sup>These are situations where the sham principle should, in theory, apply. In the absence of externalities, standards are a disguised restriction to trade and ruling them out would improve welfare. As mentioned in the introduction, however, it is not clear how to administer that principle in practice.



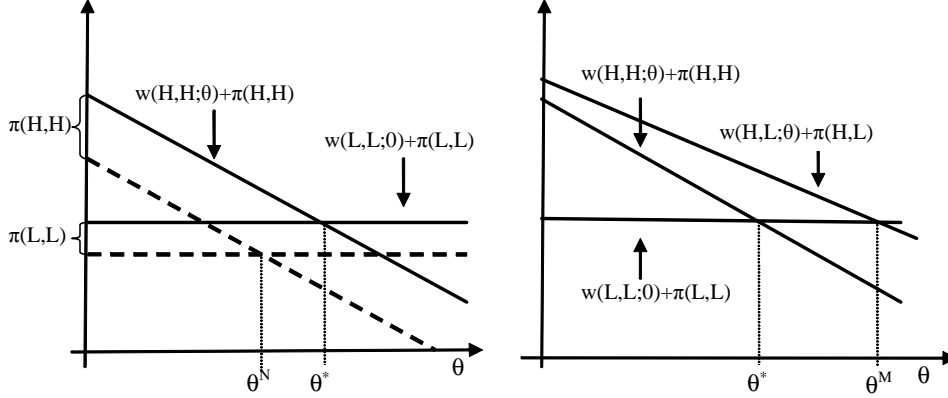


Figure 5: Green Protectionism and the Race to the Bottom

## 4 Sensitivity Analysis

### 4.1 Market Structure

Our analysis builds on a very simple market structure: a Cournot duopoly with linear demand. We know from the literature on strategic trade policy that changes in market structure have dramatic effects on the form of the optimal trade policy; see e.g. Grossman and Eaton (1986) and Krishna and Thursby (1991). We now investigate whether such changes would also affect the comparative performance of MR and NT. For expositional purposes, we focus on the case of quality standards; the logic in the case of compatibility standards is similar.

The core of our analysis relies on three inequalities:

- I1.  $\pi(H, H) \geq \pi(L, L)$ ;
- I2.  $\pi(H, L) \geq \pi(H, H)$ ;
- I3.  $w(H, L; 0) \geq w(H, H; 0)$ .

The pattern of “*Green Protectionism*” under NT derives from inequality I1. For any market structure, higher levels of pollution lead to higher benefits from imposing standards:  $w(L, L; \theta) - w(H, H; \theta)$  is increasing in  $\theta$ . Since  $\theta^N$  is such that  $w(L, L; \theta^N) - w(H, H; \theta^N) = 0$  and  $\theta^*$  is such that  $w(L, L; \theta^*) - w(H, H; \theta^*) = \pi(H, H) - \pi(L, L)$ , inequality I1 directly implies  $\theta^N \leq \theta^*$ . This is illustrated in figure 5.

The “*Race to the bottom*” under MR derives from inequalities I2 and I3. To see this, note that  $w(H, L; 0) \geq w(H, H; 0)$  implies  $w(H, L; \theta) \geq$

$w(H, H; \theta)$  for all  $\theta$ . (This is the same argument that leads to “*Discriminatory Green Protectionism*” under USS.) Combining this last inequality with *I2*, we get  $w(H, L; \theta) + \pi(H, L) \geq w(H, H; \theta) + \pi(H, H)$ . Using the definitions of  $\theta^M$  and  $\theta^*$  —  $w(H, L; \theta^M) + \pi(H, L) = w(L, L; \theta^M) + \pi(L, L)$  and  $w(H, H; \theta^*) + \pi(H, H) = w(L, L; \theta^*) + \pi(L, L)$  — we then obtain  $\theta^M \geq \theta^*$ ; see figure 5.

In our view, inequalities *I1* and *I2* are very mild. The former states that domestic profits should be higher when their marginal costs (and those of foreign producers) are lower, whereas the latter states that they should be higher when the marginal costs of their foreign competitors are higher. Clearly, the same inequalities would hold if demand functions were not linear; if there was more than one firm in each country; or if firms were competing in prices rather than quantities.

