Regulatory Protection and the Role of International Cooperation

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Abstract

Domestic regulations that impede international trade have become a central concern in contemporary trade negotiations. In this paper, I develop a general-equilibrium framework to analyze the welfare consequences of product regulations and their international harmonization. In my model, raising product standards reduces a negative externality associated with consumption but also increases the marginal and fixed costs of production. When a country sets its product standards non-cooperatively, the effects of standards on other countries' wages and number of firms are not internalized, giving rise to an international inefficiency. I show that the World Trade Organization's non-discrimination principle of national treatment cannot lead to an efficient equilibrium when standards affect the fixed cost of production. I then conduct a quantitative exercise and find that current international cooperation on product standards is still far from complete: welfare losses from abandoning national treatment average 1.44 percent, whereas potential welfare gains from efficient multilateral cooperation average 12.59 percent.

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I Introduction

With very low tariffs in developed countries, the focus of modern trade negotiations has shifted towards reducing trade barriers associated with domestic regulations on products. Regulatory barriers are in general "murkier" than tariff barriers (Baldwin and Evenett, 2011): although product standards can inhibit trade, they may also serve legitimate policy goals by addressing issues related to health, product safety, and environment. Whereas tariffs on most products effectively raise the marginal cost of production, standards can affect both marginal and fixed production costs (Baldwin, 2000; Fontagne, Orefice, Piermartini, and Rocha, 2015). Since fixed costs directly affect product variety, it is essential to incorporate this feature of product standards when analyzing the welfare consequences of regulatory protection.

The distinctive features of regulatory protection can be illustrated by a dispute case in the World Trade Organization (WTO): *Brazil-Retreaded Tires*, (WT/DS332).[1] In 2005, the European Union (EU) issued a complaint about Brazil's regulation on retreaded tires. This type of re-manufactured tire is cheap to produce, but has a shorter lifespan than new tires. When discarded without proper management, retreaded tires can create breeding grounds for disease-carrying mosquitoes. The Brazilian government imposed an import ban on retreaded tires, but domestic products were exempted. This regulation benefited the Brazilians by reducing the negative health externality, but also created trade frictions. On one hand, tire exporters outside Brazil faced a higher marginal cost of production. On the other hand, production line upgrading increased the fixed cost of production. Some companies in the EU "were unable to find new export markets and went into liquidation" (European Commission, 2004).

In this paper, I analyze regulatory protection and the role of international cooperation from both theoretical and quantitative perspectives. Specifically, I introduce product standards into a Krugman (1980) "new trade" model. In my model, raising product standards may increase both the marginal and fixed costs of production. Governments can use product standards to improve welfare in two ways. First, raising standards reduces a negative externality associated with consumption as in Costinot (2008) and Staiger and Sykes (2011). Second, governments can use standards to manipulate trade and improve real income at the expense of other countries. When a country sets its product standards non-cooperatively, the partial- and general-equilibrium effects of standards on other countries' wages and number of firms are not internalized, giving rise to an international inefficiency. In addition to theoretical analysis, the model can be calibrated to match industry level standards and trade for a quantitative analysis of cooperative and non-cooperative standards.

One novel analytical result in this paper is that the partial-equilibrium effect of product standards on the fixed cost of production renders the non-cooperative Nash equilibrium inefficient, but

[1] Details of this dispute can be found at https://www.wto.org/english/tratop_e/dispu_e/cases_e/ds332_e.htm.

the partial equilibrium effect on the marginal cost does not create any inefficiency. The rationale behind this result can be illustrated by the *Brazil-Retreaded Tires* case. The import ban on retreaded tires led to higher prices of imported tires in Brazil, a consequence that was internalized when the Brazilian government set the standard. However, the higher fixed costs faced by foreign tire producers reduced the number of varieties available to consumers in both Brazil and other countries. This negative effect on foreign consumers was not internalized by the Brazilian government, thus creating an international inefficiency.

Changes to product standards also trigger two general-equilibrium effects, both of which render the non-cooperative equilibrium inefficient. The first effect does so through changes in relative wages, or *terms of trade*. Governments can raise standards on imports to improve relative wages at the expense of other countries (Bagwell and Staiger, 2001). The second effect creates inefficiency through the number of firms: higher standards on imports reduce the sales of foreign firms, triggering entry of domestic firms and exit of foreign firms. Due to the presence of trade costs, this *production relocation* effect reduces the domestic price index but raises the price index in foreign countries (Ossa, 2011). Both general-equilibrium effects incentivize governments to impose higher (discriminatory) standards on imports. This feature is consistent with the fact that almost all WTO disputes about domestic regulations involve excessively stringent regulations by importing nations (Staiger and Sykes, 2011).

I use this general-equilibrium framework to evaluate current international cooperation to reduce regulatory barriers. Even though they are generally considered domestic policies, product standards have been disciplined by the non-discrimination principle of national treatment from the General Agreement on Tariffs and Trade (GATT) and its successor, the WTO. National treatment requires that imported and locally-produced goods should be treated equally, at least after the foreign goods have entered the market. I find that national treatment addresses the inefficiency from the general-equilibrium effects that incentivize governments to impose high standards on imports. However, the Nash equilibrium under the constraint of national treatment is still inefficient when standards affect the fixed cost of production, because the partial-equilibrium effect on other countries' product variety is not internalized.

The model I develop is flexible enough to conduct a comprehensive quantitative analysis of cooperative and non-cooperative product standards. In this paper, I focus on 21 sectors in seven major economies of international trade and a residual rest-of-world. Following existing literature (Goldberg and Maggi 1999; Disdier, Fontagne, and Mimouni 2008; Essaji 2008), I quantify standards by the share of products covered by regulatory measures in each sector using data collected by the World Bank. To reduce the number of parameters that need to be estimated, I use the "exact hat algebra" technique popularized in Dekle, Eaton, and Kortum (2007), and express the equilibrium conditions in changes relative to data. The elasticity estimation follows the Feenstra (1994) method. I exploit the variations in the unit values across destinations in international trade data to estimate how the marginal cost of production in each sector changes with product standards. Given data on wage, total sale, and number of firms, the effect of product standards on the fixed cost of production is derived from the free-entry condition in the model. Lastly, the weight of the consumption externality in welfare is calibrated by matching each country's computed optimal standards subject to national treatment with observed standards. In other words, calibrating the weight of the externality rests on the assumption that the data is a Nash equilibrium under the constraint of national treatment.

I use the calibrated model to compute the equilibrium standards and welfare outcomes in two counterfactual scenarios of policy salience. In the first scenario, countries abandon national treatment and can freely impose standards to maximize welfare. In equilibrium, all countries impose high standards on imports and low standards on domestic products. This negative-sum game has no winner, and the average welfare loss is 1.44 percent. In the second scenario, all countries engage in efficient negotiations to maximize their welfare symmetrically. The computed cooperative standards improve all countries' welfare by 12.59 percent from the factual equilibrium. Ossa (2014) provides a first quantitative analysis of non-cooperative and cooperative tariffs. He finds that the average welfare loss from a trade war of tariffs is 2.9 percent and the average welfare gain from cooperative tariffs is 0.5 percent. Comparing the quantitative results in this paper with those in Ossa (2014) indicates that the international cooperation of standards is still far from complete. The observed product standards are far more distant from the efficient frontier than tariffs. This comparison also rationalizes the increasing focus on regulatory protection in recent trade negotiations.

My analysis provides new insight into the "shallow integration" approach of the multilateral trade policy negotiation led by the WTO. "Shallow" trade agreements generally focus on tariff commitments and principles of non-discrimination (WTO, 2011). Bagwell and Staiger (2001) use a neoclassical trade model to illustrate the rationale of "shallow integration:" domestic policies like product standards are substitutes for tariffs and can lead to inefficient outcomes when tariffs are constrained by WTO rules. This is because both standards and tariffs can distort prices and generate terms-of-trade improvement. However, such inefficiency will disappear if each country makes credible commitment to market access, or import volume given world prices. For this reason, there is no need for "deep integration," as contracting over individual domestic policies can be very costly. In this paper, I show that market access commitments are no longer sufficient to secure efficient outcomes. Even when the volume of imports can be contracted under "shallow integration," product variety, and therefore welfare, can still be affected by standards set by other countries.[2]

This paper complements previous research on regulatory protection that either focuses on partial-equilibrium effects (Baldwin, 2000; Fischer and Serra 2000; Staiger and Sykes 2011; Staiger and Sykes 2016), or uses neoclassical trade models that only include the terms-of-trade effect (Bagwell and Staiger 2001; Ederington 2001).[3] My model incorporates the forces found in earlier papers but also identifies a novel and important channel through which standards affect welfare: the adjustment in number of varieties. This channel has been emphasized by numerous works on the welfare effects of trade liberalization (see, for example, Feenstra 1994; Broda and Weinstein 2006; Caliendo and Parro 2015; and Hsieh, Li, Ossa, and Yang 2016) but has yet to be associated with regulatory protection.

Trade policy and trade negotiations in "new trade" models have been studied extensively, but existing works mostly focus on the role of tariffs.[4] For example, Venables (1987) isolates the production relocation effect when tariffs are set unilaterally in "new trade" models. Gros (1987) uses a variant of the Krugman (1980) model to isolate the terms-of-trade effect of tariffs. Ossa (2011) considers the welfare implications of the production relocation effect from non-cooperative tariffs and GATT/WTO negotiations. In this paper, I show that both the terms-of-trade effect and the production relocation effect also exist when standards affect the fixed cost of production. Moreover, this paper is the first attempt to analyze national treatment in a general-equilibrium framework. Existing studies on international cooperation in reducing regulatory protection focus mostly on the marginal cost channel and emphasize the partial-equilibrium effect: national treatment makes raising standards on imports costlier, thus reducing the distortion created by regulatory protection (Horn 2006; Costinot 2008; Gulati and Roy 2008; Staiger and Sykes 2011).

Product standards modeled in this paper feature both "vertical" and "horizontal" components. Vertical standards refer to the standards that can be ordered by stringency, whereas horizontal standards refer to alternative means that deliver the same level of utility. On one hand, higher standards reduce the "eye-sore" consumption externality in my model. On the other hand, I allow the fixed cost of production to depend on the number of export destinations in addition to product standards. Although I focus on the frictional dimension of product standards, it is possible that regulating horizontal product standards can reduce costs of production. This scenario is interesting in its own right and has been studied in partial-equilibrium models (Baldwin 2000; Costinot 2008), but will not be the focus of this paper.

[2] Staiger and Sykes (2016) argue that lack of tariff-equivalent policy in the service sector would cause the government to distort all of its behind-the-border policies, providing another rationale for the deep integration approach of the General Agreements on Trade in Services (GATS).

[3] See Ederington and Ruta (2016) for a comprehensive review.

[4] DeRemer (2013) studies the shallow integration approach of the WTO in a differentiated product setting. However, his analysis focuses on the role of capital requirement but not product standards.

The rest of the paper is structured as follows: in Section II, I construct a multi-country, multi-sector Krugman (1980) model that includes product standards. I show that standards can affect welfare through two partial-equilibrium effects and two general-equilibrium effects. The next two sections are devoted to analyzing the welfare outcomes in the non-cooperative Nash equilibrium and the equilibrium constrained by national treatment. In Section III, I focus on the production relocation effect by studying a special case with two countries and two sectors. In Section IV, I study another special case with two countries and one sector that isolates the terms-of-trade effect. Additional discussions on the theoretical analysis are provided in Section V. In Section VI, I use the full model to quantitatively analyze the welfare consequences of two counterfactual scenarios: trade war without national treatment and efficient trade negotiations. The last section concludes.

II General Framework

I develop a multi-country, multi-sector trade model that features monopolistic competition and increasing returns as in Krugman (1980). Raising product standards can affect the marginal and fixed costs of production, as well as a consumption externality. I first describe the model and then characterize the equilibrium given standards. Next, I discuss the channels through which welfare is affected by standard changes.

II.1 Setup

Consider an economy that consists of M countries and R industries. W_j is the welfare of households in country j and is defined as

$$W_j = U_j - \Omega_j,$$

where

$$U_j = \prod_{r=1}^{R} \left(\sum_{i=1}^{M} \int_0^{n_{ir}} x_{ijr}(\nu_{ir})^{\frac{\sigma_r - 1}{\sigma_r}} d\nu_{ir} \right)^{\frac{\sigma_r}{\sigma_r - 1}\mu_{jr}}, \tag{1}$$

is the utility derived from consumption. ν_{ir} indexes a variety produced in sector r of country i, x_{ijr} is the quantity of an industry r product manufactured in country i consumed in country j, n_{ir} is the mass of sector r varieties produced in country i, μ_{jr} is the Cobb-Douglas share of country j's expenditure spent on sector r varieties, and $\sigma_r > 1$ is the elasticity of substitution across sector r varieties.

The second component of welfare, represented by Ω_j, is a negative externality stemming from the consumption of differentiated goods. Throughout this section, I focus on the case in which higher standards improve the welfare of consumers by reducing the consumption externality.[5] In this case, Ω_j is a function of product standards imposed on goods sold to country j. In other words, let s_{ijr} denote the standard requirement on sector r varieties sold in country j from country i. Then Ω_j is a function of $\{s_{ijr}\}_{i\in M, r\in R}$. If standards are imposed only for protectionist purposes, then $\Omega_j = 0$, and $W_j = U_j$. Following the setup in existing works,[6] I abstract from the possibility that consumption externality is a function of other countries' standards. In this case, there is an additional channel through which one country's policy decisions affect another's welfare. The focus of this paper is to explore how regulatory barriers influence welfare through international trade. Allowing the possibility of global consumption externalities will create another channel of international inefficiency.

The labor market is perfectly competitive, and workers are freely mobile between sectors within each country. Each consumption variety is produced by a single firm. Firms producing differentiated goods in country i follow the inverse production function:

$$l_{ir} = f_{ir} + \sum_{j=1}^{M} \tau_{ijr} c_{ijr} x_{ijr}, \tag{2}$$

where l_{ir} is the labor an industry r firm requires in country i, f_{ir} is the fixed labor requirement in sector r of country i, c_{ijr} is the marginal cost of production of sector r varieties from country i to country j, and $\tau_{ijr} > 1$ is the corresponding iceberg trade barrier.

Product standards can affect both the marginal and the fixed costs of production. If s_{ijr} affects the marginal cost of production only, then f_{ir} is constant and c_{ijr} is a function of s_{ijr}. On the other hand, if standards affect the fixed cost of production only, then c_{ijr} is a constant and f_{ir} is a function of $\{s_{ijr}\}_{j\in M, x_{ijr}>0}$. Note that this formulation captures the horizontal component of product standards: exporting to more countries can increase the fixed cost because the standards are different. Furthermore, because standards imposed by each country can potentially affect the marginal cost of production, c_{ijr} is destination-specific.[7]

[5] In addition to the *Brazil-Retreaded Tires* case, many disputes in the WTO also involve standards related to environmental or health externalities. Examples include WT/DS58 and DS61 (US prohibition on shrimp imports from countries not certified to harvest in a manner that protects sea turtles); WT/DS391 (Canadian challenge to Korean beef import restrictions imposed to prevent mad cow disease); and the famous Tuna-Dolphin case, involving a US prohibition on imports of tuna from countries that were not certified as fishing in a dolphin-safe manner (Staiger and Sykes, 2011). Staiger and Sykes (2016) has a similar formulation and refers it as a negative "eye sore" externality, even though they focus on the negative externalities related to services.

[6] See Bagwell and Staiger (2001), Staiger and Sykes (2011), and Fischer and Serra (2000) for example.

[7] Note that firms in each sector have the same productivity. A Melitz (2003) model is not used in this paper because firm-specific product standards are very rare in reality. As discussed in Arkolakis, Costinot, and Rodriguez-clare (2012), welfare changes are the same in quantitative trade models conditional on observed domestic expenditure and estimated trade elasticity. Ossa (2011) shows that the results of the production relocation effects of tariffs in

One feature of this setup is that product standards do not directly affect the utility from consumption, and hence should not be thought of as qualities. This assumption greatly simplifies the analysis, since there is no need for firms to solve for optimal quality of the product.[8] Under this setup, the demand for differentiated goods are only influenced by standards indirectly through prices. In this way, products from each sector r firm in country i selling to country j satisfy exactly s_{ijr}, but not any higher standard.

Governments also impose tariffs in addition to standards. Let t_{ijr} denote the ad-valorem tariff imposed by country j against industry r imports from country i. I assume $t_{ijr} \geq 0$ for all $i \neq j$ and $t_{ijr} = 0$ for all $i = j$. In equilibrium, households maximize their utilities subject to the budget constraint given prices. Solving for the households' utility maximization gives the demand for varieties in sector r produced in country i:

$$x_{ijr} = \frac{(p_{ijr}\tau_{ijr}(1 + t_{ijr}))^{-\sigma_r}}{P_{jr}^{1-\sigma_r}}\mu_{jr}E_j, \tag{3}$$

where $P_{jr} = \left(\sum_{i=1}^{M} n_{ir}(p_{ijr}\tau_{ijr}(1 + t_{ijr}))^{1-\sigma_r}\right)^{\frac{1}{1-\sigma_r}}$ is the ideal price index of sector r in country j. I let p_{ijr} be the ex-factory price of sector r varieties sold in country j from country i, thus the corresponding price faced by country j consumers is $\tau_{ijr}(1 + t_{ijr})p_{ijr}$. Given (3), each firm from sector r in country i maximizes its profit by charging a constant markup over marginal costs, so

$$p_{ijr} = \frac{\sigma_r c_{ijr} w_i}{\sigma_r - 1}. \tag{4}$$

Substituting (4) back into the definition of P_{jr} produces:

$$P_{jr} = \left(\sum_{i=1}^{M} n_{ir}\left(\frac{\sigma_r c_{ijr} w_i \tau_{ijr}(1 + t_{ijr})}{\sigma_r - 1}\right)^{1-\sigma_r}\right)^{\frac{1}{1-\sigma_r}}. \tag{5}$$

Define $X_{ijr} = n_{ir}p_{ijr}\tau_{ijr}x_{ijr}$ as the value of trade flow from country i to country j in industry r, so that $E_j = \sum_{i=1}^{M}\sum_{r=1}^{R}(1 + t_{ijr})X_{ijr}$. Substituting (3) and (4) into the definition of X_{ijr} gives:

$$X_{ijr} = n_{ir}(1 + t_{ijr})^{-\sigma_r}\left(\frac{\sigma_r \tau_{ijr} c_{ijr} w_i}{\sigma_r - 1}\right)^{1-\sigma_r}(P_{jr})^{\sigma_r - 1}\mu_{jr}E_j. \tag{6}$$

The equilibrium given standards and tariffs can be characterized by three equations. The first

Krugman (1980) model also hold in a two-sector Melitz (2003) model.

[8] An alternative approach is to assume that standards affect the quality of products and analyze policy interactions in an environment similar to the one in Fajgelbaum, Grossman, and Helpman (2011). In this case, additional structures of asymmetric information are needed to rationalize the need to regulate product standards. Linking regulatory protection with quality is an interesting area for future research, but this paper will just focus on a simpler path.

equilibrium condition describes households' budget constraint:

$$E_i = w_i L_i + \sum_{m=1}^{M} \sum_{r=1}^{R} t_{mir} X_{mir} - B_i, \tag{7}$$

where B_i is an international transfer that captures trade imbalances. By definition, $\sum_{i=1}^{M} B_i = 0$. The second condition describes the market free-entry condition:

$$w_i n_{ir} f_{ir} = \frac{1}{\sigma_r} \sum_{j=1}^{M} X_{ijr}. \tag{8}$$

Lastly, we have a condition that relates labor income with total revenue:

$$w_i L_i = \sum_{j=1}^{M} \sum_{r=1}^{R} X_{ijr}. \tag{9}$$

The system of equations (7) to (9), in which P_{jr} and X_{ijr} are defined by (5) and (6) respectively, fully describes the equilibrium given tariffs and standards. This system of $M(2+R)$ equations has $M(2+R)$ unknowns $\{E_i, w_i, n_{ir}\}$, which can be solved given a numeraire.

