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REGULATORY PROTECTION AND THE ROLE OF INTERNATIONAL COOPERATION*

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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 consumption externality, but also increases the marginal and fixed costs of production. When product standards are set noncooperatively, the effects of standards on other countries' wages and number of firms are not internalized, giving rise to an international inefficiency. The World Trade Organization's nondiscrimination principle of national treatment only partly addresses this inefficiency. Welfare losses from abandoning national treatment average 2.8%, whereas the maximum welfare gains from efficient cooperation average 11.8%.

1. INTRODUCTION

Despite the ongoing trade war between the United States and China, the focus of modern trade negotiations has shifted toward 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 et al., 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 in the context of international trade.

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) filed a complaint about Brazil's regulation on retreaded tires. This type of remanufactured 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 Brazilians by reducing the negative health externality, but it also created trade frictions. At the same time, tire exporters outside of Brazil faced a higher marginal cost of production and higher fixed cost of production due to production line upgrading. Some companies in the EU "were unable to find new export markets and went into liquidation" (European Commission, 2004).

In this article, I analyze regulatory protection and the role of international cooperation from both theoretical and quantitative perspectives. Specifically, I introduce product

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

standards into a Krugman (1980)-style "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 noncooperatively, 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 flows for a quantitative analysis of the welfare effects of cooperative and noncooperative standards.

One novel analytical result of this article is that the partial equilibrium effect of product standards on the fixed cost of production renders the noncooperative Nash equilibrium inefficient, but 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 noncooperative equilibrium inefficient. The first effect does so through changes in relative wages, or *terms of trade*. This channel allows governments to raise standards on imports to improve relative wages at the expense of other countries. 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. Since the welfare effects of domestic policies through the terms-of-trade effect have been studied extensively in neoclassical trade models (Bagwell and Staiger, 2001; Ederington, 2001), the theoretical analysis in this article focuses on the production relocation effect of product standards when no other policy instrument is available. Both effects are incorporated into the quantitative exercise when I compute the welfare outcomes of cooperative and noncooperative standards.

I use this framework to evaluate current international cooperation to reduce regulatory barriers from both theoretical and quantitative perspectives. Even though product standards are generally considered to be domestic policies, they have been disciplined by the nondiscrimination 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 be treated equally, at least after the foreign goods have entered the market. I first theoretically analyze the role of national treatment in a simplified two-country, two-sector model with product standards as the only available policy instrument. I find that national treatment addresses the inefficiency from production relocation that incentivizes 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.

I then utilize the full model to conduct a comprehensive quantitative analysis of cooperative and noncooperative product standards using only publicly available data. In this article, 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 et al., 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. In order to reduce the number of parameters that need to be estimated, I use the "exact hat algebra" technique popularized by Dekle et al. (2007), and express the equilibrium conditions in changes relative to data. The elasticity estimation follows the Feenstra (1994) method, which has been heavily used in economic research on international trade and spatial economics. 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 wages, total sales, 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. Finally, I calibrate the weight of the consumption externality in welfare 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 are 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 salient to policy. 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 2.8%. In the second scenario, all countries engage in efficient negotiations to maximize their welfare symmetrically. The computed cooperative standards improve all countries' welfare by 7.5% if national treatment is still followed and by 11.8% without national treatment. Even in the "harmonization" scenario in which all countries agree to impose one uniform standard on each sector, the prospective welfare improvement is still 1.4%. Ossa (2014) provides a first quantitative analysis of noncooperative and cooperative tariffs. He finds that the average welfare loss from a trade war of tariffs is 2.9% and the average welfare gain from cooperative tariffs is 0.5%. Comparing the quantitative results in this article with those of Ossa (2014) indicates that international cooperation on standards is still far from complete. The observed product standards are far more distant from the efficient frontier compared to tariffs, which rationalizes the increasing focus on regulatory protection in recent trade negotiations.