By contrast, inequality *I3* states that, in the absence of externalities, the domestic government should have incentives to impose standards in order to shift profits from the foreign to the domestic firm at the expense of consumer surplus. We already know from the strategic trade literature that this “shifting profits” motive may not always be operational; see e.g. HELPMAN and KRUGMAN [1989]. For example, a welfare-maximizing government is more likely to find an import tariff beneficial if firms compete in quantities (which are strategic substitutes) rather than prices (which are strategic complements). The same considerations apply to the case of a product standard. The main difference between an import tariff and a product standard is that the latter does not generate any tax revenue. This suggests that, *ceteris paribus*, the “shifting profits” motive is less likely to be operational in the case of a standard.

From the above discussion, we draw two conclusions. First, the pattern of “*Green Protectionism*” uncovered under NT is fairly robust to changes in the market structure. It only derives from the fact that the domestic government ignores foreigners’ profits, and that these profits are lower once standards are imposed. Second, the “*Race to the bottom*” uncovered under MR is closely related to the existence of a “shifting profits” motive. In other words, governments must be willing to sacrifice consumer surplus in order to increase firms’ profits for a “*Race to the bottom*” to arise. Whereas this is always the case in a Cournot duopoly with linear demand, this may not be true under more general demand functions or different modes of competition.<sup>20</sup> It would be inappropri-

<sup>20</sup>It is easy to check that inequality *I3* still holds if we allow an arbitrary number of firms  $n$  in each country, while maintaining Cournot competition and a linear demand. Formally, we get  $w(H, L; 0) = \frac{n}{2n+1} + \frac{3}{2} \left( \frac{nc}{2n+1} \right)^2 \geq w(H, H; 0) = \frac{n}{2n+1}$ .

ate, however, to infer from this final observation that a “*Race to the bottom*” is unlikely to arise in practice. This conclusion crucially relies on the assumption that governments maximize welfare. Irrespective of the market structure, if governments are politically motivated — that is, if they assign a weight big enough on the profits of their firms — then inequality *I3*, as well as our qualitative insights, will hold.

## 4.2 Other Robustness Checks

**Fixed Costs.** Our results are robust to the introduction of fixed costs.<sup>21</sup> In particular, it can be shown that the comparative performance of NT and MR is unchanged if fixed costs are small, and tilted in favor of MR if fixed costs are large enough to affect market structure. The intuition is the following. When fixed costs are large, governments can use standards as a barrier to entry under both NT and MR. But, while imposing standards can deter the entry of the *foreign* firm under NT, it can only deter the entry of the *national* firm under MR.

**Information Failures.** In our model, the efficiency rationale for quality standards comes from consumption externalities. Because consumers’ impacts on aggregate consumption are infinitesimal, they have the same demands for polluting and non-polluting products. However, the same behaviors could be derived from information failures. If consumers cannot distinguish between two versions, then they will also have the same demand for all products. Within this framework, one could extend the analysis of governments’ decisions to “informational policies” such as labeling. Clearly, labels would improve consumers’ abilities to discriminate between products. Nevertheless, it is very unlikely that they would entirely correct the information failures. On the one hand, labeling costs may limit governments’ willingness to impose them in the first place; on the other hand, even if all products have been labeled, cognitive constraints may still limit consumers’ ability to extract information from the labels. As a consequence, we conjecture that our results would still hold in this new environment. This seems particularly relevant in the case of standards on agricultural products.

**Global Externalities.** Although we assume that both consumption and network externalities are local, pollution and network effects may not stop at national borders in practice. Would the introduction of global externalities affect our results? Let us start with the incentives that lead standards to be imposed for levels of externalities that are too

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<sup>21</sup>Fisher and Serra (2000) and Suwa-Eisenmann and Verdier (2002) analyze the effects of fixed costs on protectionist incentives under Cournot competition.

low under NT and too high under MR. These two incentives would not change. Indeed, they depend on the control variables that are available to the two governments, “market standards” versus “firm standards”, not on the magnitude of the externalities. Still, the introduction of global externalities would have an impact on the relative performance of NT and MR. The intuition is the following. Under MR, governments set standards which are used in both markets. As a result, they take into account the global character of the externalities. Under NT, they do not: each government sets a standard on its own market, ignoring pollution in the other market. Ironically, this new inefficiency may improve the relative performance of NT by compensating the over-estimation of the externalities described in sections 2 and 3.