II.2 Welfare Effects of Standard Changes

The welfare of country j can be expressed as

$$W_j = \frac{E_j}{P_j} - \Omega_j, \tag{10}$$

where $P_j = \prod_{r=1}^{R} (P_{jr})^{\mu_{jr}}$ is the aggregate price index in country j. In other words, country j's welfare is the real income subtracted by the negative consumption externality. In this multi-sector, multi-country, environment, an international inefficiency arises when one country's policy affects other countries' welfare via international trade. To illustrate through which channels standard changes can affect welfare, I log-linearize around the equilibrium with zero tariffs and no consumption externality to obtain:

$$\frac{dW_j}{W_j} \approx \sum_{i=1}^{M} \sum_{r=1}^{R} \frac{X_{ijr}}{E_j} \left(\frac{dw_j}{w_j} - \frac{dw_i}{w_i} \right) + \sum_{i=1}^{M} \sum_{r=1}^{R} \frac{X_{ijr}}{E_j} \frac{1}{\sigma_r - 1} \frac{dn_{ir}}{n_{ir}} - \sum_{i=1}^{M} \sum_{r=1}^{R} \frac{X_{ijr}}{E_j} \frac{dc_{ijr}}{c_{ijr}}, \tag{11}$$

where $\frac{dW_j}{W_j}$ and other similar variables represent percentage changes. Algebraic details are presented in Section A.1 of the Appendix.[9]

The three terms in (11) capture the effect of standard changes on relative wages, the extensive margin, and the marginal cost of production, respectively. The first term represents a general-equilibrium effect on relative wages created by policy changes. Throughout this paper, I will refer to this effect as the *terms-of-trade* effect. The second term represents the combination of two effects on the extensive margin: one is a partial-equilibrium effect on the number of firms when standards affect the fixed cost of production, and the other is a general-equilibrium effect that is a consequence of the changes to standard. I will refer to this general-equilibrium effect, operating through adjustment in the extensive margin, as the *production relocation* effect. The last term captures the partial-equilibrium effect of standards on product prices. When standards only affect the fixed cost, the third term will disappear as there is no partial-equilibrium effect on product prices. When standards only affect the marginal cost, the second term will only capture the production relocation effect since there is no partial-equilibrium effect on the extensive margin.

The partial-equilibrium effect of standards on the fixed cost of production included in the second term of (11) is a channel of international inefficiency, but the partial-equilibrium effect of standards on the marginal cost is not. This is because the direct effect on prices, captured by the third term of (11), only depends on standards set by country j but not on standards set by other countries. When country j sets its standards, the effect on W_j via the third term of (11) is internalized. On the contrary, standards set by other countries will directly affect the fixed cost of all countries, and consequently W_j via the second term of (11). This effect on W_j is not internalized by other countries, creating an international inefficiency.

The relative strengths of the terms-of-trade effect and the production relocation effect depend on sectoral labor supply elasticity. In the next two sections, I construct two simplified versions of the framework described in this section, and analyze the two general-equilibrium effects separately. In Section III, I use a two-country, two-sector model to illustrate how standards affect welfare through production relocation. One sector is assumed to be homogeneous and freely traded, hence wage is equalized. As a result, the labor supply in the differentiated sector is completely elastic and there will be no terms-of-trade changes. In Section IV, a two-country, one-sector model is used to illustrate the terms-of-trade mechanism. In this case, the labor supply is completely inelastic and standard changes affect welfare through adjustment in relative wages.

[9] Log-linearization around positive tariffs will generate another term that captures tariff revenue, which is not the focus of this paper. Moreover, log-linearization with the consumption externality generates an additional local effect, which will not contribute to the international inefficiency.

III Production Relocation Effect

This section presents a simplified version of the model introduced in Section II. The model consists of two countries and two sectors.I assume one sector produces a homogeneous good with no trade cost. Introducing the freely traded homogeneous sector equalizes wages, thus eliminating the terms-of-trade effect. After discussing the additional assumptions, I first focus on the case in which standards affect the marginal cost of production, and then turn to the fixed cost case. For both cases, I analyze the welfare outcomes in the non-cooperative Nash equilibrium, and also the Nash equilibrium in which national treatment is imposed. I show that the non-cooperative equilibrium is always inefficient because of the production relocation effect. When national treatment is imposed, however, the Nash equilibrium becomes efficient only in the marginal cost case. In the fixed cost case, the international inefficiency remains because the partial-equilibrium effect on foreign country's number of firms is not internalized.

III.1 Setup

Throughout this section, it is assumed that the economy now consists of two countries, 1 and 2. In addition, there are only two sectors: one is differentiated with elasticity of substitution $\sigma > 1$, and the other is homogeneous. Since there is only one differentiated sector, the "r" subscript is dropped. The utility function (1) is this special case can be written as:

$$U_j = \left(\sum_{i=1}^{2} \int_0^{n_i} x_{ij}(v_i)^{(\sigma-1)/\sigma} dv_i \right)^{\mu\sigma/(\sigma-1)} Y_j^{1-\mu}$$

where Y_j is the quantity of the homogeneous good consumed in country j.

The inverse production function of the differentiated sector still follows (2). $f_i = f(s_{ii}, s_{ij})$ is the fixed cost function of country i's firms producing differentiated goods, whereas $c_{ii} = c(s_{ii})$ and $c_{ij} = c(s_{ij})$ are the marginal cost functions of differentiated goods sold in country i and j, respectively. s_{ij} represents the standard imposed by the government of country j on differentiated goods produced in country i. The inverse production function for homogeneous good y is: $l_i^y = y_i$, where y_i is the homogeneous good produced in country i. The differentiated goods still has an iceberg trade cost τ, but the homogeneous good y is freely traded. Note that the cost functions f and c are identical across countries, therefore no country has a technological advantage.[10]

Throughout Section III, I assume that the standards set by the governments are within an interval $s \in [0, s^{max}]$. In addition, I assume that, the differentiated sector and the homogeneous sector

[10] I also analyze the model with asymmetric cost functions in Section A.4 of the Appendix. Section A.5 of the Appendix discusses the role of tariffs as additional policy instruments in the two-sector model.

are active in both countries. These two assumptions eliminate uninteresting corner solutions and shut down the term-of-trade effect, allowing me to focus on the production relocation effect (see Section A.2 in the Appendix for more details). I choose the price of the freely-traded homogeneous good as the numeraire; wages in both countries are therefore equal to one. The free-entry condition (8) is now simplified to:

$$f_i = \frac{p_{ii}x_{ii} + \tau p_{ij}x_{ij}}{\sigma}. \tag{12}$$

The market-clearing conditions (3) becomes:

$$\begin{aligned} p_{ii}x_{ii} &= (\frac{p_{ii}}{P_i})^{1-\sigma}\mu L_i \\ p_{ij}x_{ij} &= (\frac{p_{ij}}{P_j})^{1-\sigma}\tau^{-\sigma}\mu L_j. \end{aligned} \tag{13}$$

Given the set of standards $\{s_{11}, s_{12}, s_{21}, s_{22}\}$, equilibrium price indices can be solved uniquely by substituting (13) into the free entry condition (12):

$$P_j = \left(\frac{\sigma}{\mu L_j}\frac{f_j p_{ii}^{1-\sigma} - f_i(p_{ji}\tau)^{1-\sigma}}{(p_{jj}p_{ii})^{1-\sigma} - (p_{ji}p_{ij}\tau^2)^{1-\sigma}}\right)^{\frac{1}{\sigma-1}}. \tag{14}$$

Equation (14) fully characterizes the equilibrium both sectors are active in the two countries.[11]

Welfare is still defined as in (10). Before discussing how governments set their standards, I impose the following assumptions on the negative consumption externality Ω_j:

Assumption 1 (Consumption Externality) *For $i, j \in \{1, 2\}$ and $s \in [0, s^{max}]$:*

1. $\Omega_j = \Omega_{jj}(s_{jj}) + \Omega_{ij}(s_{ij})$.
2. $\Omega_{ij}(0) > 0$, $\Omega'_{ij} < 0$, *and* $\Omega''_{ij} > 0$.
3. $\Omega'_{ij}(s_{ij}) \to \infty$ *as* $s_{ij} \to 0$. $\Omega'_{ij}(s_{ij}) \to 0$ *as* $s_{ij} \to s^{max}$.

Note first that Ω_j is a function of s_{jj} and s_{ij}, the standards imposed on the differentiated goods consumed in country j. This is consistent with the interpretation that Ω_j captures the negative consumption externality. The additive separability assumption simplifies the analysis.[12] The final two assumptions rule out the possibility that the consumption externality is so significant relative to the real expenditure that it is optimal for the government to impose maximum standards.

[11] Note that the ideal price index of the differentiated sector in country j does not depend on L_i. A more detailed explanation to this is in Section A.3 of the Appendix.

[12] The case in which this assumption is dropped is discussed in Section A.6. The two propositions presented in this section still hold when the consumption externality also depends on the total expenditure of the differentiated good.

The setup of this model allows standards to affect both the fixed and the marginal cost of production. I analyze the two possibilities separately and show that governments can manipulate standards to improve welfare by production relocation in both cases. However, both the mechanisms through which standards affect welfare and the welfare outcomes are different.

III.2 Standard Affect Only Marginal Costs

In the remainder of this paper, I will refer to the case in which fixed cost f_j does not depend on standards as the marginal cost case. The assumptions are formally stated as follows:

Assumption 2 (Marginal Cost Case) *For* $i, j \in \{1,2\}$ *and* $s \in [0, s^{max}]$:

1. $f_1 = f_2 = f$.
2. $c' > 0$ *and* $c'' > 0$.

Note that when fixed cost is constant, the total number of firms producing differentiated goods does not depend on the standards imposed.[13] Given these assumptions, (14) is simplified to:

$$P_j = \left(\frac{f\sigma}{\mu L_j}\frac{p_{ii}^{1-\sigma} - (p_{ji}\tau)^{1-\sigma}}{(p_{jj}p_{ii})^{1-\sigma} - (p_{ji}p_{ij}\tau^2)^{1-\sigma}}\right)^{\frac{1}{\sigma-1}}.$$

A positive P_j requires that $\frac{p_{ii}^{1-\sigma} - (p_{ji}\tau)^{1-\sigma}}{(p_{jj}p_{ii})^{1-\sigma} - (p_{ji}p_{ij}\tau^2)^{1-\sigma}} > 0$. One sufficient condition for this to hold is a sufficiently large trade cost τ, such that $c(s_{jj}) < \tau c(s_{ij})$ for all s_{jj} and s_{ij} in the range $[0, s^{max}]$. Throughout this subsection, I will assume that this condition is satisfied. The following lemma will be used heavily in analyzing how governments set the standards to maximize welfare:

Lemma 1 *In the marginal cost case of the two-sector model, if Assumption 2 is satisfied, then in equilibrium* $\frac{\partial P_j}{\partial s_{jj}} > 0$, $\frac{\partial P_j}{\partial s_{ji}} > 0$, $\frac{\partial P_j}{\partial s_{ii}} < 0$, *and* $\frac{\partial P_j}{\partial s_{ij}} < 0$.

Proof. See Section B.1 in the Appendix. ■

In the marginal cost case of the two-sector model, raising s_{ij} generates two effects. The first one is the partial-equilibrium effect: a higher s_{ij} increases p_{ij}, thus raising the domestic price index P_j. The higher p_{ij} also triggers adjustments in the extensive margin. Domestic firms in country j now sell more relative to foreign firms due to more expensive imports, triggering entry in the domestic differentiated sector and exit in the foreign differentiated sector. Such production relocation reduces P_j due to the existence of trade cost τ. On the other hand, raising s_{jj} will also trigger production relocation but in the opposite direction, which increases P_j.

[13] To see this, first calculate the total expenditure on differentiated goods: $\mu(L_1 + L_2) = n_1(p_{11}x_{11} + \tau p_{12}x_{12}) + n_2(p_{22}x_{22} + \tau p_{21}x_{21})$. Substitute (12) into this equation gives $n_1 + n_2 = \frac{\mu(L_1+L_2)}{f\sigma}$.

Lemma 1 tells us that P_j is decreasing monotonically with s_{ij}. In other words, the partial-equilibrium marginal cost effect is always dominated by the production relocation effect. To see this, consider an increase of s_{ij} that raises p_{ij}. Now country j firms increase sales and earn positive profit. To restore equilibrium, there has to be entry in country j which reduces P_j. P_j in the new equilibrium must be lower than in the old equilibrium so that it is harder for country j firms to sell in the domestic market. If P_j returns to its previous level, country j will still earn positive profit, because the exit triggered in country i raises P_i.

No Cooperation

I now consider the welfare outcome of the non-cooperative Nash equilibrium. In this case, country j's government solves the following optimization problem;

$$\max_{s_{ij},s_{jj}} \frac{L_j}{P_j(s_{ij}, s_{jj})} - \Omega_j(s_{ij}, s_{jj})$$

subject to the equilibrium condition described by (14). When country j sets s_{jj}, it faces a trade off between the real expenditure and the negative consumption externality. On one hand, we know from Lemma 1 that a higher s_{jj} will reduce real expenditure by raising P_j. On the other hand, a higher s_{jj} will reduce the negative consumption externality. The optimal s_{jj} will be pinned down by the first order condition $\frac{\partial W_j}{\partial s_{jj}} = 0$.[14] However, because $\frac{\partial P_j}{\partial s_{ij}} < 0$ and $\Omega'_{ij} < 0$, W_j increases monotonically in s_{ij}. Therefore, country j will always impose maximum standards s_{max} on differentiated goods imported from country i.

When country j increases s_{ij} to improve welfare, production relocation also drives up P_i. This effect does not enter country j's objective function when country j determines its standards, thereby creating an international externality. Notice that because the optimal s_{jj} satisfies $\frac{\partial W_j}{\partial s_{jj}} = 0$, a marginal increase in s_{jj} in the Nash equilibrium will not affect W_j. On the other hand, since $\frac{\partial P_i}{\partial s_{jj}} < 0$ from Lemma 1, W_i will increase as a result. Therefore, we have found a Pareto improvement from the Nash equilibrium. Thus the Nash equilibrium in which standards are set non-cooperatively is Pareto inefficient.

National Treatment

I compare the non-cooperative Nash equilibrium with the outcome under national treatment. Throughout this paper, national treatment is interpreted as a rule that requires the same standards to be imposed upon all differentiated goods, regardless of their origin. In other words, the government

[14] This section and Section IV only consider the interior solution. When product standards are solely used for protectionist purposes, the first order condition will not hold. This scenario is analyzed in Section V.3.

of country j now faces an additional constraint $s_{jj} = s_{ij}$ when determining the optimal standards. I use s_j^{NT} to represent the standard imposed on the differentiated goods consumed in country j under national treatment. (14) can be rewritten as:

$$P_j = \frac{\sigma}{\sigma - 1}\left(\frac{f\sigma}{\mu L_j(1 + \tau^{1-\sigma})}\right)^{\frac{1}{\sigma-1}} c(s_j^{NT}). \tag{15}$$

Note first that P_j now only depends on s_j^{NT} but not s_i^{NT}. As a result, both the real expenditure and the consumption externality of country j are independent of s_i^{NT}. In other words, country j's optimal standard under national treatment is independent of the standard imposed in country i. The production relocation effect that creates the international inefficiency vanishes, rendering the resulting Nash equilibrium Pareto efficient.

The intuition of efficient equilibrium under national treatment is straightforward: when standards only affect the marginal cost of production, the partial-equilibrium effect on prices does not create any international inefficiency. Production relocation in the non-cooperative equilibrium is brought about by the price differences of the differentiated goods. National treatment equalizes p_{ij} and p_{jj}, hence standards cannot be used to induce production relocation. Because the partial-equilibrium effect on the marginal cost of production does not create any inefficiency, the resulting Nash equilibrium is Pareto efficient.

The above welfare analysis can be summarized in the following proposition:

Proposition 1 *In the marginal cost case of the two-sector model where Assumption 1 and Assumption 2 are satisfied:*

1. *The unique Nash equilibrium with non-cooperative policies is Pareto inefficient.*
2. *The unique Nash equilibrium with national treatment is Pareto efficient.*

Proof. See Section B.2 in the Appendix. ■

III.3 Standard Affect Only Fixed Costs

Now consider the situation in which standards affect the fixed cost only, but not the marginal cost of production (which I will refer to as the fixed cost case). The additional assumptions in this scenario are formally stated as follows:

Assumption 3 (Fixed Cost Case) *For* $i, j \in \{1, 2\}$ *and* $s \in [0, s^{max}]$:

1. $f_i = f(s_{ii}) + f(s_{ij})$*, where* $f' > 0$ *and* $f'' > 0$.

2. $c_{ij} = c_{ji} = c$.

The additive separable functional form simplifies the analysis, whereas the convexity of f eliminates corner solutions.[15] I also assume that the marginal cost is a constant c in two countries. This assumption will equalize ex-factory prices. Notice that in this case, $n_1 f_1 + n_2 f_2 = \frac{\mu(L_1+L_2)}{\sigma}$. Therefore, the total number of differentiated firms is no longer fixed. Country j can reduce n_i, and hence increase n_j by imposing a higher s_{ij}.

Given the combination of standards, (14) is simplified to:

$$P_j = \left(\frac{\sigma p^{\sigma-1}(f(s_{jj}) + f(s_{ji}) - \tau^{1-\sigma}(f(s_{ii}) + f(s_{ij}))}{\mu L_j(1 - \tau^{2(1-\sigma)})} \right)^{\frac{1}{\sigma-1}}. \tag{16}$$

Positive ideal price indices in equilibrium require $f(s_{jj}) + f(s_{ji}) - \tau^{1-\sigma}(f(s_{ii}) + f(s_{ij})) > 0$, which I assume always holds for all combinations of standards. Similar to the case in which standards affect marginal costs only, this condition is satisfied when trade cost τ is large. Analogous to Lemma 1 in the case of marginal cost, we have the following lemma:

Lemma 2 *In the marginal cost case of the two-sector model, if Assumption 3 is satisfied, then in equilibrium* $\frac{\partial P_j}{\partial s_{jj}} > 0$, $\frac{\partial P_j}{\partial s_{ij}} < 0$, $\frac{\partial P_j}{\partial s_{ji}} > 0$, *and* $\frac{\partial P_j}{\partial s_{ii}} < 0$.

Proof. See Section B.3 in the Appendix. ■

In the fixed cost case, there are also a partial-equilibrium effect and a general-equilibrium production relocation effect. However, in this case the prices of differentiated goods do not change at all. An increase in s_{ij} reduces n_i and hence increases both P_j and P_i. Firms in country j now earn more profit due to less competition. Entry is triggered in country j, which reduces the price index P_j.

The positive partial-equilibrium effect of raising s_{ij} on P_j is always triumphed by the negative effect from production relocation, just like in the marginal cost case. To see this, consider an increase of s_{ij} that raises f_i. The partial-equilibrium effect will trigger exit of firms in country i, raising both P_i and P_j. Now firms in country j increase sales and earn positive profit. To restore equilibrium, there has to be entry in country j which reduces P_j. P_j in the new equilibrium must be lower than in the old equilibrium so that it is harder for country j's firms to sell in the domestic market. If P_j returns to its previous level, firms in country j will still earn positive profit, because the direct effect of higher f_i raises P_i. On the other hand, raising s_{jj} will also trigger production relocation but in the opposite direction, which increases P_j.

[15] I also analyze the case in which $f_i = f(\max[s_{ii}, s_{ij}])$ in Section A.7 in the Appendix. The main results about the efficiency outcomes in equilibrium still hold.

No Cooperation

In the fixed cost case, the governments of the two countries solve the same optimization problem as in the marginal cost case. Notice that the signs of the partials in Lemma 2 are identical as those in Lemma 1. Therefore, the reasoning presented in the marginal cost case also applies in the fixed cost case. s^{max} is always imposed on imported differentiated goods in the unique Nash equilibrium, and the Nash equilibrium is Pareto inefficient.

National Treatment

Analogous to the marginal cost case, here the governments of the two countries face an additional constraint under national treatment. Let s_j^{NT} represent the standard country j imposes under national treatment, which is equal to s_{jj} and s_{ij}. The fixed cost for each firm becomes: $f_i = f_j = f(s_j^{NT}) + f(s_i^{NT})$. In other words, in the fixed cost case, national treatment equalizes the fixed cost in both countries. This is different from the marginal cost case with national treatment, in which the marginal cost of goods sold in two countries may still differ. Now (16) becomes:

$$P_j = \left(\frac{\sigma p^{\sigma-1}(f(s_j^{NT}) + f(s_i^{NT}))}{\mu L_j(1 + \tau^{1-\sigma})} \right)^{\frac{1}{\sigma-1}} \tag{17}$$

Observe that from (17), $\frac{\partial P_j}{\partial s_j^{NT}} > 0$, which is the same as in the marginal cost case. What distinguishes (17) from (15) is that in the fixed cost case, $\frac{\partial P_j}{\partial s_i^{NT}}$ is also positive. In other words, national treatment eliminates the production relocation effect but the partial-equilibrium effect on the foreign country's fixed cost remains. When each country sets product standards separately, this effect is not internalized by the government. For this reason, the Nash equilibrium under national treatment is still inefficient in the fixed cost case.

The welfare analysis in the fixed cost case can be summarized in the following proposition:

Proposition 2 *Consider the fixed cost case of the two-sector model where Assumption 1 and Assumption 3 are satisfied. The Nash equilibrium is Pareto inefficient both when standards are set non-cooperatively and when national treatment is followed.*

Proof. See Section B.4 in the Appendix. ■

IV Terms-of-Trade Effect

In this section, I will keep the additional assumptions made in Section III, but remove the freely-traded homogeneous sector. This one-sector model isolates the terms-of-trade effect of product standards, as now standard changes lead to the adjustment in relative wages. In the marginal cost case, this general-equilibrium effect is the only channel through which the international inefficiency can arise. However, in the fixed cost case, the partial-equilibrium effect on the foreign country's fixed cost can also create inefficiency. In both cases, the Nash equilibrium with national treatment is still Pareto inefficient.