This article complements previous research on regulatory protection that either focuses on partial equilibrium effects (Baldwin, 2000; Fischer and Serra, 2000; Staiger and Sykes, 2011, 2020) or uses neoclassical trade models that include only the terms-of-trade effect (Bagwell and Staiger, 2001; Ederington, 2001; Maggi and Ossa, 2023).[2] My model incorporates the forces found in earlier papers, but identifies a novel and important channel through which standards affect welfare: the adjustment in the number of varieties. This channel has been emphasized in numerous works on the welfare effects of trade liberalization (see, e.g., Feenstra, 1994; Broda and Weinstein, 2006; Caliendo and Parro, 2015; and Hsieh et al., 2020), 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.[3] 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 noncooperative tariffs and GATT/WTO negotiations. In this article, I show that both the terms-of-trade effect and the production relocation effect also exist when standards affect the fixed cost of production in a general equilibrium framework. Existing studies on international cooperation to reduce regulatory protection focus mostly on the marginal cost channel and emphasize the partial equilibrium effect: National treatment makes raising standards on imports costlier, thereby reducing the distortion created by regulatory protection (Horn, 2006; Costinot, 2008; Gulati and Roy, 2008; Staiger and Sykes, 2011).

My analysis also provides new insight into the "shallow integration" approach of the multilateral trade policy negotiations led by the WTO. "Shallow" trade agreements generally focus

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

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

on tariff commitments and principles of nondiscrimination (WTO, 2011). Bagwell and Staiger (2001) use a neoclassical trade model to illustrate the rationale of "shallow integration": Domestic policies, such as product standards, are substitutes for tariffs and can lead to inefficient outcomes when tariffs are constrained by WTO rules. However, such inefficiency will disappear if each country makes a credible commitment to market access in a "shallow" trade agreement. Contemporaneously, Grossman et al. (2021) also theoretically analyze the welfare consequences of "shallow" and "deep" trade agreements in a Krugman (1980)-style model. In their paper, however, fixed costs rise with the distance between the versions of products that firms offer in the two markets.[4] At the same time, Rebeyrol (2023) assumes a fixed number of firms in a Melitz (2003)-style model and analyzes the profit-shifting effect of product standards. Despite the quite different settings, Grossman et al. (2021), Rebeyrol (2023), and this article all find that "shallow" agreements such as national treatment cannot lead to an efficient equilibrium.[5] In comparison, the model I develop is flexible enough to comprehensively quantify the welfare effects of cooperative and noncooperative product standards.

Since the influential work of Ossa (2014), a number of studies have analyzed the welfare effects of cooperative and noncooperative trade policies through numerical optimization (Mei, 2020; Bagwell et al., 2021; Beshkar et al., 2022; de Souza et al., 2022). Several recent works have also advanced this strand of literature by providing analytical characterization of optimal trade and industrial policy (Beshkar and Lashkaripour, 2020; Bartelme et al., 2021; Lashkaripour, 2021; Lashkaripour and Lugovskyy, 2023). My article is distinct from existing works by being the first to quantify the importance of product standards within a general equilibrium framework, thereby providing a reference point for how much countries could potentially gain through further regulatory cooperation.

The rest of the article is structured as follows: I start by constructing a two-country, two-sector, Krugman (1980)-style model in Section 2. The freely traded homogeneous sector shuts down the terms-of-trade effect, so that I can focus on the role of the production relocation channel. The next section is devoted to analyzing the welfare outcomes in the noncooperative Nash equilibrium and the equilibrium constrained by national treatment. In Section 4, I extend the model to a richer multicountry, multisector environment that incorporates both production relocation and terms-of-trade effects. After presenting data and calibrations in Section 5, the counterfactual exercises on trade war and efficient trade negotiations are discussed in Section 6. The last section concludes.

2. THEORETICAL FRAMEWORK

In this section, I develop a trade model that features monopolistic competition and increasing returns, as in Krugman (1980). The model consists of two countries and two sectors. I assume that one sector produces a homogeneous good with no trade cost. Introducing the freely traded homogeneous sector equalizes wages, thereby eliminating the terms-of-trade effect emphasized in Bagwell and Staiger (2001). Raising product standards reduces a negative externality associated with consumption, but also increases the marginal and fixed costs of production. I first describe the model and then characterize the competitive equilibrium for any given set of standards.