**Imperfect Compatibility.** The analysis of section 3 focuses on the extreme situation in which the domestic and foreign versions are either compatible or incompatible. In reality, many technologies can be made partially compatible by means of adaptors or converters. Within our theoretical framework, imperfect compatibility could be introduced by assuming that: (i) firms need to pay less to make their versions compatible; but that in turn: (ii) consumers benefit from smaller network externalities once compatibility is achieved. Such a change may either increase or decrease the thresholds at which standards are imposed under various rigid rules, depending on which of the two previous effects dominate. Yet, this would not affect our two main qualitative insights. Under NT, the domestic government would not take into account the (now smaller) costs supported by the foreign firm, which would lead to “*Systematic Standardization*”; and under MR, it would not take into account the (now smaller) gains from standardization abroad, which would lead to “*Under Standardization*”.

**Additional Rigid Rules.** We have excluded from our analysis one obvious rigid rule: “No Standards” (NS). However, it is easy to check that irrespective of the nature of the externalities, NS is dominated by MR. Let’s first consider the case of vertical standards. Under NS, firms will always sell polluting products since pollution does not affect the demand for the good. In contrast, we know that despite the “*Race to the Bottom*” effect, non-polluting products are ultimately sold under MR. Thus, MR dominates NS in the vertical case. The case of horizontal standards is more subtle. Because network effects do affect the demand for the good, we will ultimately observe *Standardization* under both NS and MR. When network effects are large enough, one firm will eventually choose to produce the same version than its competitor, even under NS.

However, because this firm still ignores the gains in consumer surplus,<sup>22</sup> *Standardization* under NS will always occur for levels of externalities that are higher than under MR. As a consequence, MR also dominates NS in the horizontal case.

**Additional Policy Instruments.** In this paper, we only consider one type of policy instruments: product standards. The benefit of this approach is to generate clear qualitative insights; its cost is to leave traditional instruments of the strategic trade literature, such as import tariffs and export subsidies, out of the scope of the model. What happens to the comparative performance of NT and MR when these instruments are available? Though we leave the general answer to this question for further research, we can already check that our results survive in one simple, but important, situation. Suppose that there only is a single level of import tariff and a single level of export subsidy that governments can impose at date 1. This corresponds to the situation where governments have committed to a pre-specified rigid rule with regards to import tariffs and export subsidies.<sup>23</sup> Compared to sections 2 and 3, the marginal cost of a given version may no longer be the same for the domestic and the foreign firm. Nevertheless, this asymmetry does not affect our qualitative insights: the domestic government still ignores foreigners' profits under NT — leading to “*Green Protectionism*” or “*Systematic Standardization*” — and it still ignores losses or gains in welfare abroad under MR — leading to a “*Race to the bottom*” or “*Under Standardization*”.

## 5 Concluding Remarks

We conclude by discussing the positive implications of our theory. Although the main focus of our paper is normative, we believe that it might also help address the following question: Why did governments choose NT within the WTO and MR within the EU? A first possible answer is that, conditional on the structure of trade within each organization, each rule is actually the “best feasible” institution. This is in line with the transaction-cost economics tradition. According to our model, NT and MR would be the best rigid rules for the WTO and the EU, respectively, because the amount of trade in goods characterized by high levels of externalities is larger in the WTO than in the EU. However, as Dixit (1996) points out, while market competition may induce the adoption of

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<sup>22</sup>If  $\pi(F, F; \gamma) \geq \pi(D, F; \gamma)$ , then  $S(F, F; \gamma) > S(D, F; \gamma)$ ; see appendix.

<sup>23</sup>When there are no externalities, this is the institutional arrangement that governments would prefer. Imposing unilaterally a tariff may be profitable, but it always lowers joint welfare in equilibrium; see Helpman and Krugman (1989). So, governments would rather commit to “no tariffs”. Similarly, they would rather commit to a positive export subsidy in order to reduce market power distortions.

efficient firms' organizations, there is no clear selection mechanism that could guarantee efficient outcomes in the case of political institutions, in general, and agreements on product standards, in particular.