IV.1 Setup

Since there is only one differentiated sector, the utility function now becomes

$$U_j = \left(\sum_{i=1}^{2} \int_0^{n_i} x_{ij}(\nu_i)^{(\sigma-1)/\sigma} d\nu_i \right)^{\sigma/(\sigma-1)}.$$

Without the freely-traded numeraire good, wages are no longer equal to one in equilibrium. Without loss of generality, we can choose the wage of country 2 to be numeraire and set $w_2 = 1$. The two conditions that characterize the equilibrium given standards in Section III still hold. The first one is the free-entry condition of the differentiated sector in country i:

$$w_i f_i = \frac{p_{ii}x_{ii} + \tau p_{ij}x_{ij}}{\sigma}. \tag{18}$$

The second one is the market-clearing conditions of the differentiated sector:

$$\begin{aligned} p_{ii}x_{ii} &= (\frac{p_{ii}}{P_i})^{1-\sigma} w_i L_i \\ p_{ij}x_{ij} &= (\frac{p_{ij}}{P_j})^{1-\sigma} \tau^{-\sigma} w_j L_j, \end{aligned}$$

Given the set of standards $\{s_{11}, s_{12}, s_{21}, s_{22}\}$, equilibrium price indices can be solved uniquely by substituting the market clearing condition into the free entry condition:

$$P_j = \left(\frac{\sigma}{w_j L_j} \frac{f_j p_{ii}^{1-\sigma} - f_i (p_{ji}\tau)^{1-\sigma}}{(p_{jj}p_{ii})^{1-\sigma} - (p_{ji}p_{ij}\tau^2)^{1-\sigma}} \right)^{\frac{1}{\sigma-1}}.$$

In this case, there are two more endogenous variables w_1, w_2. Given $w_2 = 1$, w_1 is determined by the balance-of-trade condition:

$$n_i p_{ij} x_{ij} = n_j p_{ji} x_{ji}. \tag{19}$$

One important feature that distinguishes the one-sector model from the two-sector one is that the production relocation effect disappears. To see this, first note that since there is only one sector and all firms are homogeneous, we have $l_i = L_i/n_i$. The budget constraint of country i is then:

$$\frac{w_i L_i}{n_i} = p_{ii} x_{ii} + \tau p_{ij} x_{ij}.$$

Further substitute this equation into the free-entry condition (18) to get:

$$n_i = \frac{L_i}{f_i \sigma}. \tag{20}$$

Since n_i does not depend on any of country j's variables, relocating firms via policies is impossible. As the labor supply in the differentiated sector is completely inelastic, changes in profit (and thus revenue) induced by policy changes will lead to relative wage adjustments (Gros, 1987). Note that even though there is no production relocation effect in this one-sector model, country j can still affect n_i through f_i when standards affect the fixed cost of production.

I define terms of trade of country j as $\psi_j \equiv w_j/w_i$.[16] To simplify notation, I also define $p_j^T \equiv p_{ji}/p_{ij}$. By definition,

$$p_j^T = \frac{\psi_j c_{ji}}{c_{ij}}.$$

Hence, p_j^T and ψ_j are equal only when $c_{ij} = c_{ji}$.

IV.2 Standard Affect Only Marginal Cost

This section focuses on the marginal cost case where Assumption 2 holds. We can see from (20) that once the fixed cost is constant, the extensive margins of both countries are independent of standards. Country j's choices on standards can only affect country i through ψ_j and hence p_j^T. The only potential source of international inefficiency is the terms-of-trade effect.

When country j increases the standard on its imports s_{ij}, p_{ij} increases as a result. Now imported goods in country j are more expensive than domestically produced goods. To eliminate the positive profit of firms in country j and restore the balance-of-trade condition (19), w_j must increase relative to w_i. For the same reason, raising s_{jj} will move the relative wages in the opposite direction. However, in this model p_{ij} also depends on c_{ij}. Though increasing s_{ij} leads to a higher relative wages of country j, a higher c_{ij} also makes imports in country j more expensive. It can be shown that this partial-equilibrium effect from c_{ij} is stronger than the counteracting movement in relative

[16]Terms of trade can be expressed either in terms of relative prices or relative wages. For example, Gros (1987) defines terms of trade in terms of pre-tariff relative prices of the differentiated goods, which is equal to the relative wages in that framework. Here, this relationship does not hold anymore, because the marginal costs, and hence prices, can also be affected by standards.

wages. Therefore, increasing s_{ij} leads to a loss for country j. On the other hand, raising s_{jj} both deteriorates country j's terms of trade and increases the prices. Hence, a higher s_{jj} will lead to a lower U_j.

Since the extensive margin is fixed in the marginal cost case, terms of trade is the only channel through which country j's standards can affect U_i. Because a higher s_{ij} increases ψ_j and a higher s_{jj} decreases ψ_j, we have $\frac{\partial U_i}{\partial s_{ij}} < 0$, and $\frac{\partial U_i}{\partial s_{jj}} > 0$. The following lemma formalizes these results:

Lemma 3 *In the marginal cost case of the one-sector model where Assumption 2 is satisfied, the following holds in equilibrium with given standards:*

1. $\frac{\partial \psi_j}{s_{ij}} > 0$ *and* $\frac{\partial \psi_j}{s_{jj}} < 0$
2. $\frac{\partial p_j^T}{\partial s_{ij}} < 0$, *and* $\frac{\partial p_j^T}{\partial s_{jj}} < 0$.
3. $\frac{\partial U_j}{\partial s_{ij}} < 0$, $\frac{\partial U_j}{\partial s_{jj}} < 0$, $\frac{\partial U_i}{\partial s_{ij}} < 0$, *and* $\frac{\partial U_i}{\partial s_{jj}} > 0$.

Proof. See Section B.7 in the Appendix. ■

The next step is to analyze how changes in standards affect equilibrium outcomes when national treatment is followed. Imposing national treatment causes $s_{ij} = s_{jj} = s_j^{NT}$, and thus $c_{ij} = c_{jj}$. Raising s_j^{NT} makes goods sold in country j more expensive relative to goods sold in country i, regardless of the origin. Since the relative prices of x_{ij} and x_{jj} do not change, firms from country i make more profits due to the rising s_j^{NT}. To compete away these positive profits and restore the the balance-of-trade condition (19), w_j must decrease relative to w_i. Because raising s_j^{NT} also has a direct negative effect on terms of trade through larger c_{ij}, $\frac{\partial p_j^T}{s_j^{NT}} < 0$ follows. Since both the relative wages and the terms of trade move in the direction unfavorable to country j, raising s_j^{NT} decreases U_j but increases U_i. The following lemma formalizes these results:

Lemma 4 *In the marginal cost case of the one-sector model where Assumption 2 is satisfied and national treatment is followed, the following holds in equilibrium with given standards:*

1. $\frac{\partial \psi_j}{s_j^{NT}} < 0$.
2. $\frac{\partial p_j^T}{s_j^{NT}} < 0$.
3. $\frac{\partial U_j}{\partial s_j^{NT}} < 0$ *and* $\frac{\partial U_i}{\partial s_j^{NT}} > 0$

Proof. See Section B.8 in the Appendix. ■

In the non-cooperative equilibrium, an international inefficiency arises because the effect of standards on foreign welfare through terms of trade is ignored. Contrary to the marginal cost case of the two-sector model in Section III, imposing national treatment in the one-sector model does not eliminate the terms-of-trade effect. As $\frac{\partial \psi_j}{s_j^{NT}} < 0$ in Lemma 4, country j's choice of standards will affect country i's welfare. As a result, there will exist an international inefficiency in the Nash equilibrium even when national treatment is imposed. The above analysis is summarized in the following proposition:

Proposition 3 *In the marginal cost case of the one-sector model where Assumption 1 and Assumption 2 are satisfied, the Nash equilibrium is Pareto inefficient, regardless of whether national treatment is followed.*

Proof. See Section B.9 in the Appendix. ■

IV.3 Standard Affect Only Fixed Cost

When Assumption 3 holds, the number of firms is no longer constant. In addition to terms of trade, foreign welfare can also be affected directly via the fixed cost of production. In addition, given c is constant, now have $p_j^T = \psi_j$. In other words, the relative wages and relative prices shift in the same direction.

When country j increases its standards on imports s_{ij}, p_{ij} does not change but f_i increases. Variable profits of country i's firms are now not enough to cover the fixed cost; hence, the firms will start to exit. This increases the demand, and thus profit, for the firms in country j. However, since the number of firms is pinned down by fixed cost, adjustments can only happen in the intensive margin. To eliminate the positive profits of country j's firms and restore the balance-of-trade condition, p_j^T increases as a result. The smaller n_i increases the intensive margin firms from both countries, whereas the larger p_j^T increases the revenue of country i's firms relative to that of country j's firms. Both forces lead to a positive adjustment of the intensive margin in country i firms, hence both $\frac{\partial x_{ij}}{\partial s_{ij}}$ and $\frac{\partial x_{ii}}{\partial s_{ij}}$ are positive in equilibrium. On the other hand, for country j's firms, we have $\frac{\partial x_{jj}}{\partial s_{ij}} > 0$ and $\frac{\partial x_{ji}}{\partial s_{ij}} < 0$. x_{ji} decreases in s_{ij} because the positive change in relative wages makes country j's products more expensive than domestic products in country i. When country j increases s_{jj}, the same mechanism operates in the opposite direction.

Changes in standards affect U_i and U_j through both the terms of trade and the extensive margin. When country j increases s_{ij}, the terms of trade improves (which increases U_j), but n_i decreases (which decreases U_j). It is shown that the negative effect from the extensive margin always dominates in equilibrium, hence $\frac{\partial U_j}{\partial s_{ij}} < 0$. On the other hand, increasing s_{jj} leads to a terms-of-trade loss and fewer of firms in j. Since both effects reduce U_j, we have $\frac{\partial U_j}{\partial s_{jj}} < 0$ in equilibrium.

Changes in country j's standards also affect U_i and creates an international trade externality. This externality functions through both the terms-of-trade effect and the partial-equilibrium effect on country i's extensive margin. When s_{ij} increases, country i's terms of trade deteriorates, and the number of its firms decreases. Hence we have $\frac{\partial U_i}{\partial s_{ij}} < 0$. When s_{jj} increases, country i's terms-of-trade improves but n_j decreases. In equilibrium, the effect from the extensive margin dominates and $\frac{\partial U_i}{\partial s_{jj}} < 0$. These results are formally stated in the following lemma:

Lemma 5 *In the marginal cost case of the one-sector model where Assumption 3 is satisfied, the following holds in equilibrium with given standards:*

1. $\frac{\partial p_j^T}{\partial s_{ij}} = \frac{\partial \psi_j}{\partial s_{ij}} > 0$, *and* $\frac{\partial p_j^T}{\partial s_{jj}} = \frac{\partial \psi_j}{\partial s_{jj}} < 0$.
2. $\frac{\partial U_j}{\partial s_{ij}} < 0$, $\frac{\partial U_j}{\partial s_{jj}} < 0$, $\frac{\partial U_i}{\partial s_{ij}} < 0$, *and* $\frac{\partial U_i}{\partial s_{jj}} < 0$.

Proof. See Section B.10 in the Appendix. ■

Under national treatment, $f_{ij} = f_{jj} = f_j^{NT}$. Substituting this into the free-entry condition gives:

$$x_{ii} + \tau x_{ij} = x_{jj} + \tau x_{ji} = \frac{(\sigma - 1)(f_i^{NT} + f_j^{NT})}{c}.$$

In other words, national treatment in the fixed cost case equalizes the fixed cost and thus the size of each firm in both countries. When f_j^{NT} increases, the number of firms decreases and the size of each firm increases in a symmetric manner in both countries. Since both sides of the balance-of-trade condition (19) adjust at the same rate, the terms of trade will not change. The only remaining effect on U_i and U_j is due to partial-equilibrium changes in the extensive margin. Since this effect always reduces welfare, we have $\frac{\partial U_j}{\partial s_j^{NT}} < 0$ and $\frac{\partial U_i}{\partial s_j^{NT}} < 0$. These results are summarized in the following lemma:

Lemma 6 *In the marginal cost case of the one-sector model where Assumption 3 is satisfied and national treatment is followed, the following holds in equilibrium with given standards:*

1. $\frac{\partial p_j^T}{\partial s_j^{NT}} = \frac{\partial \psi_j}{\partial s_j^{NT}} = 0$.
2. $\frac{\partial U_j}{\partial s_j^{NT}} < 0$ *and* $\frac{\partial U_i}{\partial s_j^{NT}} < 0$.

Proof. See Section B.11 in the Appendix. ■

When standards are set non-cooperatively, the international inefficiency arises due to both the terms-of-trade effect and the partial-equilibrium effect on the fixed cost of production. The resulting Nash equilibrium is Pareto inefficient. Lemma 6 tells us that national treatment eliminates the terms-of-trade channel of international inefficiency in the fixed cost case. However, the partial-equilibrium effect on fixed cost still remains. Country j ignores the effect of its standards on country i's extensive margin. As a result, the Nash equilibrium in which national treatment is followed is still Pareto inefficient. The welfare outcomes in the both the non-cooperative Nash equilibrium and the Nash equilibrium under national treatment are formalized in the following proposition:

Proposition 4 *In the fixed cost case of the one-sector model where Assumption 1 and Assumption 3 are satisfied, the Nash equilibrium is Pareto inefficient, regardless of whether national treatment is followed.*

Proof. See Section B.12 in the Appendix. ■

V Discussions

In this section, I discuss some extensions to the two simple models in Section III and Section IV. I first focus on the Agreement on Technical Barriers to Trade (TBT) and the Agreement on Sanitary and Phytosanitary (SPS) Measures from the WTO, and link my analysis to the rationale of shallow integration presented in Bagwell and Staiger (1999). Next, I analyze the scenario in which standards are used solely for protectionist purposes. This case can be considered as a corner scenario, as the first order conditions no longer hold when governments choose standards. Lastly, I analyze the welfare consequences if the EU's principle of mutual recognition is adopted.

V.1 TBT/SPS Agreements and Market Access

In addition to national treatment, the WTO further disciplines domestic regulatory activities by imposing the TBT and SPS Agreements. These agreements oblige WTO members to adopt measures that are *least restrictive on trade*. These agreements complement national treatment because certain non-discriminatory domestic regulations can still create frictions in international trade. Here I analyze the consequences of following the TBT and SPS Agreements when standards are already constrained by national treatment. I interpret the restrictiveness of standards on international trade as a measure analogous to the notion of market access in Bagwell and Staiger (1999). Within the Krugman model used in this paper, I follow the spirit of Ossa (2011) and use the net exports of the differentiated goods as a measure of restrictiveness in trade. Since net exports in the one-sector model developed in Section IV always equal zero, my analysis will focus on the two-sector model developed in Section III.

In the two-sector model in Section III, I have shown that improving welfare through production relocation is impossible under national treatment in the marginal cost case. As a result, the number of firms producing differentiated goods in each country is independent of the standards imposed. In addition, the revenue of each firm producing differentiated goods is also fixed by the free-entry condition (12). Combining these two results, we know that the total revenue of the differentiated sector is independent of the combination of standards. Since expenditure on differentiated goods in country j is μL_j, the gross exports of differentiated products must also be independent of the standards imposed. In the fixed cost case, on the other hand, an increase in s_j^{NT} will increase the fixed cost in both countries. Both n_j and n_i will decrease in equilibrium as a result. However, a higher fixed cost also increases the revenue of firms producing differentiated goods. In equilibrium, the two changes cancel each other out, rendering the total revenue and net exports of the differentiated sector independent of standards. In other words, the net exports of the differentiated sector are independent of standards, regardless of whether standards affect the marginal of fixed cost of production.

This result is formally stated as the following proposition:

Proposition 5 *Define X_j as the value of country j's net exports in differentiated goods. Then, in equilibrium, X_j does not depend on $\{s_{jj}, s_{ij}, s_{ji}, s_{ii}\}$, both in the marginal cost case described in Section III.2 and the fixed cost case described in Section III.3.*

Proof. See Section B.13 in the Appendix. ■

Since the value of net exports of the differentiated goods is independent of standards under national treatment, the TBT and SPS Agreements will not play any role in the standard decisions when national treatment is followed by the two countries. As a result, further implementing the requirement that standards should be least restrictive on international trade does not change any outcome when national treatment has already been followed.[17]

If the role of the TBT and SPS Agreements is interpreted as disciplines on market access, the result stated in Proposition 5 can be compared with corresponding results in Bagwell and Staiger (2001). For example, one main result in Bagwell and Staiger (2001) is that once the efficient level of market access is ensured, domestic policies that preserve this level of market access also lead to efficient outcomes. This result holds in the framework constructed in the present paper when standards affect the marginal cost of production. However, in the fixed cost case under national treatment, the resulting Nash equilibrium may still be inefficient when the market access is preserved. This is because of the different model assumptions on the demand side. The CES demand function in this paper implies that welfare depends on product variety. To the contrary, the extensive margin plays no role in Bagwell and Staiger (2001) when the level of market access is preserved.

V.2 Mutual Recognition

In this section I analyze the welfare consequences of mutual recognition in the setup in Section III and in Section IV respectively. The EU adopts a mutual recognition principle to discipline

[17] An alternative interpretation is to measure trade in terms of gross exports. In this case the results presented in Proposition 5 still holds. In the one-sector model developed in Section IV, raising s_j^{NT} decreases the relative price of country j's product, hence increasing its gross export. In the fixed cost case, raising s_j^{NT} either increases or decreases gross export, depending on the relative labor size of country j.

technical rules imposed at national levels which may create unnecessary obstacles to intra-EU trade. According to the website of the European Commission, mutual recognition requires "EU countries accept products lawfully sold in another EU country, unless very specific conditions are met." According to Costinot (2008), mutual recognition can be applied to either vertical or horizontal standards. Toulemonde (2013) focuses on horizontal standards and discusses the role of mutual recognition in shifting the cost of adapting local norms from producers to consumers. I follow the interpretation in Costinot (2008) and consider mutual recognition equivalent to an additional policy constraint requiring $s_{ji} = s_{jj}$. In other words, when country j imposes a standard requirement on the differentiated goods sold and produced domestically, the same standard is also imposed on its exported differentiated goods. Note that mutual recognition requires a transfer of the regulatory power of differentiated goods that are produced and sold in different countries: country j has the right to determine the standard of its exports sold in country i under mutual recognition.

Two-Sector Model

Let $s_j^{MR} = s_{ji} = s_{jj}$. In the marginal cost case in which the additional assumptions in Section III.2 are satisfied, country j's ideal price index of the differentiated sector now can be written as:

$$P_j = \frac{\sigma}{\sigma - 1}\left(\frac{f\sigma}{\mu L_j}\frac{c(s_i^{MR})^{1-\sigma} - (c(s_j^{MR})\tau)^{1-\sigma}}{(c(s_j^{MR})c(s_i^{MR}))^{1-\sigma} - (c(s_j^{MR})c(s_i^{MR})\tau^2)^{1-\sigma})}\right)^{\frac{1}{\sigma-1}}.$$

Notice that for P_j to be positive, we need $c(s_j^{MR})\tau > c(s_i^{MR})$, which is always satisfied if the trade cost τ is large. This condition is the same as the one stated in Section III.2, and will be taken as given in this section. The derivative of P_j with respect to s_j^{MR} is:

$$\frac{\partial P_j}{\partial s_j^{MR}} = \frac{c(s_i^{MR})^{1-\sigma}P_j}{c(s_j^{MR})(c(s_i^{MR})^{1-\sigma} - (c(s_j^{MR})\tau)^{1-\sigma})}c'(s_j^{MR}),$$

which is always positive. We can also calculate the derivative with respect to s_i^{MR}:

$$\frac{\partial P_j}{\partial s_i^{MR}} = \frac{-(c(s_j^{MR})\tau)^{1-\sigma}P_j}{c(s_i^{MR})(c(s_i^{MR})^{1-\sigma} - (c(s_j^{MR})\tau)^{1-\sigma})}c'(s_i^{MR}),$$

which is always negative. We can see that mutual recognition prevents government to improve welfare via production relocation, because $\frac{\partial P_j}{\partial s_j^{MR}} > 0$. However, the trade externality associated with production relocation still exists, because P_j can now be affected by s_i^{MR}. In the Nash equilibrium, a positive change ds_j^{MR} does not change W_j but increases W_i. Therefore, contrary to the equilibrium under national treatment, the Nash equilibrium in the marginal case under mutual recognition is still Pareto inefficient.

In the fixed cost case in which the additional assumptions in Section III.3 are satisfied, the free entry condition of country i now becomes: $f(s_i^{MR})\sigma = p(x_{ii} + \tau x_{ij})$. The ideal price index of the differentiated sector in country j in equilibrium is:

$$P_j = \left(\frac{\sigma p^{\sigma-1}(f(s_j^{MR}) - \tau^{1-\sigma} f(s_i^{MR}))}{\mu L_j(1 - \tau^{2(1-\sigma)})} \right)^{\frac{1}{\sigma-1}}$$

Again, the trade externality associated with production relocation still exists. In the Nash equilibrium, Pareto improvement is possible.

Note that the Pareto inefficiency in the Nash equilibrium under mutual recognition differs from the fixed cost case under national treatment, in the sense that the inefficiency is the result of sub-optimal standards under mutual recognition. This is because $\frac{\partial P_j}{\partial s_i^{MR}} < 0$ in both the marginal and fixed cost cases. When setting standards, country i ignores the positive influence of s_i^{MR} on W_j. On the other hand, in the fixed cost case under national treatment, $\frac{\partial P_j}{\partial s_i^{NT}} > 0$. In the Nash equilibrium, what is ignored is the negative influence of s_i^{NT} on W_j, resulting a super-optimal combination of standards under national treatment. This feature also exists in Costinot (2008), even though the model setup in that paper is very different.

Under either national treatment or mutual recognition, increasing country j's standards will increase P_j. However, the effect on P_i does depend on which principle is followed: increasing j's standards increases P_i under national treatment but decreases P_i under mutual recognition in both the marginal and fixed cost cases. In other words, if the country j realizes that its standard is too high and wants to decrease it, country i's welfare will hurt under mutual recognition but increase under national treatment. If non-violation complaints are available in this hypothetical scenario, country i will complain in the mutual recognition case but not in the national treatment case.

One-Sector Model

Now consider mutual recognition in the same setup in Section IV. We can follow the procedure in the proof of Lemma 4 and Lemma 6 to calculate the partials of welfare with respect to standards under mutual recognition.[18] In both the marginal cost case and the fixed cost case, we have $\frac{\partial U_j}{\partial s_j^{MR}} < 0$ and $\frac{\partial U_j}{\partial s_j^{MR}} < 0$. In other words, increasing one country's standards will reduce both countries' real expenditure.

Similar to the two-sector model, increasing country j's standards here will always decrease country j's real expenditure under national treatment or mutual recognition. However, the effect on

[18] The algebraic details are presented in Section A.8 of the Appendix.

country i is different: under national treatment $\frac{\partial U_i}{\partial s_j^{NT}}$ is positive in the marginal cost case but negative in the fixed cost case. On the other hand, under mutual recognition $\frac{\partial U_j}{\partial s_j^{MR}}$ is always negative. Hence, in the one-sector model, reducing country j's standards will lead to a non-violation compliant from country i if national treatment is followed, and standards affect the marginal cost of production.

V.3 Protectionist Standards

This section focuses on the scenario of protectionist standards: these standards are imposed solely for protectionist purposes; hence, there will be no associated consumption externality. I analyze the welfare outcomes in both the two-sector model developed in Section III and the one-sector model developed in Section IV. Protectionist standards can be thought of as a corner case to standards that reduce consumption externality. This is because now the government may not have any incentive to impose standards that are above the minimum, hence first order conditions with respect to standards may not hold in equilibrium.

Two-Sector Model

When standards do not affect consumer welfare and are used solely for protectionist purposes, $\Omega_j = 0$ for $j = \{1, 2\}$. Now both countries' welfare is: $W_j = \frac{L_j}{P_j}$. Without the externality term, Lemma 1 and Lemma 2 still hold in the marginal cost case and the fixed cost case, respectively. Hence, when standards are imposed non-cooperatively, the resulting Nash equilibrium will be Pareto inefficient. The rationale is exactly the same as in Section III.

In the marginal cost case with national treatment, P_j is still independent of s_i^{NT}. Hence, the Nash equilibrium with national treatment is still Pareto efficient. However, in the fixed cost case, removing the negative consumption externality renders the Nash equilibrium with national treatment Pareto efficient: when $\Omega_j = 0$, both countries will impose minimum standard at $s_j^{NT} = 0$. This is because $\frac{\partial P_j}{\partial s_j^{NT}} > 0$ and there is no incentive for either country to raise standards. In the Nash equilibrium, the first order conditions with respect to standards $\frac{\partial W_j}{\partial s_j^{NT}} = 0$ no longer hold, and further improving country i's welfare by lowering s_j^{NT} is impossible. For this reason, the Nash equilibrium under national treatment in the fixed cost case becomes Pareto efficient.

The analysis of protectionist product standards in a two-sector model can be formalized by the following proposition:

Proposition 6 *Suppose that both countries follow national treatment and* $\Omega_1 = \Omega_2 = 0$ *in the two-sector model developed in Section III. Then in both the marginal cost case that follows Assumption 2 and the fixed cost case that follows Assumption 3, the unique Nash equilibrium is Pareto efficient.*

Proof. See Section B.5 in the Appendix. ■

One-Sector Model

In the one-sector model, the results in Lemma 3 and Lemma 5 still hold in the non-cooperative equilibrium. In both the marginal cost case and the fixed cost case, neither country will impose standards above the minimum level in the Nash equilibrium. Since the first order conditions do not hold anymore, marginal changes in country j's standards that increase W_i will also decrease W_j, rendering any Pareto improvement impossible. In other words, when standards are protectionist in the one-sector model, the non-cooperative Nash equilibrium is Pareto efficient. This result differs from the one derived in the two-sector model, in which the non-cooperative equilibrium is inefficient even when there is no consumption externality.

When national treatment is imposed in the one-sector model, raising standards on imports becomes more costly. However, this additional constraint does not lead to any change in equilibrium standards, as minimum standards are imposed in the non-cooperative equilibrium already. Similar to the non-cooperative equilibrium, the equilibrium under national treatment is Pareto efficient for the exact same reason.

The analysis of protectionist product standards in a one-sector model can be formalized by the following proposition:

Proposition 7 *Suppose that $\Omega_1 = \Omega_2 = 0$ in the one-sector model developed in Section IV. Then in both the marginal cost case that follows Assumption 2 and the fixed cost case that follows Assumption 3, the unique Nash equilibrium is Pareto efficient regardless of whether national treatment is imposed.*

Proof. See Section B.6 in the Appendix. ■

VI Quantitative Analysis

In this section, I use the framework introduced in Section II to analyze the quantitative importance of product standards. I first present additional assumptions and then represent the equilibrium conditions (25)-(27) in terms of changes, following the "exact hat algebra" approach in Dekle, Eaton, and Kortum (2007). Next, I briefly discuss the data and calibration. I then use the full model to compute optimal standards and welfare changes in several relevant counterfactual scenarios.

First, I consider the scenario in which each country abandons national treatment unilaterally. In this case, all countries gain at the expense of other countries. The average welfare gain is

1.34 percent, whereas the average welfare loss from other countries is 0.42 percent. I then use an iterative procedure to compute welfare changes in the Nash equilibrium, in which all countries abandon national treatment. In this trade war of standards, all countries suffer a welfare loss, and the average loss from the factual equilibrium is 1.44 percent. Finally I consider the counterfactual scenario in which all countries follow a Nash bargaining protocol and negotiate efficient standards. In the equilibrium with cooperative standards, all countries' welfare improves by 12.59 percent.

VI.1 Model

I assume that the negative consumption externality affects welfare as if the externality reduces expenditure. In other words, the welfare of country j is

$$W_j = \frac{(1 - \sum_{r=1}^{R} \Omega_{jr})E_j}{\prod_{r=1}^{R}(P_{jr})^{\mu_{jr}}}, \tag{21}$$

where Ω_{jr} represent the negative consumption externality generated in sector r of country j. I assume Ω_{jr} has the following functional form:

$$\Omega_{jr} = \omega_{jr} \sum_{i=1}^{M} \frac{(1 + t_{ijr})X_{ijr}}{E_j} \frac{s^{max} - s_{ijr}}{s^{max}}. \tag{22}$$

where s^{max} is the upper bound of product standards (the lower bound is set to zero), and ω_{jr} is a weight parameter. This formulation of the consumption externality is relatively straightforward, and the only additional parameter to be calibrated is the weight parameter ω_{jr}. When $\omega_{jr} = 1$ for all sectors, the consumption externality for each sector is weighted by Cobb-Douglas share μ_{jr}. In this case, imposing the maximum standard s^{max} will lead to no consumption externality. On the other hand, if $s_{ijr} = 0$ for all sectors, W_j also becomes zero. I use to $\tilde{s}_{ijr} = s_{ijr}/s^{max}$ represent the normalized measure of standards. By definition, $\tilde{s}_{ijr} \in [0, 1]$. As will be seen later, this normalization also helps incorporate the data into the model, because the data on standards is also normalized. Substituting (22) into (21) gives:

$$W_j = \frac{E_j}{\prod_{r=1}^{R}(P_{jr})^{\mu_{jr}}} - \frac{\sum_{r=1}^{R} \omega_{jr}(\sum_{i=1}^{M}(1 + t_{ijr})X_{ijr}(1 - \tilde{s}_{ijr}))}{\prod_{r=1}^{R}(P_{jr})^{\mu_{jr}}}.$$

We can see that W_j is the sum of a real expenditure term and a consumption externality term, which is consistent with the assumption in Section II.[19]

[19] In this formulation, country j's consumption externality is a function of each sector's expenditure share, which in turn is a function of $s_{ijr}, i \neq j$. Technically, country i can affect W_j through changing the expenditure share of Ω_{jr}, thus creating a new channel of international inefficiency. However, the magnitude of this effect on welfare is small

I assume that c_{ijr}, the sector-specific marginal cost function that depends on normalized standard $\tilde{s}_{ijr}$, has the following functional form:

$$c_{ijr} = \exp(c_r^1 \tilde{s}_{ijr}). \tag{23}$$

For the fixed cost of production, I assume that:

$$f_{ir} = \sum_{j=1}^{M} \mathbb{1}\{X_{ijr} > 0\} \exp(f_r^1 \tilde{s}_{ijr}). \tag{24}$$

where $\mathbb{1}\{X_{ijr} > 0\}$ is an indicator function of positive trade flow. The exponential functional form is chosen because it satisfies the assumptions in the theoretical analysis presented in Section III and Section IV. Only two additional parameters, c_r^1 and f_r^1, need to be estimated. Because of the exponential assumption, c_r^1 and f_r^1 can be interpreted as the elasticity of the marginal and fixed cost of production with respect to standards, respectively.

Directly solving the system of equations system of equations (7) - (9) is challenging, because the parameters $\{\tau_{ijr}, L_i, f_{ir}\}$ are difficult to estimate empirically. To circumvent this problem, the "exact hat algebra" technique popularized in Dekle, Eaton, and Kortum (2007) is used. In particular, assuming standards are the only possible policy instruments, conditions (7) - (9) can be rewritten in changes as:

$$\hat{E}_i = \beta_i \hat{w}_i + \sum_{m=1}^{M} \sum_{r=1}^{R} \gamma_{mir} t_{mir} \hat{X}_{mir} - \frac{B_i'}{E_i} \tag{25}$$

$$\hat{w}_i \hat{n}_{ir} \hat{f}_{ir} = \sum_{j=1}^{M} \eta_{ijr} \hat{X}_{ijr} \tag{26}$$

$$\hat{w}_i = \sum_{m=1}^{M} \sum_{r=1}^{R} \delta_{imr} \hat{X}_{imr} \tag{27}$$

where

$$\hat{P}_{jr} = \left(\sum_{i=1}^{M} \alpha_{ijr} \hat{n}_{ir} (\hat{w}_i \hat{c}_{ijr})^{1-\sigma_r} \right)^{\frac{1}{1-\sigma_r}},$$

$$\hat{X}_{ijr} = \hat{n}_{ir} (\hat{c}_{ijr} \hat{w}_i)^{1-\sigma_r} (\hat{P}_{jr})^{\sigma_r - 1} \hat{E}_j.$$

The "hat" variables denote the ratios between the counterfactual and factual values and variables

relative to the channels discussed in previous sections.

with prime denote counterfactual values. Moreover, $\alpha_{ijr} = \frac{(1+t_{ijr})X_{ijr}}{\sum_{m=1}^{M}(1+t_{mjr})X_{mjr}}$, $\beta_i = \frac{w_i L_i}{E_i}$, $\gamma_{ijr} = \frac{X_{ijr}}{E_j}$, $\delta_{ijr} = \frac{X_{ijr}}{w_i L_i}$, and $\eta_{ijr} = \frac{X_{ijr}}{\sum_{m=1}^{M} X_{imr}}$. From (23) and (24), we have[20]

$$\hat{c}_{ijr} = \exp\left(c_r^1(\tilde{s}'_{ijr} - \tilde{s}_{ijr})\right),$$
$$\hat{f}_{ir} = \sum_{j=1}^{M} \frac{\exp(f_r^1 \tilde{s}_{ijr})}{\sum_{j=1}^{M} \exp(f_r^1 \tilde{s}_{ijr})} \exp(f_r^1(\tilde{s}'_{ijr} - \tilde{s}_{ijr})).$$

Equations (25) - (27) represent a system of $M(2+R)$ equations with $M(2+R)$ unknowns $\{E_i, w_i, n_{ir}\}$. Compared to the system represented by (7) - (9), this system has the following advantages: first, the coefficients depend only on σ_r and observables so that information on $\{\tau_{ijr}, L_i, f_{ir}\}$ is no longer needed. In addition, all observables can be inferred directly from widely available trade, standard, and tariff data. For example, expenditure share can be calibrated by $\mu_{jr} = \frac{\sum_{i=1}^{M}(1+t_{ijr})X_{ijr}}{E_j}$. Given any counterfactual tariffs and standards, we can calculate welfare changes in the new equilibrium by solving equations (25) - (27) simultaneously.[21] Lastly, in the counterfactual equilibrium, the welfare change relative to the factual equilibrium is

$$\hat{W}_j = \frac{1}{\prod_{r=1}^{R}(\hat{P}_{jr})^{\mu_{jr}}}\left(\hat{E}_j\frac{E_j}{\xi_j} - \sum_{r=1}^{R}\sum_{i=1}^{M}\omega_{jr}(1-\tilde{s}'_{ijr})(1+t_{ijr})\hat{X}_{ijr}\frac{X_{ijr}}{\xi_j}\right),$$

where $\xi_j = E_j - \sum_{r=1}^{R}\sum_{i=1}^{M}\omega_{jr}(1+t_{ijr})X_{ijr}(1-\tilde{s}_{ijr})$.

VI.2 Data

Export data is collected from the UN ComTrade Database, where c.i.f. (cost, insurance, and freight) values are recorded. Tariff data is from the International Trade Centre's Market Access Map database (MAcMap). Distance and various measures of trade frictions are from the CEPII database and documented in Head and Mayer (2014). The trade data I use is from the National Input-Output Tables available at World Input-Output Database, one of the few public databases with within-country trade flows at industry level. I use the data for the year 2014, which consists of 42 countries and 21 agriculture and manufacturing sectors defined by ISIC revision 4 from the United Nations Statistics Division. I focus on seven large blocks (Brazil, Canada, China, India, Japan, the United States, and EU-28 countries), and group the remaining countries (Australia,

[20]The indicator function in $\hat{f}_{ir}$ is dropped because all trade pairs in the quantitative exercise have positive trade flows.

[21]As discussed in Ossa (2014), the presence of aggregate trade imbalances in the data is not coherent with this model. Hence, I follow the exercise in Dekle, Eaton, and Kortum (2007) to construct a trade flow matrix without trade imbalance. All later calculations of welfare changes given counterfactual tariffs and standards will use this purged trade flow data.

Indonesia, Mexico, Norway, South Korea, Russia and Switzerland) as one Rest of the World.

Measurement is one of the toughest issues faced in research on non-tariff barriers (Goldberg and Pavcnik, 2016). Unfortunately, existing measures on the strictness of product standards are far from ideal, and usually do not apply to multiple sectors. I follow the approach of coverage ratio used in Essaji (2008) and Disdier, Fontagne, and Mimouni (2008). Note that since all countries involved in the quantitative exercise are members of the WTO, I assume that national treatment is strictly followed.[22] The coverage ratio of sector r in country j is defined as the share of its HS 6-digit products covered by non-tariff measures (NTM), which is available from TRAINS.[23] In other words, the number of products covered by regulations in each sector is interpreted as s_{ir}^{NT}, hence the coverage ratio represents the normalized standard under national treatment $\tilde{s}_{jr}^{NT}$. This dataset is an unbalanced panel covering 60 countries from 2010 to 2015. Since the focus of this paper is product standards, I only focus on TBT and SPS categories of the NTM data. All trade, tariff and NTM data at HS 6-digit level are converted to sectors using a concordance I construct.

Estimating the fixed cost function requires the number of firms in each sector. I use the Structural and Demographic Business Statistics from the OECD, which records the total number of enterprises of 37 OECD countries at industry level in 2012. The industry-level number of firms for India, China, Canada and Japan are also needed for the quantitative exercise. I obtain them from their own Statistics Bureaus respectively.[24]

VI.3 Estimation and Calibration

This section focuses on the estimation of the marginal cost parameter c_r^1, the fixed cost parameter f_r^1, the elasticity of substitution σ_r, the calibration of the weight parameter of the consumption externality Ω_{jr}.

Marginal Cost Parameter c_r^1

Estimating the marginal cost function replies on the optimal pricing equation:

$$p_{ijr} = \frac{\sigma_r \tau_{ijr} w_i c_i(\tilde{s}_{jr}^{NT})}{\sigma_r - 1},$$

[22] The WTO has received complaints related to violation of the principle of national treatment. The *Brazil-Retreaded Tires* case discussed in the introduction is one example. However, those complaints are mostly industry-specific and the cases only constitute a very small share of international trade.

[23] Available through the World Integrated Trade Solution (WITS) at: http://wits/worldbank.org/.

[24] Data for India is from its Annual Survey of Industries vailable at http://www.csoisw.gov.in/cms/En/1023-annual-survey-of-industries.aspx. Data for China is from its National Bureau of Statistics. Data for Japan is from the 2012 Economic Census for Business Activity. Data for Canada is from the Canadian Industry Statistics. Some countries do not have data for 2012, so I use the data for the closest year instead.

where p_{ijr} is the price of a sector r variety sold in country j from country i, w_i is the wage in country i, and τ_{ijr} is the trade cost. Substituting (23) into the optimal pricing equation and taking log gives:

$$\log p_{ijr} = \log(\frac{\sigma_r}{\sigma_r - 1}) + \log \tau_{ijr} + \log w_i + c_r^1 \tilde{s}_{jr}^{NT} \tag{28}$$

(28) can then be applied to each sector of the exporting country to estimate $\{c_{ir}^l\}, l \in \{0, n\}$.[25]

Even though in the quantitative model developed in this section, p_{ijrt} is just a constant mark-up over the marginal cost and the trade cost, variations from the demand side will also affect prices in reality. The actual regression equation is for each sector r of exporting country i is:

$$\log p_{ijrt} = \log(\frac{\sigma_r}{\sigma_r - 1}) + c_r^1 \tilde{s}_{jrt}^{NT} + \log \tau_{ijrt} + \Lambda_{jrt} + \log(X_{ijrt}) + \lambda_{irt} + \varepsilon_{ijrt}. \tag{29}$$

p_{ijrt} is defined as the total sum of trade values divided by total quantity from country i to country j in each sector r at year t. w_{it} is approximated by country i's GDP per capita. $\tilde{s}_{jrt}^{NT}$ is the coverage ratio, defined as the share of HS 6-digit products covered by TBT or SPS in each sector. The trade friction τ_{ijrt} is approximated by distance and other measures of trade costs commonly used in gravity estimations.

I run (29) separately for each of the 21 sectors to estimate c_r^1. I add an exporter-year fixed effect λ_{irt}, rather than just the wage of the origin country, to control for supply side unobservables. Since I run the regression for each sector separately, the importer-year fixed effect cannot be included.[26] Λ_{ijrt} represents the variables included to capture demand-side variations from country j that can affect p_{ijrt}. In particular, I include the GDP per capita and the average coverage ratio (excluding sector r) of country j to control for the possible heterogeneous qualities that are destination-specific. Moreover, I also add $\log(X_{ijrt})$ to control for destination-sector-specific preference shocks. To deal with the obvious endogeneity problem of $\log(X_{ijrt})$, I use the trade flow from other major sector r exporters to country j as instruments. The underlying assumption is that the preference shocks of each importer is sector-specific, but not specific to varieties from any single exporter. In addition, unobserved shocks should not be a concern if they affect demand but not prices. See a more detailed discussion in Section C.1 in the Appendix.

Since the export data is very noisy, I trim the data following the procedure in Khandelwal (2010). As some sectors record exports in multiple units, trade flows recorded with the most popular unit are kept. I then exclude all HS 6-digit trade flows with quantities of less than one unit

[25] In theory, I can allow the marginal cost function to be origin-sector specific. However, limited data availability on coverage ratio makes the estimated results less reliable. Moreover, I can allow c_{ir} to have higher orders. However, when I add a second order term of $\tilde{s}_{jr}^{NT}$, the estimated coefficients fluctuate depending on variables included in the regressions.

[26] Importer fixed effect is not included because only few countries have coverage ratio data for more than one year.

or total values less than \$ 5,000. Calibrated values of c_r^1 are not very sensitive to the threshold value between \$5,000 and \$15,000. Next, I remove extreme unit values that are below the 5th percentile or above the 95th percentile within each sector.