Another perspective on the choice of institutions is that they are not selected because they maximize global welfare, but because they serve the interests of those who choose to adopt them. This is in the spirit of recent work in political economy by Acemoglu and Robinson (2006). In this respect, our theoretical analysis also provides some interesting insights. Consider a world economy comprising a poor and a rich country,  $P$  and  $R$ , with different preferences over standards. Namely, the poor country,  $P$ , is less likely to impose a standard, either because its technology is less efficient or because it has a higher marginal utility of income. In this new environment, our previous analysis suggests that the preferences of the rich country,  $R$ , will be biased towards NT; if  $R$  is initially indifferent between MR and NT when trading with another rich country, then it will strictly prefer NT when trading with a poor country. The logic is simple. Under MR, facing a poor trading partner reduces welfare in  $R$ : it leads to more competitive exporters (because a poor country cares less about the externalities), which exacerbates the disutility of a “*Race to the bottom*”/“*Under Standardization*”. On the contrary, trading with a poor country increases welfare in  $R$  under NT: the rich country can impose the same standards on its market but its export profits increase (because the poor country imposes less stringent standards). To sum up, within this extended version of our model, the relative homogeneity of the EU and the importance of rich countries in the choice of WTO's institutions may also shed light on the adoption of MR and NT.<sup>24</sup>

An interesting implication of the previous discussion is that differences in levels of development across countries may have a significant impact on the comparative performance of various trading rules. We view the general analysis of optimal trade agreements in environments with heterogeneous countries as an exciting avenue for future research.

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<sup>24</sup>One may, of course, imagine alternative explanations. For example, if there is significant heterogeneity in the costs of pollution across *importing* countries, then efficiency would call for different standards by location. This may also help explain why NT has been preferred within the WTO. The same type of explanations, however, would suggest that if differences in costs of production between *exporting* countries are large, then MR should have been preferred. Our “political-economy” perspective does not depend on this distinction.

## 6 Appendix

### 6.1 Quality Standards

#### Cournot Equilibria

	$(H, H)$	$(H, L)$	$(L, H)$	$(L, L)$
$q_d =$	$\frac{1}{3}$	$\frac{1+c}{3}$	$\frac{1-2c}{3}$	$\frac{1-c}{3}$
$\pi_d =$	$\frac{1}{9}$	$\left(\frac{1+c}{3}\right)^2$	$\left(\frac{1-2c}{3}\right)^2$	$\left(\frac{1-c}{3}\right)^2$
$S =$	$\frac{2}{9} - \frac{2}{3}\theta$	$\frac{1}{2} \left(\frac{2-c}{3}\right)^2 - \left(\frac{1+c}{3}\right)\theta$	$\frac{1}{2} \left(\frac{2-c}{3}\right)^2 - \left(\frac{1+c}{3}\right)\theta$	$2 \left(\frac{1-c}{3}\right)^2$

#### Optimal complete contract

**Lemma 1** *For quality standards, the optimal complete contract implies:*

$$\begin{cases} (\mathbf{H}, \mathbf{H}) \text{ for } 0 \leq \theta \leq \theta^* \\ (\mathbf{L}, \mathbf{L}) \text{ for } \theta^* \leq \theta \end{cases}$$

**Proof.** Let us define  $\underline{\theta}$  implicitly by:

$$w(H, L; \underline{\theta}) + \pi(L, H) = w(L, L; \underline{\theta}) + \pi(L, L)$$

For  $\theta = 0$ , we know that

$$w(H, H; 0) + \pi(H, H) > w(H, L; 0) + \pi(L, H) > w(L, L; 0) + \pi(L, L)$$

Thus, to show that  $(\mathbf{H}, \mathbf{L})$  is never optimal, we just need to show that:

$$\underline{\theta} < \theta^* \Leftrightarrow \frac{c(4/3 + 1/2c)}{1+c} < 2/3c(2-c)$$