Fixed Cost Parameter f_r^1

Estimating the fixed cost parameter f_r^1 relies on the equilibrium condition (8). Rearranging this equation and express it in terms of f_{ir} gives: $f_{ir} = \frac{\sum_{j=1}^{M} X_{ijr}}{\sigma_r w_i n_{ir}}$. Using this equation, we can calculate f_{ir} given total exports, elasticity of substitution, average income and number of firms. The data used for the estimation consists of 34 countries. Average income is approximated by GDP per capita. All trade and GDP per capita data are 2012 values. Most countries' data of number of firms and standards are also 2012 values. For those without 2012 observations I use the available values closest to 2012 instead. For the three agricultural sectors, I have standards data for five countries. Other countries' data is assumed to impose the sectoral average.

I use a non-linear least squares approach to estimate f_r^1. Specifically, I compute f_r^1 that solves

$$\min_{f_r^1} \quad \sum_{i=1}^{M} \left(f_{ir} - \sum_{j=1}^{M} \mathbb{1}\{X_{ijr} > 0\} \exp(f_r^1 \tilde{s}_{jr}^{NT}) \right)^2.$$

The estimation is run separately for each sector. Note that for each regression, standards data does not vary across exporters due to national treatment. In addition, all variations are cross-sectional due to data constraints.

Table 1 lists the average coverage ratio, as well as the estimated c_r^1 and f_r^1 of 21 sectors. As expected, sectors related to food and agricultural products have relatively high coverage ratios. On the other hand, minerals and machinery sectors tend to have low coverage ratios. All 21 sectors have positive f_r^1, and the average $\bar{R}^2$ over 21 sectors is 0.97. However, 5 out of 21 sectors have a negative c_r^1. This is probably because sectors like "manufacture of machinery and equipment etc" and "manufacture of electronic products" are far more heterogeneous than sectors related to agriculture and raw materials. In fact, the three sectors with the highest number of products all have negative c_r^1. The negative coefficients may also indicate that product standards in these industries are more horizontal, hence regulations over these standards can reduce trade frictions. This channel is not the focus of this paper, therefore the negative coefficients will be set to zero in the quantitative analysis.

Elasticity of Substitution σ_r

I estimate the demand elasticities using the procedure first described by Feenstra (1994) and documented in Feenstra (2010). The trade value and quantity data used are from UN's Comtrade database, covering the time period 1999-2015. Instead of focusing on single importers, I use all available trade flow to a collection of importers that includes Brazil, China, India, Japan, the United States, and the EU countries. For all 21 sectors, China is used as the reference exporting country. The estimated elasticities of substitution are listed in the last column of Table 1. The estimates appear plausible, as more homogeneous products like fishing and dairy products have larger values.

Externality Weight ω_{jr}

The calibration of ω_{jr} follows the technique developed in Ossa (2014). I start from an initial guess of $\omega_{jr} = 1$ for all sectors and compute each country's predicted optimal standards under national treatment. I increase ω_{jr} if the predicted standard of sector r in country j is larger than the factual standard and decrease ω_{jr} if it is smaller. This procedure is iterated, and the size of each adjustment in ω_{jr} decreases along the iteration. The iteration continues until the optimal standards under national treatment converge to the factual standards, or the size of adjustment is less than 10^{-6}. The calibration of the weight parameter of the consumption externality relies on the assumption that the factual standards unilaterally maximize the welfare of each country given national treatment.

The calibrated values of ω_{jr} are presented in Table 2. Sectors and countries are both sorted by average ω_{jr} in descending order. We can see that developed countries all have higher average ω_{jr} than the developing countries. Also, sectors related to agriculture and food products have higher average weight. This is reasonable since these sectors are closely related to consumers' health, yet their expenditure share is relatively small.

VI.4 Unilateral Optimal Standards

I first compute the optimal standards and welfare changes when countries unilaterally abandon national treatment and do not fear retaliation. In this scenario, each country maximizes $\hat{W}_j$ subject to equilibrium conditions (25)-(27). I will refer to the computed optimal standards as unilateral standards. Table 3 summarizes the computed optimal standards. Each row represents the counterfactual equilibrium of one country abandoning national treatment. Compared to the average factual standards in the first column, the unilateral standards listed in the second column are higher for all countries. The last two columns further decompose the unilateral standards by markets. We can see that for all eight countries, the unilateral standards imposed on domestically-produced goods are lower than the average factual standards. On the other hand, the average unilateral standards on imported goods are higher than the factual average. These results are coherent with the theoretical analysis in Section III: national treatment constrains the production relocation incentive to impose high standards on imports.

Table 4 presents the welfare effects of imposing unilateral standards. The first two columns list total welfare changes of the country imposing unilateral standards and other countries separately. We can see that all countries gain at the expense of other countries. To further decompose total welfare changes, the last two columns of the table present changes in real expenditure. We can see that Brazil is the only country that experiences a decrease in real expenditure. There are no obvious patterns in both total welfare changes and changes in real expenditure. This is probably because unilateral standards in this comprehensive model are determined by numerous factors such as externality weight, factual trade patterns, and costs of production.[27]

When computing unilateral optimal standards for Table 3 and Table 4, standards affect both the marginal and fixed costs of production. I also conduct the same exercise but shut down the marginal or fixed cost channel. The welfare outcomes are summarized in Table 5. The first two columns are exactly the same as the first two columns in Table 4 and are listed for comparison purpose. The two center columns represent results with only the marginal cost channel, whereas the two furthest right shut down the fixed cost channel. From the columns under "MC Only," we can see that other countries' welfare does not hurt much when the fixed cost channel is shut down. The "beggar-thy-neighbor" nature of regulatory protection mostly comes from the effect of product standards on the fixed cost of production. Note that the welfare gains under "FC only" are much larger than those listed in the first column. This is because now countries do not worry about the higher prices in the domestic market when raising standards on imports. In other words, by shutting down the marginal cost channel, the cost of raising standards on imports decreases.

VI.5 Trade War

I now analyze the Nash equilibrium in which all countries abandon national treatment and retaliate optimally. In this scenario, the standards in the new equilibrium (which I refer to as Nash standards) are such that each government chooses the standards to maximize its welfare, given the standards of all other countries. The standards are computed using an iterative procedure. Specifically, I compute each country's optimal standards from the factual equilibrium when abandoning national treatment unilaterally. I then let each country to re-optimize until the welfare gain from the previous iteration is less than 10^{-4} for all countries.

The first two columns of Table 6 list the Nash standards for each country. Similar to the case in which national treatment is abandoned unilaterally, in the new Nash equilibrium all countries impose high standards on imports and relatively low standards on domestic products. Moreover, comparing these two columns with the last two columns of Table 3, we see that both the Nash

[27] Note that welfare changes under both columns of "Other" are the same. This is because imposing unilateral standards affects other countries' real expenditure and consumption externality proportionally.

standards on domestic products and those on imports are very close to their counterparts in the unilateral case. In other words, the best response function is very flat for all countries.

The last two columns of Table 6 list the welfare and real expenditure changes for all countries. Note that here all changes are in one equilibrium, whereas each row in the tables presenting unilateral standards represents one separate equilibrium. We can see that no country enjoys a welfare improvement in this trade war of standards. Canada has the smallest welfare loss, and is the only country with a higher real expenditure. This is consistent with the result that Canada also enjoys the largest welfare improvement in the scenario of unilateral standards. Similarly, China's welfare loss is the largest, and its gain in the unilateral scenario is also the smallest.

VI.6 Cooperative Standards

If the trade war of standards is considered to be an extreme scenario with no international cooperation at all, the other extreme would be equilibria with cooperative standards on the efficiency frontier. The factual equilibrium that follows national treatment is then between the two extremes. I adopt the Nash bargaining protocol that improves all countries' welfare symmetrically from the factual equilibrium. In other words, the cooperative standards solve $\max \hat{W}_1$ s.t. $\hat{W}_j = \hat{W}_1 \forall j$. This protocol specifies a path from the factual equilibrium to one particular point on the efficient frontier.

The first two columns of Table 7 list cooperative standards in this scenario. We can see that all countries impose relatively high standards on domestic products and low standards on imports. This is the opposite to the pattern of unilateral standards in Table 3 and Nash standards in Table 6. Also note that some countries impose very low standards on imports. Japan imposes minimum standards on all imports in all sectors. This can be interpreted as a side payment from Japan to other countries: by imposing the minimum standards, Japan increases the number of firms in other countries at the expense of a larger consumption externality.

The last two columns of Table 7 present the welfare changes and changes in real expenditure in the cooperative equilibrium. We see that the total welfare gain is substantial. In addition, all countries experience a larger percentage gain in real expenditure. In other words, an international cooperative in standards raises all countries' real expenditure at the expense of larger consumption externality.[28]

The welfare changes presented in Table 6 and Table 7 can be used to infer the progress of international cooperation in product standards. From the two tables, we see that the average welfare loss in the trade war scenario is 1.44 percent, whereas the average welfare gain form efficient

[28] I also compute cooperative standards by assuming each country's welfare gain to be proportional to its expenditure (after removing trade imbalance). In this case, China gains most with a welfare improvement of 17.71 percent. Canada gains least with a 0.68 percent welfare improvement. The average welfare gain is 4.99 percent.

negotiation is 12.59 percent. In Ossa (2014), the average loss and gain with non-cooperative and cooperative tariffs is 2.9 percent and 0.5 percent, respectively. Comparing the quantitative results in that paper with those presented in this section, we can see that factual tariffs are much closer to the efficient frontier than factual standards. This result is sensible – tariff cuts from multilateral and bilateral trade policy negotiations have made much more progress than international cooperation in product standards. This result also rationalizes why recent trade agreements have emphasized the importance of reducing regulator barriers to trade.

VII Conclusion

I develop a flexible framework to study regulatory protection and international cooperation in product standards. This framework features monopolistic competition, and countries can use product standards to reduce a negative consumption externality. Product standards also affect marginal and fixed costs of production, which can be used to gain from trade at the expense of other countries. After setting up the model, I focus on two simple cases to disentangle the channels of inefficiency from non-cooperative standards. I show that the WTO's principle of national treatment cannot lead to an efficient equilibrium when standards affect the fixed cost of production. I then use the full model to quantitatively analyze cooperative and non-cooperative standards. In the scenario of global trade war in which all countries abandon national treatment, the average welfare loss is 1.44 percent. On the other hand, when countries negotiate efficient product standards, all countries enjoy a substantial welfare improvement of 12.59 percent.

The contribution of this paper is twofold. From a theoretical perspective, I incorporate product standards in to a "new trade" model. My model incorporates the forces found in earlier papers but also identifies a novel and important channel through which standards affect welfare: the adjustment in number of varieties. In this environment, the WTO's principle of national treatment no longer leads to an efficient equilibrium when standards affect the fixed cost of production. From a quantitative perspective, this paper provides the first comprehensive analysis of non-cooperative and cooperative standards. The results indicate that international cooperation over standards is still in its early stages, which is consistent with the focus on regulatory protection observed in recent trade negotiations.

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Appendix

A Complementary Discussions of Theoretical Analysis

A.1 Derivation of Welfare Effects

Log-linearizing (5) and (7) around zero tariffs gives

$$\frac{dP_{jr}}{P_{jr}} \approx \sum_{i=1}^{M} \frac{X_{ijr}(1+t_{ijr})}{\mu_{jr}E_j}\left(\frac{1}{1-\sigma_r}\frac{dn_{ir}}{n_{ir}} + \frac{dp_{ijr}}{p_{ijr}}\right) \tag{A.1}$$

$$\frac{dE_j}{E_j} \approx \frac{w_j L_j}{E_j}\frac{dw_j}{w_j}. \tag{A.2}$$

Because $E_j = \sum_{i=1}^{M}\sum_{r=1}^{R} X_{ijr}(1+t_{ijr})$, (A.2) can be re-written as:

$$\frac{dE_j}{E_j} \approx \sum_{i=1}^{M}\sum_{r=1}^{R} \frac{X_{ijr}(1+t_{ijr})}{E_j}\frac{dw_j}{w_j}. \tag{A.3}$$

Since $P_j = \prod_{r=1}^{R}(P_{jr})^{\mu_{jr}}$, we have

$$\frac{dP_j}{P_j} \approx \sum_{r=1}^{R}\sum_{i=1}^{M} \frac{X_{ijr}(1+t_{ijr})}{E_j}\left(\frac{1}{1-\sigma_r}\frac{dn_{ir}}{n_{ir}} + \frac{dp_{ijr}}{p_{ijr}}\right). \tag{A.4}$$

From $W_j = E_j/P_j$, we have $\frac{dW_j}{W_j} \approx \frac{dE_j}{E_j} - \frac{dP_j}{P_j}$. Substituting in (A.3) and (A.4), and $\frac{dp_{ijr}}{p_{ijr}} = \frac{dw_i}{w_i} + \frac{dc_{ijr}}{c_{ijr}}$ from (4), (11) follows immediately.

A.2 Active Differentiated and Homogeneous Sectors

From (14), we can derive the equilibrium number of firms in the differentiated sector:

$$n_j = \frac{\mu}{\sigma}\left(\frac{L_j p_{ii}^{1-\sigma}}{f_j p_{ii}^{1-\sigma} - f_i(p_{ji}\tau)^{1-\sigma}} - \frac{L_i(p_{ij}\tau)^{1-\sigma}}{f_i p_{jj}^{1-\sigma} - f_j(p_{ij}\tau)^{1-\sigma}}\right). \tag{A.5}$$

A positive n_j requires

$$\frac{L_j c_{ii}^{1-\sigma}}{f_j c_{ii}^{1-\sigma} - f_i(c_{ji}\tau)^{1-\sigma}} > \frac{L_i(c_{ij}\tau)^{1-\sigma}}{f_i c_{jj}^{1-\sigma} - f_j(c_{ij}\tau)^{1-\sigma}}, \tag{A.6}$$

for all combinations of standards within the range $[0, s^{max}]$.

Active homogeneous sectors in both countries requires $l_i^y > 0$ for $i \in \{1, 2\}$. Combining the definition of ideal price index, (12) and the labor market clearing condition $L_i = l_i^x + l_i^y$ gives:

$$L_i - \sigma f_i > 0, \tag{A.7}$$

for all combinations of standards within the range $[0, s^{max}]$.

A.3 P_j Independent of L_i

The ideal price index of the differentiated sector is defined by:

$$P_j \equiv \left(n_j p_{jj}^{1-\sigma} + n_i(\tau p_{ij})^{1-\sigma}\right)^{1/(1-\sigma)}.$$

From (A.5), both n_j and n_i depend on L_j and L_i in equilibrium. However, because of the assumption that the differentiated sector is active in both countries, the free-entry condition (12) allows L_j and L_i to substitute with each other. To see this, substitute (13) into (12) and rearrange to get:

$$L_i = \frac{f_i\sigma - (p_{ij}\tau)^{1-\sigma} P_j^{\sigma-1} \mu L_j}{\mu p_{ii}^{1-\sigma} P_i^{\sigma-1}}. \tag{A.8}$$

A.4 Asymmetric cost function

In this section, I drop the symmetry assumption to allow for asymmetric cost functions in the two countries. To simplify the analysis, I focus on the linear case of marginal and fixed cost function, respectively. I show that adding asymmetry does not change the main results related to National Treatment presented in previous sections.

Intuitively, making the fixed cost function asymmetric should not change anything: as long as higher standards lead to higher fixed costs, we have $\frac{\partial P_j}{\partial s_j^{NT}} > 0$. On the other hand, when the marginal cost function is asymmetric, one would expect the country with lower marginal cost to gain through production relocation even with NT. However, in turns out that when one country's marginal cost is significantly lower than the other's, the less efficient country will fully specialize in the homogeneous good. Therefore, as long as the differentiated sector is active in both countries, neither can gain through production relocation under NT.

Let us first analyze the marginal cost case. Now the marginal cost function of the two countries are different. To simplify the analysis, I further assume that $c_1(s) = c_1 s$ and $c_2(s) = c_2 s$ in addition to other assumptions in Section III.2. Under NT, we have still have $s_j^{NT} = s_{jj} = s_{ij}$. However, since now $c_1 \neq c_2$, we do not have $p_{jj} = p_{ij}$ any more. The ideal price index in equilibrium given the combination standards is:

$$P_j = \frac{\sigma s_j^{NT}}{\sigma - 1}\left(\frac{f\sigma}{\mu L_j(1-\tau^{2(1-\sigma)})}(c_j^{\sigma-1} - (\frac{c_i}{\tau})^{\sigma-1})\right)^{\frac{1}{\sigma-1}}$$

We can see that, similar to the symmetry case, P_j does not depend on s_i^{NT} and $\frac{\partial P_j}{\partial s_j^{NT}} > 0$.[29] In other words, even when the marginal cost function is asymmetric, NT still shuts down production relocation. As a result, the Nash equilibrium under NT will be Pareto efficient.

In the fixed cost case, I instead assume that $f_1(s) = f_1 s$ and $f_2(s) = f_2 s$ in addition to in addition to other assumptions in Section III.3. Now the free-entry condition is $f_i(s_i + s_j) = \frac{p}{\sigma}(x_{ii} + \tau x_{ij})$. Substitute the demand for the differentiated products into free-entry condition to solve for the price indexes in equilibrium under NT:

$$P_j = \left(\frac{\sigma p^{\sigma-1}(s_i^{NT} + s_j^{NT})(f_j - \tau^{1-\sigma} f_i)}{\mu L_j(1-\tau^{2(1-\sigma)})}\right)^{\frac{1}{\sigma-1}}.$$

Observe that $\frac{\partial P_j}{\partial s_j^{NT}} = \frac{\partial P_j}{\partial s_i^{NT}} > 0$, which again is the same as in Section III.3.[30] In the Nash equilibrium, the negative impact of s_i^{NT} on P_j is again ignored. The Nash equilibrium under NT is Pareto inefficient, with the same reasoning presented in Section III.3.

A.5 Interaction between Standards and Tariffs

Now I introduce tariffs into the model described in Section III. Following the terminology in Ossa (2011), I let t_{ij} to represent the tariffs imposed by country j on differentiated goods imported from country i. Tariffs are assumed to be non-negative and do not generate any revenue.

The Marginal Cost Case

When standards affect marginal cost of production, the ideal price index given the combination of standards and tariffs are:

$$P_j = \left(\frac{f\sigma}{\mu L_j}\frac{p_{ii}^{1-\sigma} - ((1+t_{ji})p_{ji}\tau)^{1-\sigma}}{(p_{jj}p_{ii})^{1-\sigma} - (p_{ji}(1+t_{ji})\tau p_{ij}(1+t_{ji})\tau)^{1-\sigma}}\right)^{\frac{1}{\sigma-1}}.$$

In this case, both raising t_{ij} and s_{ij} will trigger production relocation by making foreign differentiated goods more expensive. Here standards and tariffs are perfect substitutes. In the non-cooperative Nash equilibrium, each country will impose the maximum standard and tariff on im-

[29]Positive price indexes require $c_j > c_i/\tau$, which we assume always holds.

[30]Positive price indexes require $f_j - \tau^{1-\sigma} f_i > 0$, which we assume always holds.

ported differentiated products to improve welfare. Under National Treatment, the ideal price index becomes:

$$P_j = p_j \left(\frac{f\sigma}{\mu L_j} \frac{1 - ((1+t_{ji})\tau)^{1-\sigma}}{1 - ((1+t_{ji})\tau(1+t_{ij})\tau)^{1-\sigma}} \right)^{\frac{1}{\sigma-1}}.$$

This expression is the same as the the equilibrium P_j in the two-country case in Ossa (2011). Here NT not only eradicates the trade externality arisen from standards, but also isolates the welfare effect of tariffs from that of standards.

Bagwell and Staiger (2001) construct a two-stage tariff negotiating game to model how efficient outcomes can be reached when both standards and tariffs are available. In that game, governments first use tariffs to negotiate efficient level of market access. Then the right of nonviolation complaints is needed in the second stage to secure the efficient level of market access. In the marginal cost case with NT, the efficient outcome can be reached without bringing in nonviolation complaints. The two countries can simply engage in reciprocal trade liberalization as illustrated in Ossa (2011) without worrying about the inefficiency arisen from standards.

The Fixed Cost Case

When standards affect fixed cost of production, the ideal price index given the combination of standards and tariffs in the non-cooperative case is:

$$P_j = \left(\frac{\sigma p^{\sigma-1}(f(s_{jj}) + f(s_{ji}) - (\tau(1+t_{ji}))^{1-\sigma}[f(s_{ii}) + f(s_{ij})])}{\mu L_j(1 - (\tau(1+t_{ij})\tau(1+t_{ji}))^{1-\sigma})} \right)^{\frac{1}{\sigma-1}}.$$

In this case, tariffs and standards are imperfect substitutes, even though both affect welfare through production relocation. The reason is because tariffs trigger production relocation by changing relative prices, whereas standards affect the extensive margin directly. Under NT, the ideal price index becomes:

$$P_j = \left(\frac{\sigma p^{\sigma-1}(f(s_j^{NT}) + f(s_i^{NT}))(1 - (\tau(1+t_{ji}))^{1-\sigma})}{\mu L_j(1 - (\tau(1+t_{ij})\tau(1+t_{ji}))^{1-\sigma})} \right)^{\frac{1}{\sigma-1}}$$

Similar to the marginal cost case, countries can engage in reciprocal trade liberalization to improve welfare under NT. However, reciprocal trade liberalization cannot deal with the inefficiency arisen from standards.