After rearrangements, one can rewrite this inequality:

$$c < 1/4$$

which is true by assumption. The rest of the claim follows directly from (4). ■

### 6.2 Compatibility Standards

#### Fulfilled expectations Cournot equilibria

	$(D, F)$	$(D, D)$	$(F, D)$	$(F, F)$
$q_d =$	$\frac{1}{3-\gamma}$	$\frac{1+c(1-\gamma)}{3-2\gamma}$	$\frac{1-c}{3-\gamma}$	$\frac{1-c(2-\gamma)}{3-2\gamma}$
$\pi_d =$	$\left(\frac{1}{3-\gamma}\right)^2$	$\left(\frac{1+c(1-\gamma)}{3-2\gamma}\right)^2$	$\left(\frac{1-c}{3-\gamma}\right)^2$	$\left(\frac{1-c(2-\gamma)}{3-2\gamma}\right)^2$
$S =$	$\frac{2}{(3-\gamma)^2}$	$\frac{1}{2} \left(\frac{2-c}{3-2\gamma}\right)^2$	$2 \left(\frac{1-c}{3-\gamma}\right)^2$	$\frac{1}{2} \left(\frac{2-c}{3-2\gamma}\right)^2$

## Optimal complete contract

**Lemma 2** *For compatibility standards, the optimal complete contract implies:*

$$\begin{cases} (\mathbf{D}, \mathbf{F}) \text{ for } 0 \leq \gamma \leq \gamma^* \\ (\mathbf{D}, \mathbf{D}) \text{ for } \gamma^* \leq \gamma \end{cases}$$

**Proof.** Let us define  $\Delta(\gamma)$  such that:

$$\Delta(\gamma) = w(D, F; \gamma) + \pi(D, F; \gamma) - w(D, D; \gamma) - \pi(F, F; \gamma)$$

After rearrangements, one gets:

$$\Delta(\gamma) = \frac{4}{(3 - \gamma)^2} - \frac{4 + c(\frac{11}{2}c - 4) - 2c^2\gamma(3 - \gamma)}{(3 - 2\gamma)^2}$$

Let us first remark that  $c < \frac{1}{4}$ :

$$\begin{cases} \Delta(0) = \frac{4}{9}c - \frac{11}{18}c^2 > 0 \\ \Delta(1) = -3 + 4c - \frac{3}{2}c^2 < 0 \end{cases} \quad (18)$$

Let us now prove that:

$$\frac{d\Delta(\gamma)}{d\gamma} < 0 \quad (19)$$

Simple algebra implies:

$$\begin{aligned} \frac{d\Delta(\gamma)}{d\gamma} &= 8 \left[ (3 - \gamma)^{-3} - (3 - 2\gamma)^{-3} \right] \\ &\quad - (3 - 2\gamma)^{-1} \left\{ (3 - 2\gamma)^{-2} \left[ 8 - 8\gamma c^2(3 - \gamma) + 4c\left(\frac{11}{2}c - 4\right) \right] - 2c^2 \right\} \end{aligned}$$

In order to have  $\frac{d\Delta(\gamma)}{d\gamma} < 0$ , we only need to check that:

$$X = (3 - 2\gamma)^{-2} \left[ 8 - 8\gamma c^2(3 - \gamma) + 4c\left(\frac{11}{2}c - 4\right) \right] > 2c^2$$

Since  $c < \frac{1}{4}$  and  $0 \leq \gamma < 1$ , we know that:

$$X > 8 - 16c^2 + 4c\left(\frac{11}{2}c - 4\right) > 0$$

This further implies:

$$X > \frac{1}{9} \left[ 8 - 16c^2 + 4c\left(\frac{11}{2}c - 4\right) \right] > 2c^2$$



As a consequence,  $\frac{d\Delta(\gamma)}{d\gamma} < 0$ . Finally, (18) and (19) imply that there exists a unique  $\gamma^*$  such that joint welfare is higher under  $(\mathbf{D}, \mathbf{F})$  than under  $(\mathbf{D}, \mathbf{D})$  if and only if  $\gamma \leq \gamma^*$ . ■

### USS and NT Games

**Lemma 3**  $w(D, D; \cdot) - w(D, F; \cdot)$  is strictly increasing in  $\gamma$

**Proof.** Let us define  $\Delta^U(\gamma)$  such that:

$$\Delta^U(\gamma) = w(D, D; \gamma) - w(D, F; \gamma)$$

After rearrangements, one gets:

$$\Delta^U(\gamma) = \frac{3 - 2\gamma c + \frac{1}{2}c^2 + c^2(1 - \gamma)^2}{(3 - 2\gamma)^2} - \frac{3}{(3 - \gamma)^2}$$

Thus,

$$\begin{aligned} \frac{d\Delta^U(\gamma)}{d\gamma} &= 6 \left[ (3 - 2\gamma)^{-3} - (3 - \gamma)^{-3} \right] + (3 - 2\gamma)^{-2} \times \\ &\quad \left\{ (3 - 2\gamma)^{-1} [6 - 8\gamma c + 2c^2 + 4c^2(1 - \gamma)^2] - [2c + 2c^2(1 - \gamma)] \right\} \end{aligned}$$

Since  $c < \frac{1}{4}$  and  $0 \leq \gamma < 1$ , we know that:

$$\begin{cases} (3 - 2\gamma)^{-1} [6 - 8\gamma c + 2c^2 + 4c^2(1 - \gamma)^2] > \frac{1}{3} [6 - 8c] > \frac{4}{3} \\ 2c + 2c^2(1 - \gamma) < 2c + 2c^2 < \frac{5}{8} \end{cases}$$

As a consequence,  $\frac{d\Delta^U(\gamma)}{d\gamma} > 0$ . ■

### MR game

**Lemma 4** In any SPNE of the MR game, each firm only sells one version of the good.

**Proof.** We proceed by contradiction. Without loss of generality, we focus on the domestic firm. Suppose that  $d$  sells both  $D$  and  $F$  in a SPNE, then the following conditions must be satisfied: (i)  $\Sigma_d = \Sigma_d^* = \{D, F\}$  (trivial); (ii)  $f$  sells  $F$  in at least one market (a direct implication of  $d$  selling  $F$  and (i)); (iii)  $\pi(F, F; \gamma) > \pi(D, F; \gamma)$  (a direct implication of  $d$  selling  $F$ , (i) and (ii)); (iv)  $f$  sells  $D$  in at least one market (a direct implication of  $d$  selling  $D$  and (iii)); (v)  $\Sigma_f = \Sigma_f^* = \{D, F\}$  (a direct implication of (ii) and (iv)).

We now show that if conditions (i)-(v) hold, then there exists a profitable deviation for the domestic government. Consider the following strategy  $\Sigma_d = \Sigma_d^* = \{D\}$ . By conditions (iii) and (v), if  $d$  sells  $D$  in

the 2 markets, then  $f$  will also sell  $D$ . Thus consumer surplus in the domestic country will remain the same, but  $d$ 's profits will be equal to  $2\pi(D, D; \gamma) > \pi(F, F; \gamma) + \pi(D, D; \gamma)$ . Hence the domestic government would like to deviate from  $\Sigma_d = \Sigma_d^* = \{D, F\}$ . A contradiction. ■

**Lemma 5**  $w(F, F; \cdot) + \pi(F, F; \cdot) - w(D, F; \cdot) - \pi(D, F; \cdot)$  is strictly increasing in  $\gamma$

**Proof.** Let us define  $\Delta^M(\gamma)$  such that:

$$\Delta^M(\gamma) = w(F, F; \cdot) + \pi(F, F; \cdot) - w(D, F; \cdot) - \pi(D, F; \cdot)$$

After rearrangements, one gets:

$$\Delta^M(\gamma) = \frac{4 - 10c + 4\gamma c + \frac{1}{2}c^2 + 2c^2(2 - \gamma)^2}{(3 - 2\gamma)^2} - \frac{4}{(3 - \gamma)^2}$$

Thus,

$$\begin{aligned} \frac{d\Delta^M(\gamma)}{d\gamma} &= 8 [(3 - 2\gamma)^{-3} - (3 - \gamma)^{-3}] + (3 - 2\gamma)^{-2} \times \\ &\{ (3 - 2\gamma)^{-1} [8 - 40c + 16\gamma c + 2c^2 + 8c^2(2 - \gamma)^2] + [4c - 4c^2(2 - \gamma)] \} \end{aligned}$$

Since  $c < \frac{1}{4}$  and  $0 \leq \gamma < 1$ , we know that:

$$\begin{cases} 8 - 40c + 16\gamma c + 2c^2 + 8c^2(2 - \gamma)^2 > 8 - 40c + 34c^2 > 0 \\ 4c - 4c^2(2 - \gamma) > 4c - 8c^2 > 0 \end{cases}$$

As a consequence,  $\frac{d\Delta^M(\gamma)}{d\gamma} > 0$ . ■

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