A.6 Externality

The analysis in Section III assume additive separability of the negative consumption externality. When this assumption is dropped, the interaction between standards on domestic and imported products will also affect Ω_j. In general, as long as Ω_j does not induce corner solutions, dropping the additive separability will not change the efficiency analysis for both the variable cost and fixed cost case. This is because this externality is local and does not depend on foreign standards. Whatever the functional form of Ω_j, country j fully internalizes the impact of standards on Ω_j.

Another possible change is to include quantity of differentiated goods consumed as an argument of Ω_j. This is reasonable when the externality is associated with environmental or health. Because I assume there is no terms-of-trade effect, total expenditure on differentiated goods is μL_j. Hence the quantity consumed only depends on the ideal price index of the differentiated goods P_j. For this reason, I can now assume that $\Omega_j \equiv \Omega_j(s_{ij}, s_{jj}, P_j(s_{jj}, s_{ij}))$, where $\frac{\partial \Omega_j}{\partial P_j} < 0$. In other words, more consumption of the differentiated goods increases the negative consumption externality. Note that now there two are channels through which the trade externality operates (one affects real expenditure whereas the other affects the negative externality), but both channels only respond to changes in P_j.

When national treatment is absent, country j's first order conditions are:

$$\frac{L_j}{P_j^2}\frac{\partial P_j}{\partial s_{ij}} + \frac{\partial \Omega_j}{\partial s_{ij}} + \frac{\partial \Omega_j}{\partial P_j}\frac{\partial P_j}{\partial s_{ij}} = 0$$
$$\frac{L_j}{P_j^2}\frac{\partial P_j}{\partial s_{jj}} + \frac{\partial \Omega_j}{\partial s_{jj}} + \frac{\partial \Omega_j}{\partial P_j}\frac{\partial P_j}{\partial s_{jj}} = 0.$$

Now s_{ij} in equilibrium is no longer s^{max}. This is because production relocation will increase consumption of the differentiated products, which increases the negative consumption externality. Country j now has less incentive to impose high standards on imported goods. The non-cooperative Nash equilibrium is still inefficient, since no country internalizes the trade externality on the other country from both trade and Ω_j.

Under national treatment, the partial derivative of country j's welfare wit respect to s_j^{NT} is:

$$\frac{\partial W_j}{\partial s_j^{NT}} = -\frac{L_j}{P_j^2}\frac{\partial P_j}{\partial s_j^{NT}} - \left(\frac{\partial \Omega_j}{\partial s_j^{NT}} + \frac{\partial \Omega_j}{\partial P_j}\frac{\partial P_j}{\partial s_j^{NT}}\right). \quad \text{(A.9)}$$

In the marginal cost case, P_j in equilibrium is still the same as in (15). Note that analogous to the result in Section III.2, $\frac{\partial P_j}{\partial s_i^{NT}} = 0$. Hence country j still chooses its optimal standard independent of country i's standard. This is because country i's standard affects Ω_j only through P_j. Under NT, both channels through which s_i^{NT} affects W_j are shut down, because $\frac{\partial P_j}{\partial s_i^{NT}} = 0$. The Nash equilibrium is Pareto efficient by the same reasoning in the proof for Proposition 1.

In the fixed cost case with national treatment, P_j in equilibrium is still the same as in (16), and the partial derivative of country j's welfare with respect to s_j^{NT} is still (A.9). But we know from (17) that $\frac{\partial P_j}{\partial s_i^{NT}} > 0$. It is not hard to follow the rationale in Proposition 2 and show that the Nash equilibrium is still Pareto inefficient. Therefore, adding quantity of consumption into the externality does not change the efficiency analysis presented in previous sections.

A.7 Alternative Functional Form of Fixed Cost

Consider an alternative case in which standards affect the fixed cost of production. Now assume $f_i = f(\max[s_{ii}, s_{ij}])$ but other assumptions in Section III.3 still hold. In other words, the fixed cost of firms in country i depends on the highest standard imposed on its differentiated goods. In equilibrium, we have

$$P_j = \left(\frac{\sigma p^{\sigma-1}(f_j - f_i \tau^{1-\sigma})}{\mu L_j (1 - \tau^{2(1-\sigma)})} \right)^{\frac{1}{\sigma-1}}.$$

Note that $\frac{\partial P_j}{\partial f_i} < 0$. Hence in the non-cooperative Nash equilibrium, country j will set $s_{ij} = s^{max}$. As a result, $f_1 = f_2 = f(s^{max})$. In addition, when f_i is pinned down by $s_{ij} = s^{max}$, raising s_{ii} will not increase P_i. Since $\frac{\partial \Omega_i}{\partial s_{ii}} < 0$, country i will also set $s_{ii} = s^{max}$. Obviously this Nash equilibrium is Pareto inefficient.

Under national treatment, fixed cost is equalized between two countries and $f_1 = f_2 = f(\max[s_1^{NT}, s_2^{NT}])$. The ideal price index in equilibrium becomes

$$P_j = \left[\frac{\sigma p^{\sigma-1}(f(\max[s_j^{NT}, s_i^{NT}]))}{\mu L_j (1 + \tau^{1-\sigma})} \right]^{\frac{1}{\sigma-1}}. \tag{A.10}$$

Now $\frac{\partial P_j}{\partial f} > 0$, so the production relocation incentive is gone. Let s_j^* be the standard imposed by country j that satisfies the first order condition $\frac{W_j}{s_j^*} = 0$. The value of s_j^* depend on both L_j and Ω_j. Without loss of generality, assume $s_1^* < s_2^*$. Let us first focus on country 1's best response. Note that whenever $s_2 \geq s_1^*$, it is optimal for country 1 to set $s_1^{NT} = s_2^{NT}$. This is because by doing so, country 1's real expenditure does not change whereas the negative consumption externality decreases. Moreover, whenever $s_2 < s_1^*$, it is optimal for country 1 to set $s_1^{NT} = s_1^*$. For the same reasoning, whenever $s_1 \geq s_2^*$, it is optimal for country 1 to set $s_2^{NT} = s_1$. Similarly, when $s_1 < s_2^*$, country 2 will still set $s_2^{NT} = s_2^*$. The two countries' best response functions can be illustrated in Figure 1.

Observe from Figure 1 that there are multiple Nash equilibria. In addition, in any equilibrium the two countries must set the same standard. This is because under national treatment, both countries' fixed cost is determined by the country with the higher standard. Therefore, the other country can always increase its standard to reduce the negative consumption externality without affecting its real expenditure. Lastly, note that any Nash equilibrium involving standards higher that s_2^* is Pareto inefficient. Reducing the standards symmetrically can improve both countries' welfare.

A.8 Algebra in Section V.2

When MR is imposed, we can denote $c_j \equiv c_{jj} = c_{ji}$ and $c_i \equiv c_{ii} = c_{ij}$. Again, since $c' > 0$ we only need to find the sign of partials with respect to c_j. Following the same procedure in the proof of Lemma 3, we have the following for equations:

$$\frac{\partial x_{ii}}{\partial c_j} + \tau \frac{\partial x_{ij}}{\partial c_j} = 0$$
$$c_j(\tau \frac{\partial x_{ji}}{\partial c_j} + \frac{\partial x_{jj}}{\partial c_j}) + \tau x_{ji} + x_{jj} = 0$$
$$\frac{\sigma x_{ii}}{\psi_j} \frac{\partial \psi_j}{\partial c_j} + \frac{\sigma x_{ii}}{c_j} + \frac{x_{ii}}{x_{ji}} \frac{\partial x_{ji}}{\partial c_j} - \frac{\partial x_{ii}}{\partial c_j} = 0$$
$$\frac{\sigma x_{ij}}{\psi_j} \frac{\partial \psi_j}{\partial c_j} + \frac{\sigma x_{ij}}{c_j} + \frac{x_{ij}}{x_{jj}} \frac{\partial x_{jj}}{\partial c_j} - \frac{\partial x_{ij}}{\partial c_j} = 0$$

The solution consists four partials in terms of parameters, endogenous variables and $\frac{\partial \psi_j}{\partial c_j}$. Next, differentiate the balance-of-trade condition gives

$$n_i c_i \frac{\partial x_{ij}}{\partial c_j} = n_j \left(c_j x_{ji} \frac{\partial \psi_j}{\partial c_j} + c_j \psi_j \frac{\partial x_{ji}}{\partial c_j} + \psi_j x_{ji} \right).$$

Substituting the solved partials into this equation, we can solve for $\frac{\partial \psi_j}{\partial c_j}$. Substituting the solved $\frac{\partial \psi_j}{\partial c_j}$ into $\{\frac{\partial x_{jj}}{\partial c_j}, \frac{\partial x_{ji}}{\partial c_j}, \frac{\partial x_{ij}}{\partial c_j}, \frac{\partial x_{ii}}{\partial c_j}\}$, and consequently into:

$$\frac{\partial U_j}{\partial c_j} = n_i x_{ij}^{-1/\sigma} U_j^{1/\sigma} \frac{\partial x_{ij}}{\partial c_j} + n_j x_{jj}^{-1/\sigma} U_j^{1/\sigma} \frac{\partial x_{jj}}{\partial c_j}$$
$$\frac{\partial U_i}{\partial c_j} = n_j x_{ji}^{-1/\sigma} U_i^{1/\sigma} \frac{\partial x_{ji}}{\partial c_j} + n_i x_{ii}^{-1/\sigma} U_i^{1/\sigma} \frac{\partial x_{ii}}{\partial c_j},$$

We have $\frac{\partial U_j}{\partial c_j} < 0$ and $\frac{\partial U_i}{\partial c_j} < 0$.

In the fixed cost case, we can let $f_j^{MR} = f_{ji} + f_{jj}$.Following the procedure in the proof of Lemma 6 in Section B.11, we can derive the following equations:

$$
\begin{aligned}
\tau\frac{\partial x_{ji}}{\partial f_j^{MR}} + \frac{\partial x_{jj}}{\partial f_j^{MR}} &= \frac{\sigma-1}{c}\\
\frac{\partial x_{ii}}{\partial f_j^{MR}} + \tau\frac{\partial x_{ij}}{\partial f_j^{MR}} &= 0\\
\frac{\sigma x_{ii}}{\psi_j}\frac{\partial \psi_j}{\partial f_j^{MR}} + \frac{x_{ii}}{x_{ji}}\frac{\partial x_{ji}}{\partial f_j^{MR}} &= \frac{\partial x_{ii}}{\partial f_j^{MR}}\\
\frac{\sigma x_{ij}}{\psi_j}\frac{\partial \psi_j}{\partial f_j^{MR}} + \frac{x_{ij}}{x_{jj}}\frac{\partial x_{jj}}{\partial f_j^{MR}} &= \frac{\partial x_{ij}}{\partial f_j^{MR}}.
\end{aligned}
$$

Differentiating the balance-of-trade condition with respect to f_j^{MR} gives:

$$
x_{ij}\frac{\partial n_i}{\partial f_j^{MR}} + n_i\frac{\partial x_{ij}}{\partial f_j^{MR}} = \psi_j x_{ji}\frac{\partial n_j}{\partial f_j^{MR}} + n_j x_{ji}\frac{\partial \psi_j}{\partial f_j^{MR}} + n_j\psi_j\frac{\partial x_{ji}}{\partial f_j^{MR}},
$$

where $\frac{\partial n_j}{\partial c_j} = -n_j/f_j$ and $\frac{\partial n_i}{\partial c_j} = 0$. Again, solving for the partials and substituting into the expressions of U_i and U_j, we have $\frac{\partial U_j}{\partial c_j} < 0$ and $\frac{\partial U_i}{\partial c_j} < 0$.

B Proofs

B.1 Proof of Lemma 1

To simplify expressions let $z_{11} = p_{11}^{1-\sigma}$, $z_{22} = p_{22}^{1-\sigma}$, $z_{21} = \tau p_{21}^{1-\sigma}$ and $z_{12} = \tau p_{12}^{1-\sigma}$. Then (14) can be expressed as:

$$
P_j = \left(\frac{f\sigma\left(z_i - z_{ji}\right)}{\mu L_j\left(z_{jj}z_{ii} - z_{ji}z_{ij}\right)}\right)^{\frac{1}{\sigma-1}}
$$

Take derivative with respect to s_{11}:

$$
\begin{aligned}
\frac{\partial P_j}{\partial s_{jj}} &= \frac{\partial P_j}{\partial z_{jj}}\frac{\partial z_{jj}}{\partial p_{jj}}\frac{\partial p_{jj}}{\partial s_{jj}}\\
&= \frac{-z_{ii}P_j}{(\sigma-1)\left(z_{jj}z_{ii} - z_{ji}z_{ij}\right)}\cdot -(\sigma-1)p_{jj}^{-\sigma}\cdot\frac{\sigma c'(s_{jj})}{\sigma-1}\\
&= \frac{\sigma z_{ii}z_{jj}^{\sigma/(\sigma-1)}}{(\sigma-1)\left(z_{jj}z_{ii} - z_{ji}z_{ij}\right)}P_1 c'(s_{jj})\\
&> 0
\end{aligned}
$$

Partially differentiate P_j with respect to s_{ij}:

$$\begin{aligned}\frac{\partial P_j}{\partial s_{ij}} =& \frac{\partial P_j}{\partial z_{ij}}\frac{\partial z_{ij}}{\partial p_{ij}}\frac{\partial p_{ij}}{\partial s_{ij}}\\ &= \frac{z_{ji}P_j}{(\sigma-1)\left(z_{jj}z_{ii}-z_{ji}z_{ij}\right)}\cdot[-(\sigma-1)\tau^{1-\sigma}p_{ij}^{-\sigma}]\cdot\frac{\sigma c'(s_{ij})}{\sigma-1}\\ &= \frac{-\sigma\tau z_{ji}z_{ij}^{\sigma/(\sigma-1)}}{(\sigma-1)\left(z_{jj}z_{ii}-z_{ji}z_{ij}\right)}P_jc'(s_{ij})\\ &< 0\end{aligned}$$

Derivative of P_j with respect to regulations in country i:

$$\begin{aligned}\frac{\partial P_j}{\partial s_{ii}} &= \frac{\partial P_j}{\partial z_{ii}}\frac{\partial z_{ii}}{\partial p_{ii}}\frac{\partial p_{ii}}{\partial s_{ii}}\\ &= \frac{z_{ji}(z_{jj}-z_{ij})P_j}{(\sigma-1)(z_{ii}-z_{ji})(z_{jj}z_{ii}-z_{ji}z_{ij})}\cdot(1-\sigma)p_{ii}^{-\sigma}\cdot\frac{\sigma}{\sigma-1}c'(s_{ii})\\ &= -\frac{\sigma z_{ji}z_{ii}^{\sigma/(\sigma-1)}(z_{jj}-z_{ij})P_j}{(\sigma-1)(z_{ii}-z_{ji})(z_{jj}z_{ii}-z_{ji}z_{ij})}c'(s_{ii})\\ &< 0\end{aligned}$$

$$\begin{aligned}\frac{\partial P_j}{\partial s_{ji}} &= \frac{\partial P_j}{\partial z_{ji}}\frac{\partial z_{ji}}{\partial p_{ji}}\frac{\partial p_{ji}}{\partial s_{ji}}\\ &= \frac{\left(z_{jj}-z_{ij}\right)z_{ii}P_j}{(\sigma-1)\left(z_{ji}-z_{ii}\right)\left(z_{jj}z_{ii}-z_{ji}z_{ij}\right)}\cdot-\tau(\sigma-1)\left(\tau p_{ji}\right)^{-\sigma}\cdot\frac{\sigma}{\sigma-1}c'(s_{ji})\\ &= \frac{\tau\sigma z_{ii}z_{ji}^{\sigma/(\sigma-1)}\left(z_{jj}-z_{ij}\right)P_j}{(\sigma-1)\left(z_{ii}-z_{ji}\right)\left(z_{jj}z_{ii}-z_{ji}z_{ij}\right)}c'(s_{ji})\\ &> 0\end{aligned}$$

B.2 Proof of Proposition 1

The following lemma is useful for other parts of the proof.

Lemma 7 *Consider the marginal cost case in which Assumption 2 is followed. Then when two government choose standards simultaneously to maximize welfare, in the unique Nash equilibrium* s^{max} *is always imposed on imported differentiated goods.*

Proof. From Lemma 1, we have $\frac{\partial W_j}{\partial s_{ij}} > 0$ for all possible combinations of standards. Hence

$s_{ij} = s_{ji} = s^{max}$ follows immediately. Uniqueness of the Nash equilibrium is due to the convexity of Ω_j and the fact that $\frac{\partial}{\partial s_{jj}}(\frac{L_j}{P_j}) < 0$ for all possible combinations of standards, which also follows immediately from Lemma 1. ■

A combination of regulations $(s_{11}, s_{12}, s_{21}, s_{22})$ is not Pareto efficient if there exists regulation changes such that $dW_1 > 0$ and $dW_2 = 0$. Total differentiation of the non-cooperative Nash equilibrium gives:

$$dW_1 = \frac{\partial W_1}{\partial s_{11}}ds_{11} + \frac{\partial W_1}{\partial s_{21}}ds_{21} + \frac{\partial W_1}{\partial s_{12}}ds_{12} + \frac{\partial W_1}{\partial s_{22}}ds_{22} \tag{B.1}$$

$$dW_2 = \frac{\partial W_2}{\partial s_{11}}ds_{11} + \frac{\partial W_2}{\partial s_{21}}ds_{21} + \frac{\partial W_2}{\partial s_{12}}ds_{12} + \frac{\partial W_2}{\partial s_{22}}ds_{22} \tag{B.2}$$

Consider the regulation changes $ds_{22} > 0$ and $ds_{11} = ds_{12} = ds_{21} = 0$. In the non-cooperative Nash equilibrium, $\frac{\partial W_2}{\partial s_{22}} = 0$. Hence from (B.2), we have $dW_2 = 0$. However, from Lemma 1, we know $\frac{\partial P_1}{\partial s_{22}} < 0$, which implies $\frac{\partial W_1}{\partial s_{22}} > 0$. Substituting this result into (B.1), we have $dW_1 > 0$. We have found a combination of regulation changes that is Pareto-improving.

To prove the equilibrium with national treatment is unique and Pareto efficient, first differentiate (15) to have:

$$\begin{aligned}\frac{\partial P_j}{\partial s_j^{NT}} &= \frac{\sigma}{\sigma-1}\left(\frac{f\sigma}{\mu L_j(1+\tau^{1-\sigma})}\right)^{\frac{1}{\sigma-1}} c'(s_j^{NT}) \\ &> 0\end{aligned}$$

And the second-order derivative is:

$$\begin{aligned}\frac{\partial^2 P_j}{\partial (s_j^{NT})^2} &= \frac{\sigma}{\sigma-1}\left(\frac{f\sigma}{\mu L_j(1+\tau^{1-\sigma})}\right)^{\frac{1}{\sigma-1}} c''(s_j^{NT}) \\ &> 0\end{aligned}$$

Given the assumptions on Ω_j and the fact that $\frac{\partial}{\partial s_j^{NT}}(\frac{L_j}{P_j}) < 0$ for all $s_j^{NT} \in [0, s^{max}]$, the optimal s_j^{NT} under NT is unique for both countries. We also know that optimal s_j^{NT} and hence W_j in the unique Nash equilibrium are independent of s_i^{NT}. Therefore, Pareto improvement in the Nash equilibrium is impossible, because country j cannot increase W_j with any combinations of (ds_1^{NT}, ds_2^{NT}).

B.3 Proof of Lemma 2

Partially differentiated P_j, we get:

$$\frac{\partial P_j}{\partial s_{jj}} = \frac{P_j f'(s_{jj})}{(\sigma-1)(f(s_{jj}) + f(s_{ji}) - \tau^{1-\sigma}[f(s_{ii}) + f(s_{ij})])} > 0$$
$$\frac{\partial P_j}{\partial s_{ji}} = \frac{P_j f'(s_{ji})}{(\sigma-1)(f(s_{jj}) + f(s_{ji}) - \tau^{1-\sigma}[f(s_{ii}) + f(s_{ij})])} > 0$$
$$\frac{\partial P_j}{\partial s_{ij}} = \frac{-\tau^{1-\sigma} P_j f'(s_{ij})}{(\sigma-1)(f(s_{jj}) + f(s_{ji}) - \tau^{1-\sigma}[f(s_{ii}) + f(s_{ij})])} < 0$$
$$\frac{\partial P_j}{\partial s_{ii}} = \frac{-\tau^{1-\sigma} P_j f'(s_{ii})}{(\sigma-1)(f(s_{jj}) + f(s_{ji}) - \tau^{1-\sigma}[f(s_{ii}) + f(s_{ij})])} < 0$$

B.4 Proof of Proposition 2

Since the signs of the partials in Lemma 2 are identical as those in Lemma 1, we can use the exact same steps in the proof of Proposition 1 to show that the non-cooperative equilibrium is Pareto inefficient.

To show that the Nash equilibrium with national treatment is also Pareto inefficient, I need to find standard changes (ds_1^{NT}, ds_2^{NT}) such that $dW_2 = 0$ and $dW_1 > 0$. Totally differentiate dW_j gives:

$$dW_j = -\frac{L_j}{P_j^2}\frac{\partial P_j}{\partial s_j^{NT}} ds_j^{NT} - \frac{L_j}{P_j^2}\frac{\partial P_j}{\partial s_i^{NT}} ds_i^{NT} - \Omega_j'(s_j^{NT}) ds_j^{NT} \tag{B.3}$$

In equilibrium, (s_1^{NT}, s_2^{NT}) satisfy the following first order conditions:

$$-\frac{L_j}{P_j^2}\frac{\partial P_j}{\partial s_j^{NT}} - \Omega_j'(s_j^{NT}) = 0 \tag{B.4}$$

Consider standard changes $ds_1^{NT} = 0$ and $ds_2^{NT} < 0$. From (B.3) and (B.4), we have $dW_2 = 0$. On the other hand, because $-\frac{L_1}{P_1^2}\frac{\partial P_1}{\partial s_2^{NT}} < 0$, we have $dW_1 > 0$. Therefore, the standard combination in the Nash equilibrium is Pareto inefficient.

B.5 Proof of Proposition 6

The following lemma is helpful in proving the proposition:

Lemma 8 *Suppose that both countries follow NT and $\Omega_1 = \Omega_2 = 0$. Then in both the marginal cost case described in Section III.2 and the fixed cost case described in Section III.3, the Pareto efficient set of standards must consist of both $s_1^{NT} = 0$ and $s_2^{NT} = 0$.*

Proof. I need to show that, Pareto-improving standard changes are only possible for any set of standards that are not both zero. Without loss of generality, consider the standard combination $s_1^{NT} \geq 0$ and $s_2^{NT} > 0$. Totally differentiate dW_j gives:

$$dW_j = -\frac{L_j}{P_j^2}\frac{\partial P_j}{\partial s_j^{NT}}ds_j^{NT} - \frac{L_j}{P_j^2}\frac{\partial P_j}{\partial s_i^{NT}}ds_i^{NT}. \tag{B.5}$$

Consider standard changes $ds_1^{NT} = 0$ and $ds_2^{NT} < 0$. In the marginal cost case, from (15), we have $\frac{\partial P_j}{\partial s_i^{NT}} = 0$ and $\frac{\partial P_j}{\partial s_j^{NT}} > 0$. Substituting $\{ds_1^{NT}, ds_2^{NT}\}$ into (B.5), we have $dW_1 = 0$ and $dW_2 > 0$. In the fixed cost case, from (17), we have $\frac{\partial P_j}{\partial s_i^{NT}} > 0$ and $\frac{\partial P_j}{\partial s_j^{NT}} > 0$. In this case, substituting $\{ds_1^{NT}, ds_2^{NT}\}$ into (B.5) gives $dW_1 > 0$ and $dW_2 > 0$. Therefore, whenever either one or both standards are positive under national treatment, Pareto-improving standard changes are possible and the standard combination is not Pareto efficient.

When $s_1^{NT} = 0$ and $s_2^{NT} = 0$, any decrease in standards are not possible. From (B.5), any standard changes that increase W_j must involve a decrease in at least one standard. Therefore, the standard combination $s_1^{NT} = 0$ and $s_2^{NT} = 0$ is Pareto efficient. ■

I first need to show that with national treatment, any standard combinations $\{s_1^{NT}, s_2^{NT}\}$ with one or two non-zero standards cannot be a Nash equilibrium. Without loss of generality, consider the standard combination $s_1^{NT} \geq 0$ and $s_2^{NT} > 0$. When standards affect marginal cost of production, we have $\frac{\partial P_2}{\partial s_2^{NT}} > 0$ from (15). When standards affect the fixed cost of production, we also have $\frac{\partial P_2}{\partial s_2^{NT}} > 0$ from (17). Hence, country 2 can improve its welfare by imposing a lower s_2^{NT}, and the standard combination cannot be a Nash equilibrium.

Next, I need to show that with national treatment, the standard combination $s_1^{NT} = 0$ and $s_2^{NT} = 0$ is a Nash equilibrium. From (15) and (17), we know that $\frac{\partial P_j}{\partial s_j^{NT}} > 0$ in both the marginal cost case and the fixed cost case. Because $\Omega_j = 0$, neither country will raise the standard, regardless of whether standards affect the marginal or fixed cost. Therefore, the tariff combination $s_1^{NT} = 0$ and $s_2^{NT} = 0$ is the only Nash equilibrium. From Lemma (8), this combination is Pareto efficient.

B.6 Proof of Proposition 7

I will prove the results in the marginal cost case under Assumption 2 first. In this case, when standards are set non-cooperatively, total differentiation of W_1 and W_2 gives:

$$dW_1 = \frac{\partial W_1}{\partial s_{11}}ds_{11} + \frac{\partial W_1}{\partial s_{21}}ds_{21} + \frac{\partial W_1}{\partial s_{12}}ds_{12} + \frac{\partial W_1}{\partial s_{22}}ds_{22} \tag{B.6}$$

$$dW_2 = \frac{\partial W_2}{\partial s_{11}}ds_{11} + \frac{\partial W_2}{\partial s_{21}}ds_{21} + \frac{\partial W_2}{\partial s_{12}}ds_{12} + \frac{\partial W_2}{\partial s_{22}}ds_{22} \tag{B.7}$$

When $\Omega_1 = \Omega_2 = 0$, $W_1 = U_1$ and $W_2 = U_2$. Since we have $\frac{\partial U_j}{\partial c_{ij}} < 0$ and $\frac{\partial U_j}{\partial c_{jj}} < 0$ from Lemma 3, neither country will impose standards above the minimum level in the Nash equilibrium. Hence only positive changes on standards are possible from the Nash equilibrium. From Lemma 3, the only possible combination that could be welfare-improving is $ds_{22} > 0$, $ds_{11} > 0$, and $ds_{12} = ds_{21} = 0$. Any combination of changes in that form and does not change dW_2 requires:

$$\frac{ds_{11}}{ds_{22}} = \frac{n_2 x_{22}\left(\tau\sigma c_{12}x_{12} + (2\sigma - 1)c_{11}x_{11}\right)}{\tau(\sigma - 1)c_{12}n_1 x_{12}x_{11}} \frac{w_2}{w_1}$$

substituting this ratio into (B.12) gives:

$$dW_1 = -\frac{(2\sigma - 1)n_2 x_{22} x_{21}^{-1/\sigma}\left(\tau c_{12}x_{12} + c_{11}x_{11}\right)}{\tau^2(\sigma - 1)c_{21}c_{12}x_{12}} U_1^{1/\sigma} ds_{22} < 0$$

In addition, combining this result and Lemma 3, any standard changes such that $dW_2 > 0$ will also lead to $dW_1 < 0$. Any Pareto improvement is impossible, thus the Nash equilibrium is Pareto efficient.

When $\Omega_1 = \Omega_2 = 0$ and national treatment is imposed, neither country imposes above-minimum standard in the Nash equilibrium because $\frac{\partial U_j}{\partial s_j^{NT}} < 0$. From Lemma 4, the only possible combination that can lead to a Pareto improvement is $ds_1^{NT} > 0, ds_2^{NT} > 0$, or equivalently $ds_{11} = ds_{21} > 0, ds_{22} = ds_{12} > 0$. However, I have shown that in the non-cooperative case, the combination $ds_{22} > 0$, $ds_{11} > 0$, and $ds_{12} = ds_{21} = 0$ can never lead to a Pareto improvement. Since $\frac{\partial U_j}{\partial c_{ij}} < 0$ and $\frac{\partial U_i}{\partial c_{ij}} < 0$ from Lemma 3, the combination $ds_{11} = ds_{21} > 0, ds_{22} = ds_{12} > 0$ can never lead to a Pareto improvement. Hence the Nash equilibrium is Pareto efficient.

Now I prove the results in the fixed cost case under Assumption 3. When standards are set non-cooperatively, (B.12) and (B.13) still hold. When $\Omega_1 = \Omega_2 = 0$, $W_1 = U_1$ and $W_2 = U_2$. Since we have $\frac{\partial U_j}{\partial c_{ij}} < 0$ and $\frac{\partial U_j}{\partial c_{jj}} < 0$ from Lemma 5, neither country will impose standards above the minimum level in the Nash equilibrium. Hence only positive changes on standards are possible from the Nash equilibrium. However, Lemma 5 also tells us that no positive change in standards will not increase any country's welfare. Therefore, Pareto improvements from the Nash equilibrium is impossible.

When national treatment is imposed, neither country will impose standards above the minimum level in the Nash equilibrium just like the non-cooperative case. However, Lemma 6 tells us that positive changes in standards do no increase any country's welfare. Hence, Pareto improvements from the Nash equilibrium is impossible.

B.7 Proof of Lemma 3

In the marginal cost case $c' > 0$. Hence we only need to find the sign of partials with respect to c_{ij} and c_{jj}. The two production functions are:

$$l_i = f_i + c_{ii}x_{ii} + \tau c_{ij}x_{ij}$$
$$l_j = f_j + c_{jj}x_{jj} + \tau c_{ji}x_{ji}.$$

Differentiate the two production functions with respect to c_{ij} to get:

$$\tau c_{ji}\frac{\partial x_{ji}}{\partial c_{ij}} + c_{jj}\frac{\partial x_{jj}}{\partial c_{ij}} = 0 \tag{B.8}$$

$$c_{ii}\frac{\partial x_{ii}}{\partial c_{ij}} + \tau c_{ij}\frac{\partial x_{ij}}{\partial c_{ij}} + \tau x_{ij} = 0. \tag{B.9}$$

The two market clearing conditions are:

$$x_{ii} = \frac{p_{ii}^{-\sigma}}{P_i^{1-\sigma}}w_i L_i$$
$$x_{ji} = \frac{(\tau p_{ji})^{-\sigma}}{P_i^{1-\sigma}}w_i L_i.$$

Divide the market clearing conditions of x_{ii} and x_{ji}, and then differentiate with respect with respect to c_{ij} to get:

$$\frac{\sigma x_{ii}}{\psi_j}\frac{\partial \psi_j}{\partial c_{ij}} + \frac{x_{ii}}{x_{ji}}\frac{\partial x_{ji}}{\partial c_{ij}} - \frac{\partial x_{ii}}{\partial c_{ij}} = 0. \tag{B.10}$$

Do the same thing for the other two market clearing conditions to get:

$$-\frac{\sigma x_{ij}}{c_{ij}} + \frac{\sigma x_{ij}}{\psi_j}\frac{\partial \psi_j}{\partial c_{ij}} + \frac{x_{ij}}{x_{jj}}\frac{\partial x_{jj}}{\partial c_{ij}} - \frac{\partial x_{ij}}{\partial c_{ij}} = 0. \tag{B.11}$$

Equations (B.8)-(B.11) is a system of four equations with four unknown partials $(\frac{\partial x_{ij}}{\partial c_{ij}}, \frac{\partial x_{jj}}{\partial c_{ij}}, \frac{\partial x_{ji}}{\partial c_{ij}}, \frac{\partial x_{ii}}{\partial c_{ij}})$. The solution consists of four partials in terms of $\frac{\partial \psi_j}{\partial c_{ij}}$ and other endogenous variables in equilibrium. Differentiating the balance-of-trade condition (19) with respect to c_{ij} gives:

$$n_i\left(c_{ij}\frac{\partial x_{ij}}{\partial c_{ij}} + x_{ij}\right) - c_{ji}n_j\left(\frac{\partial \psi_j}{\partial c_{ij}}x_{ji} + \frac{\partial x_{ji}}{\partial c_{ij}}\psi_j\right) = 0.$$

Substituting the solved partials into this equation and further solving for $\frac{\partial \psi_j}{\partial c_{ij}}$, we have $\frac{\partial \psi_j}{\partial c_{ij}} > 0$.

Substituting the solved $\frac{\partial \psi_j}{\partial c_{ij}}$ back to the solution to (B.8)-(B.11) gives the four partials with respect to c_{ij}. Apply the same procedure with respect to c_{jj}, we have $\frac{\partial \psi_j}{\partial c_{jj}} < 0$ and four c_{jj} partials. Dividing the two partials gives:

$$\frac{\partial \psi_j / \partial c_{ij}}{\partial \psi_j / \partial c_{jj}} = -\frac{c_{jj}}{c_{ij}}.$$

Differentiating p_j^T with respect to c_{ij} gives

$$\frac{\partial p_j^T}{\partial c_{ij}} = \frac{c_{ji}}{c_{ij}}\Big(\frac{\partial \psi_j}{\partial c_{ij}} - \frac{w_j}{w_i}\frac{1}{c_{ij}}\Big),$$

which is negative after substituting in the solved $\frac{\partial \psi_j}{\partial c_{ij}}$. On the other hand, differentiating p_j^T with respect to c_{jj} gives

$$\frac{\partial p_j^T}{\partial c_{jj}} = \frac{c_{ji}}{c_{ij}}\frac{\partial \psi_j}{\partial c_{jj}},$$

which is also negative since $\frac{\partial \psi_j}{\partial c_{jj}} < 0$.

Lastly, differentiating U_j with respect to c_{ij} and c_{jj} respectively to get:

$$\begin{aligned}
\frac{\partial U_j}{\partial c_{ij}} &= n_i x_{ij}^{-1/\sigma} U_j^{1/\sigma} \frac{\partial x_{ij}}{\partial c_{ij}} + n_j x_{jj}^{-1/\sigma} U_j^{1/\sigma} \frac{\partial x_{jj}}{\partial c_{ij}} \\
\frac{\partial U_j}{\partial c_{jj}} &= n_i x_{ij}^{-1/\sigma} U_j^{1/\sigma} \frac{\partial x_{ij}}{\partial c_{jj}} + n_j x_{jj}^{-1/\sigma} U_j^{1/\sigma} \frac{\partial x_{jj}}{\partial c_{jj}} \\
\frac{\partial U_i}{\partial c_{ij}} &= n_i x_{ii}^{-1/\sigma} U_i^{1/\sigma} \frac{\partial x_{ii}}{\partial c_{ij}} + n_j x_{ji}^{-1/\sigma} U_i^{1/\sigma} \frac{\partial x_{ji}}{\partial c_{ij}} \\
\frac{\partial U_i}{\partial c_{jj}} &= n_i x_{ii}^{-1/\sigma} U_i^{1/\sigma} \frac{\partial x_{ii}}{\partial c_{jj}} + n_j x_{ji}^{-1/\sigma} U_i^{1/\sigma} \frac{\partial x_{ji}}{\partial c_{jj}}.
\end{aligned}$$

Substituting the solved partials into these two expressions, we have $\frac{\partial U_j}{\partial c_{ij}} < 0$, $\frac{\partial U_j}{\partial c_{jj}} < 0$, $\frac{\partial U_i}{\partial c_{ij}} < 0$, $\frac{\partial U_i}{\partial c_{jj}} > 0$.

B.8 Proof of Lemma 4

When NT is imposed, we can denote $c_j \equiv c_{ij} = c_{jj}$ and $c_i \equiv c_{ii} = c_{ji}$. Again, since $c' > 0$ we only need to find the sign of partials with respect to c_j. Following the same procedure in the proof of Lemma 3, we have the following for equations:

$$\begin{aligned} c_i \frac{\partial x_{ii}}{\partial c_j} + \tau c_j \frac{\partial x_{ij}}{\partial c_j} + \tau x_{ij} &= 0 \\ \tau c_i \frac{\partial x_{ji}}{\partial c_j} + c_j \frac{\partial x_{jj}}{\partial c_j} &= 0 \\ \sigma x_{ii} x_{ji} \frac{\partial \psi_j}{\partial c_j} + x_{ii} \psi_j \frac{\partial x_{ji}}{\partial c_j} - \psi_j x_{ji} \frac{\partial x_{ii}}{\partial c_j} &= 0 \\ \sigma x_{ij} x_{jj} \frac{\partial \psi_j}{\partial c_j} + x_{ij} \psi_j \frac{\partial x_{jj}}{\partial c_j} - \psi_j x_{jj} \frac{\partial x_{ij}}{\partial c_j} &= 0. \end{aligned}$$

The solution consists four partials in terms of parameters, endogenous variables and $\frac{\partial \psi_j}{\partial c_j}$. Next, differentiate the balance-of-trade condition gives

$$n_i \left(c_j \frac{\partial x_{ij}}{\partial c_j} + x_{ij} \right) = n_j \left(c_i x_{ji} \frac{\partial \psi_j}{\partial c_j} + c_i \psi_j \frac{\partial x_{ji}}{\partial c_j} \right).$$

Substituting the solved partials into this equation and solving for $\frac{\partial \psi_j}{\partial c_j}$, we have $\frac{\partial \psi_j}{\partial c_j} < 0$. Moreover, when NT is followed, the terms of trade p_j^T can be expressed as

$$\frac{p_{ji}}{p_{ij}} = \frac{w_j}{w_i} \frac{c_i}{c_j}.$$

Because $\frac{\partial \psi_j}{\partial c_j} < 0$, we also have $\frac{\partial p_j^T}{\partial c_j} < 0$. Lastly, differentiating U_i and U_j with respect to c_j gives

$$\begin{aligned} \frac{\partial U_j}{\partial c_j} &= n_i x_{ij}^{-1/\sigma} U_j^{1/\sigma} \frac{\partial x_{ij}}{\partial c_j} + n_j x_{jj}^{-1/\sigma} U_j^{1/\sigma} \frac{\partial x_{jj}}{\partial c_j} \\ \frac{\partial U_i}{\partial c_j} &= n_j x_{ji}^{-1/\sigma} U_i^{1/\sigma} \frac{\partial x_{ji}}{\partial c_j} + n_i x_{ii}^{-1/\sigma} U_i^{1/\sigma} \frac{\partial x_{ii}}{\partial c_j}. \end{aligned}$$

We can substitute the solved $\frac{\partial \psi_j}{\partial c_j}$ back into the solution of four partials and then further further substitute into these two equations. The results show that $\frac{\partial U_j}{\partial c_j} < 0$ and $\frac{\partial U_i}{\partial c_j} > 0$.

B.9 Proof of Proposition 3

When standards are set non-cooperatively, total differentiation of W_1 and W_2 gives:

$$dW_1 = \frac{\partial W_1}{\partial s_{11}}ds_{11} + \frac{\partial W_1}{\partial s_{21}}ds_{21} + \frac{\partial W_1}{\partial s_{12}}ds_{12} + \frac{\partial W_1}{\partial s_{22}}ds_{22} \tag{B.12}$$

$$dW_2 = \frac{\partial W_2}{\partial s_{11}}ds_{11} + \frac{\partial W_2}{\partial s_{21}}ds_{21} + \frac{\partial W_2}{\partial s_{12}}ds_{12} + \frac{\partial W_2}{\partial s_{22}}ds_{22} \tag{B.13}$$

If the consumption externality follows Assumption 1, country j chooses standards to satisfy $\frac{\partial W_j}{\partial s_{ij}} = 0$ and $\frac{\partial W_j}{\partial s_{jj}} = 0$ in equilibrium. Consider the regulation changes $ds_{22} > 0$ and $ds_{11} = ds_{12} = ds_{21} = 0$. From Lemma 3, we know $\frac{\partial U_1}{\partial c_{22}} > 0$ and hence $\frac{\partial W_1}{\partial s_{22}} > 0$. Substituting these values into (B.12), we have $dW_1 > 0$. On the other hand, since $\frac{\partial W_2}{\partial s_{22}} = 0$ in the Nash equilibrium, we have $dW_2 = 0$ from (B.13). We have found a combination of regulation changes that is Pareto-improving.

When the consumption externality follows Assumption 1 and NT is imposed, we have $c_{ij} = c_{jj}$. From Lemma 4, we have $\frac{\partial U_j}{\partial s_j^{NT}} < 0$ and $\frac{\partial U_i}{\partial s_j^{NT}} > 0$. In the Nash equilibrium, both countries will impose standards such that the $\frac{\partial W_j}{\partial s_j^{NT}} = 0$. A combination of changes $ds_1^{NT} < 0, ds_2^{NT} < 0$ will increase both W_1 and W_2, constituting a Pareto improvement. Hence the Nash equilibrium under NT is also Pareto inefficient.

B.10 Proof of Lemma 5

Since $f' > 0$ we only need to find the sign of partials with respect to f_{ij}. Since the marginal cost of production is fixed at c, we can rewrite the free-entry conditions as:

$$x_{ii} + \tau x_{ij} = \frac{(\sigma - 1)\left(f_{ii} + f_{ij}\right)}{c}$$

$$\tau x_{ji} + x_{jj} = \frac{(\sigma - 1)\left(f_{ji} + f_{jj}\right)}{c}.$$

Differentiating these two equations with respect to f_{ij} gives

$$\tau\frac{\partial x_{ji}}{\partial f_{ij}} + \frac{\partial x_{jj}}{\partial f_{ij}} = 0$$

$$\frac{\partial x_{ii}}{\partial f_{ij}} + \tau\frac{\partial x_{ij}}{\partial f_{ij}} = \frac{\sigma - 1}{c}.$$

Dividing the market-clearing conditions and take partial with respect to f_{ij} gives:

$$\frac{\sigma x_{ii}}{\psi_j}\frac{\partial\psi_j}{\partial f_{ij}} + \frac{x_{ii}}{x_{ji}}\frac{\partial x_{ji}}{\partial f_{ij}} = \frac{\partial x_{ii}}{\partial f_{ij}}$$
$$\frac{\sigma x_{ij}}{\psi_j}\frac{\partial\psi_j}{\partial f_{ij}} + \frac{x_{ij}}{x_{jj}}\frac{\partial x_{jj}}{\partial f_{ij}} = \frac{\partial x_{ij}}{\partial f_{ij}}$$

The solution to this system of four equations are four partials in terms of $\frac{\partial\psi_j}{\partial f_{ij}}$ and other variables. Differentiating the balance-of-trade condition with respect to f_{ij} gives:

$$x_{ij}\frac{\partial n_i}{\partial f_{ij}} + n_i\frac{\partial x_{ij}}{\partial f_{ij}} = \psi_j x_{ji}\frac{\partial n_j}{\partial f_{ij}} + n_j x_{ji}\frac{\partial\psi_j}{\partial f_{ij}} + n_j\psi_j\frac{\partial x_{ji}}{\partial f_{ij}}. \tag{B.14}$$

From (20), we have $\frac{\partial n_i}{\partial f_{ij}} = \frac{-n_i}{f_{ii}+f_{ij}}$ and $\frac{\partial n_j}{\partial f_{ij}} = 0$. We can substitute these two results and the four solved partials in to (B.14) and solve for $\frac{\partial\psi_j}{\partial f_{ij}}$ in terms of parameters and variables in the equilibrium only. The result shows that $\frac{\partial\psi_j}{\partial f_{ij}} > 0$, hence $\frac{\partial p_j^T}{\partial f_{ij}} > 0$. Substituting the solved $\frac{\partial\psi_j}{\partial f_{ij}}$ into the four partials and then into

$$\frac{\partial U_j}{\partial f_{ij}} = \frac{\partial U_j}{\partial n_j}\frac{\partial n_j}{\partial f_{ij}} + \frac{\partial U_j}{\partial n_i}\frac{\partial n_i}{\partial f_{ij}} + \frac{\partial U_j}{\partial x_{ij}}\frac{\partial x_{ij}}{\partial f_{ij}} + \frac{\partial U_j}{\partial x_{jj}}\frac{\partial x_{jj}}{\partial f_{ij}}$$
$$\frac{\partial U_i}{\partial f_{ij}} = \frac{\partial U_i}{\partial n_j}\frac{\partial n_j}{\partial f_{ij}} + \frac{\partial U_i}{\partial n_i}\frac{\partial n_i}{\partial f_{ij}} + \frac{\partial U_i}{\partial x_{ii}}\frac{\partial x_{ii}}{\partial f_{ij}} + \frac{\partial U_i}{\partial x_{ji}}\frac{\partial x_{ji}}{\partial f_{ij}},$$

We have $\frac{\partial U_j}{\partial f_{ij}} < 0$ and $\frac{\partial U_i}{\partial f_{ij}} < 0$. Repeat the same procedure for f_{jj}, we have $\frac{\partial p_j^T}{\partial f_{jj}} < 0$, $\frac{\partial U_j}{\partial f_{jj}} < 0$ and $\frac{\partial U_i}{\partial f_{jj}} < 0$.

B.11 Proof of Lemma 6

The system of equations of the four partials ($\frac{\partial x_{ij}}{\partial s_j^{NT}}, \frac{\partial x_{jj}}{\partial s_j^{NT}}, \frac{\partial x_{ji}}{\partial s_j^{NT}}, \frac{\partial x_{ii}}{\partial s_j^{NT}}$) is very similar to the one in the proof of Lemma 5:

$$\tau \frac{\partial x_{ji}}{\partial f_j^{NT}} + \frac{\partial x_{jj}}{\partial f_j^{NT}} = \frac{\sigma - 1}{c}$$
$$\frac{\partial x_{ii}}{\partial f_j^{NT}} + \tau \frac{\partial x_{ij}}{\partial f_j^{NT}} = \frac{\sigma - 1}{c}$$
$$\frac{\sigma x_{ii}}{\psi_j} \frac{\partial \psi_j}{\partial f_j^{NT}} + \frac{x_{ii}}{x_{ji}} \frac{\partial x_{ji}}{\partial f_j^{NT}} = \frac{\partial x_{ii}}{\partial f_j^{NT}}$$
$$\frac{\sigma x_{ij}}{\psi_j} \frac{\partial \psi_j}{\partial f_j^{NT}} + \frac{x_{ij}}{x_{jj}} \frac{\partial x_{jj}}{\partial f_j^{NT}} = \frac{\partial x_{ij}}{\partial f_j^{NT}}.$$

Differentiating the balance-of-trade condition with respect to f_j^{NT} gives:

$$x_{ij} \frac{\partial n_i}{\partial f_j^{NT}} + n_i \frac{\partial x_{ij}}{\partial f_j^{NT}} = \psi_j x_{ji} \frac{\partial n_j}{\partial f_j^{NT}} + n_j x_{ji} \frac{\partial \psi_j}{\partial f_j^{NT}} + n_j \psi_j \frac{\partial x_{ji}}{\partial f_j^{NT}}, \tag{B.15}$$

which has the same format as (B.14). In addition, differentiating (20) gives $\frac{\partial n_i}{\partial f_j^{NT}} = \frac{-n_i}{f_i^{NT} + f_j^{NT}}$ and $\frac{\partial n_j}{\partial f_j^{NT}} = \frac{-n_j}{f_i^{NT} + f_j^{NT}}$. Following the same procedure in the proof of Lemma 5, we have $\frac{\partial \psi_j}{\partial f_j^{NT}} = 0$.

From Lemma 5, we know $\frac{\partial U_j}{\partial f_{ij}} < 0$ and $\frac{\partial U_j}{\partial f_{jj}} < 0$. These two results hold in any equilibrium including those in which NT is followed. Hence, any combination of marginal changes $ds_{ij} = ds_{jj} > 0$ decreases U_j, implying $\frac{\partial U_j}{\partial f_j^{NT}} < 0$. For the same reasoning, $\frac{\partial U_i}{\partial f_{ij}} < 0$ and $\frac{\partial U_i}{\partial f_{jj}} < 0$ from Lemma 5 imply that $\frac{\partial U_i}{\partial f_j^{NT}} < 0$.

B.12 Proof of Proposition 4

When standards are set non-cooperatively, (B.12) and (B.13) still hold. If the consumption externality follows Assumption 1, country j chooses standards to satisfy $\frac{\partial W_j}{\partial s_{ij}} = 0$ and $\frac{\partial W_j}{\partial s_{jj}} = 0$ in equilibrium. Consider the regulation changes $ds_{22} < 0$ and $ds_{11} = ds_{12} = ds_{21} = 0$. From Lemma 5, we know $\frac{\partial U_1}{\partial c_{22}} > 0$ and hence $\frac{\partial W_1}{\partial s_{22}} > 0$. Substituting these values into (B.12), we have $dW_1 > 0$. On the other hand, since $\frac{\partial W_2}{\partial s_{22}} = 0$ in the Nash equilibrium, we have $dW_2 = 0$ from (B.13). We have found a combination of regulation changes that is Pareto-improving.

When NT is imposed, we have $\frac{\partial U_j}{\partial f_j^{NT}} < 0$ and $\frac{\partial U_i}{\partial f_j^{NT}} < 0$ from Lemma 6. If the consumption externality follows Assumption 1, country j chooses standards to satisfy $\frac{\partial W_j}{\partial s_j^{NT}} = 0$ in the Nash equilibrium. For the same reason in the non-cooperative case, a combination of changes $ds_1^{NT} = 0, ds_2^{NT} < 0$ will increase W_1 while keeping W_2 unchanged, constituting a Pareto improvement.

B.13 Proof of Proposition 5

Regardless of whether standards affect marginal or fixed cost, next exports of differentiated goods from country j is calculated by:

$$X_j = n_j(p_j x_{jj} + \tau p_i x_{ji}) - \mu L_j$$

When standards affect marginal costs of production and both countries follow NT, we can describe the equilibrium given the combination of standards in terms of the number of firms:

$$n_j = \frac{\mu(L_j - \tau^{1-\sigma} L_i)}{f\sigma(1-\tau^{1-\sigma})}.$$

And $p_j x_{jj} + \tau p_i x_{ji} = f\sigma$ from the free-entry condition. This gives:

$$X_j = \frac{\tau^{1-\sigma}\mu(L_j - L_i)}{1-\tau^{1-\sigma}}.$$

In the fixed cost case under NT, the total number of of firms producing differentiated products are:

$$n_j = \frac{\mu(L_j - \tau^{1-\sigma} L_i)}{\sigma(1-\tau^{1-\sigma})(f(s_j^{NT}) + f(s_i^{NT}))}.$$

And the the value of country j's net exports in differentiated goods is:

$$\begin{aligned} X_j &= n_j\sigma(f(s_j^{NT}) + f(s_i^{NT})) - \mu L_j \\ &= \frac{\tau^{1-\sigma}\mu(L_j - L_i)}{1-\tau^{1-\sigma}}. \end{aligned}$$

In both case, the net export of the differentiated goods under NT is independent of standards.

C Quantitative Exercise

C.1 Unobserved Quality/Preference Shocks

One conventional way of modeling preference shocks is to add a shift parameter in the utility function. For example, we can rewrite (1) as

$$U_j = \prod_{r=1}^{R} \Big[\sum_{i=1}^{M} \int_0^{n_{ir}} z_{ijr} x_{ijr}(\nu_{ir})^{\frac{\sigma_r - 1}{\sigma_r}} d\nu_{ir} \Big]^{\frac{\sigma_r}{\sigma_r - 1}\mu_{jr}}.$$

Comparing to (1), the only change is the preference parameter z_{ijr}. Demand for x_{ijr} now becomes

$$x_{ijr} = \frac{(p_{ijr}\tau_{ijr}(1 + t_{ijr}))^{-\sigma_r}}{P_{jr}^{1-\sigma_r}} z_{ijr}^{\sigma_r} \mu_{jr} E_j.$$

However, firms still maximize profit by charging a constant mark-up over marginal cost. Hence, (29) should still be valid even without including any control for z_{ijr}. On the other hand, the preference shocks do affect the estimation of the demand elasticities. The Feenstra (1994) method already take the preference shocks into consideration. The key identification assumption is that for each sector, the demand and supply shocks are independent of each other.

Figure 1: BEST RESPONSE FUNCTIONS

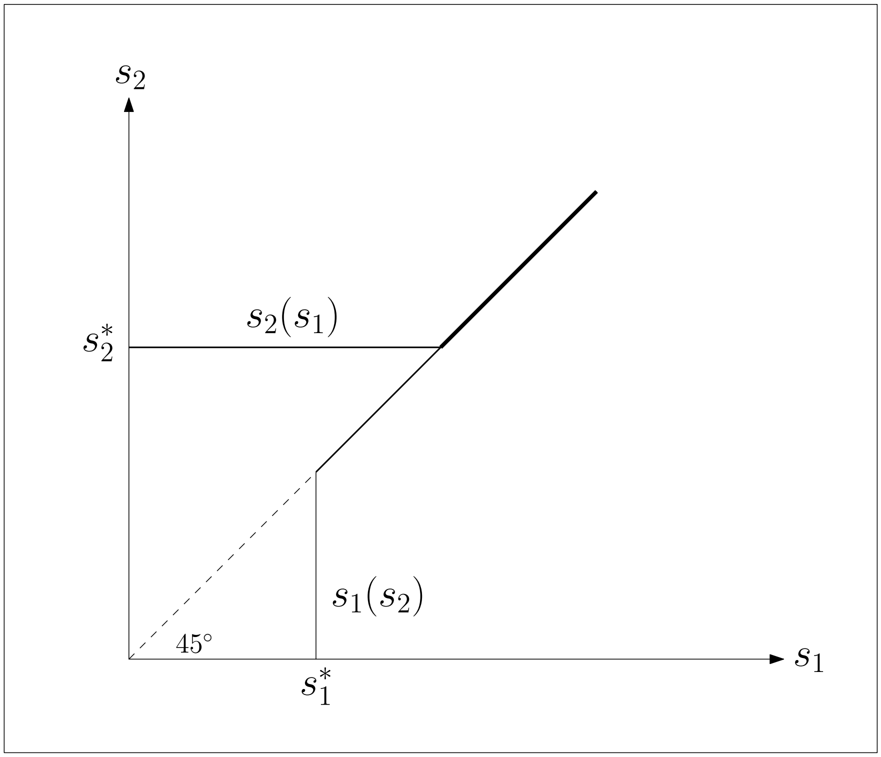

Table 1: Parameters by Sectors

	Coverage Ratio	c_r^1	f_r^1	σ_r
Crop and animal production, hunting etc	0.92	1	1.83	2.75
Forestry and logging	0.75	0.85	1.83	2.39
Fishing and aquaculture	0.96	0.06	1.55	3.99
Mining and quarrying	0.56	0.23	0.54	3.01
Manufacture of food products, etc	0.96	0.08	0.11	2.33
Manufacture of textiles, wearing apparel etc	0.6	-0.33	0.11	2.73
Manufacture of wood and of products of wood	0.76	0	0.16	2.56
Manufacture of paper and paper products	0.72	0.07	0.23	2.56
Printing and reproduction of recorded media	0.43	0.03	0.21	3.38
Manufacture of coke and refined petroleum products	0.9	0.21	0.34	3.65
Manufacture of chemicals and chemical products	0.78	-0.43	0.19	2.27
Manufacture of rubber and plastic products	0.84	0.03	0.12	2.77
Manufacture of other non-metallic mineral products	0.7	0.55	0.15	2.34
Manufacture of basic metals	0.79	0.7	0.23	3.1
Manufacture of fabricated metal products	0.67	0.2	0.07	2.54
Manufacture of electronic products	0.22	-2.02	0.25	2.08
Manufacture of electrical equipment	0.93	0.08	0.14	2.72
Manufacture of machinery and equipment etc.	0.96	-0.07	0.13	2.57
Manufacture of motor vehicles	0.91	0.29	0.19	2.73
Manufacture of other transport equipment	0.75	-0.74	0.16	2.95
Manufacture of furniture; other manufacturing	0.62	0.48	0.07	3.33
Mean	0.75	0.23	0.41	2.80

Table 2: Calibrated Externality Weight ω_{jr}

	Canada	USA	Japan	EU	RoW	India	Brazil	China
Crop and animal production, hunting etc	1.1	1.11	1.06	1.1	1.07	1.06	1.05	1.02
Forestry and logging	1.04	1	1	1	0.95	0.94	0.96	0.86
Manufacture of motor vehicles	1.1	1	1	1	0.29	1	1	1
Manufacture of food products, etc	1.1	1	1	1	1	1	1	0.09
Manufacture of basic metals	1.1	1	1	1	1	0.66	0.66	0.64
Fishing and aquaculture	1.1	1	1	1	1	1	0.11	0.11
Manufacture of other non-metallic mineral products	1.1	1	1	1	0.53	0.52	0.52	0.51
Manufacture of rubber and plastic products	1.1	1	1	1	1	1	0.04	0.03
Manufacture of machinery and equipment etc.	1.1	1	1	1	1	0.01	1	0.01
Manufacture of coke and refined petroleum products	1.1	1	1	1	1	0.21	0.21	0.2
Manufacture of fabricated metal products	1.1	1	1	1	0.19	0.19	0.19	0.19
Manufacture of other transport equipment	1.1	1	1	1	0.02	0.02	0.02	0.01
Manufacture of furniture; other manufacturing	0.46	0.48	0.47	0.48	0.47	0.46	0.45	0.44
Mining and quarrying	0.26	0.26	0.26	0.26	0.25	0.25	0.25	0.25
Manufacture of electrical equipment	0.13	0.09	0.09	0.09	0.08	0.08	0.09	0.07
Manufacture of paper and paper products	0.13	0.09	0.09	0.09	0	0.08	0.08	0.07
Printing and reproduction of recorded media	0.07	0.04	0.04	0.05	0	0.03	0.04	0.04
Manufacture of electronic products	0.05	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Manufacture of wood and of products of wood	0.09	0.02	0.02	0.02	0.02	0.02	0.01	0.02
Manufacture of textiles, wearing apparel etc	0.07	0.01	0.02	0.01	0.02	0.01	0	0.01
Manufacture of chemicals and chemical products	0.03	0.02	0.02	0.01	0.02	0.02	0.02	0.01
Mean	0.69	0.63	0.62	0.62	0.47	0.41	0.37	0.27

Table 3: Unilateral Standards: Domestic versus Foreign

	Factual Standard	Optimal Standard		
	Mean	Mean	Own	Other
Brazil	0.64	0.77	0.5	0.81
Canada	0.86	0.94	0.78	0.96
China	0.53	0.78	0.46	0.83
India	0.78	0.91	0.49	0.97
Japan	0.86	0.9	0.74	0.93
USA	0.86	0.91	0.66	0.95
EU	0.86	0.93	0.66	0.97
RoW	0.59	0.78	0.55	0.81
Mean	0.75	0.87	0.6	0.9

Notes: Columns under "Mean" are the average of all standards imposed by the country. Columns under "Own" are averages of each country's standards on itself. Columns under "Other" are averages of standards imposed on imports.

Table 4: Unilateral Standards: Welfare Changes

	ΔW_j		$\Delta(E_j/P_j)$	
	Own	Other	Own	Other
Brazil	1.19	-0.52	-0.24	-0.52
Canada	2.19	-0.34	3.32	-0.34
China	0.54	-0.55	1.17	-0.55
India	1.4	-0.55	4.49	-0.55
Japan	1	-0.2	0.74	-0.2
USA	1.56	-0.29	0.14	-0.29
EU	1.58	-0.41	1.02	-0.41
RoW	1.25	-0.49	0.32	-0.49
Mean	1.34	-0.42	1.37	-0.42

Notes: All entries are percentage changes from the factual equilibrium. Columns under "Own" are each country's own change when setting the standards unilaterally. Columns under "Other" are the average of other countries' changes.

Table 5: Unilateral Standards: Marginal Cost versus Fixed Cost

	Both		MC Only		FC Only	
	Own	Other	Own	Other	Own	Other
Brazil	1.19	-0.52	1.53	0	8.69	-0.57
Canada	2.19	-0.34	2.13	-0.01	4	-0.34
China	0.54	-0.55	0.91	-0.11	9.49	-0.61
India	1.4	-0.55	1.38	-0.03	4.24	-0.5
Japan	1	-0.2	1.35	0	4.8	-0.28
USA	1.56	-0.29	1.74	0	2.85	-0.35
EU	1.58	-0.41	1.65	-0.02	3.24	-0.37
RoW	1.25	-0.49	1.53	-0.02	5.95	-0.59
Mean	1.34	-0.42	1.53	-0.02	5.41	-0.45

Notes: All entries are percentage changes from the factual equilibrium. Columns under "Own" are each country's own welfare change when setting the standards unilaterally. Columns under "Other" are the average of other countries' welfare changes.

Table 6: Nash Standards

	Optimal Standard		% Welfare Change	
	Own	Other	ΔW_j	$\Delta(E_j/P_j)$
Brazil	0.52	0.79	-1.09	-2.56
Canada	0.79	0.96	-0.28	0.22
China	0.51	0.82	-2.54	-1.86
India	0.5	0.97	-1.15	1.92
Japan	0.75	0.91	-2.05	-2.9
USA	0.68	0.95	-0.92	-2.57
EU	0.67	0.97	-1.48	-2.65
RoW	0.56	0.8	-2	-3.24
Mean	0.62	0.9	-1.44	-1.71

Notes: Columns under "Own" are averages of each country's standards on itself. Columns under "Other" are averages of standards imposed on other countries' goods. Entries under ΔW_j and $\Delta(E_j/P_j)$ are percentage changes relative to the factual equilibrium.

Table 7: Cooperative Standards

	Optimal Standard		% Welfare Change	
	Own	Other	ΔW_j	$\Delta(E_j/P_j)$
Brazil	0.67	0.03	12.59	21.64
Canada	0.77	0.31	12.59	20.86
China	0.44	0.04	12.59	13.91
India	0.51	0.19	12.59	24.27
Japan	0.91	0	12.59	28.37
USA	0.61	0.38	12.59	17.08
EU	0.64	0.46	12.59	17.8
RoW	0.59	0.22	12.59	20.53
Mean	0.64	0.2	12.59	20.56

Notes: Columns under "Own" are averages of each country's standards on itself. Columns under "Other" are averages of standards imposed on other countries' goods. Entries under ΔW_j and $\Delta(E_j/P_j)$ are percentage changes relative to the factual equilibrium.