2.1. *Setup.* Throughout this section, I assume that the economy consists of two countries indexed by $i, j \in \{1, 2\}$. In addition, there are only two sectors: One is heterogeneous with

[4] This assumption in Grossman et al. (2021) allows for the possibility that regulating horizontal product standards can reduce the costs of production and increase trade through both the intensive and extensive margins, which has been empirically analyzed in Schmidt and Steingress (2022). This scenario is interesting in its own right and has been studied in partial equilibrium models (Baldwin, 2000; Costinot, 2008); however, it will not be the focus of this article.

[5] Rebeyrol (2023) and this article both abstract from other policy instruments and focus on product standards only. In Grossman et al. (2021), however, noncooperative standards (regardless of whether national treatment is followed) are inefficient even when tariffs, trade subsidies, and consumption taxes are set at efficient levels.

elasticity of substitution $\sigma > 1$, and the other is homogeneous. I use W_j to denote the welfare of households in country j, which is defined as

$$W_j = U_j - \Omega_j,$$

where

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

is the utility derived from consumption. ν_i indexes the variety produced in the heterogeneous sector of country i, x_{ij} is the quantity of the heterogeneous good manufactured in country i and consumed in country j, n_i is the mass of heterogeneous varieties produced in country i, μ is the Cobb–Douglas share of country j's expenditure on heterogeneous varieties, and Y_j is the quantity of the homogeneous good consumed in country j.

Product standards are usually assumed to generate positive welfare effects in order to justify their implementation despite the additional costs involved. In this article, standards are motivated by the existence of an externality not internalized by consumers. This negative externality stemming from the consumption of heterogeneous goods is represented by Ω_j, the second component of welfare.[6] In the theoretical analysis, I focus on the case in which higher standards improve the welfare of consumers by reducing the consumption externality. In addition to the *Brazil-Retreaded Tires* case, many disputes in the WTO have also involved standards related to environmental or health externalities. Examples include WT/DS58 and DS61 (U.S. 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 U.S. prohibition on imports of tuna from countries not certified as fishing in a dolphin-safe manner (Staiger and Sykes, 2011). In this context, the consumption externality Ω_j captures the disutility of U.S. consumers who care about the well-being of dolphins.[7]

In addition, I assume that Ω_j is a function of product standards imposed on goods sold to country j. In other words, let s_{ij} denote the standard requirement on heterogeneous varieties from country i sold in country j. Ω_j therefore is a function of $\{s_{ij}\}_{i,j\in\{1,2\}}$. This assumption implies that, for example, raising the standard on country j's car emissions reduces the environmental externality in country j, but not in other countries. Following the setup in existing works on nontariff barriers, I abstract from the possibility that the consumption externality is a function of other countries' standards. Allowing for the possibility of global consumption externalities would create another channel of international inefficiency, whereas the purpose of this article is to explore how regulatory barriers influence welfare through international trade.[8]

Labor is the only factor of production and the labor market is perfectly competitive. Workers are freely mobile between sectors within each country. Each consumption variety is produced by a single firm. Firms producing heterogeneous goods in country i follow the inverse

[6] A popular alternative approach is to incorporate political economy motives, as in Maggi and Ossa (2023) and Rebeyrol (2023). As shown later, this approach is less suitable, since I assume free entry in the model, which leads to zero profit for firms producing heterogeneous goods.

[7] Staiger and Sykes (2020) have a similar formulation and refer to it as a negative "eye sore" externality, even though they focus on the negative externalities related to services.

[8] This article and Grossman et al. (2021) both assume that consumption externalities only affect domestic consumers and abstract from global consumption externalities. As argued in Grossman et al. (2021), "…consumers in a country might also care about the types of goods that are purchased abroad. Since such nonpecuniary externalities introduce an obvious need for international cooperation, we restrict our attention here to externalities that are local in scope."

production function:

$$l_i = f_i + \sum_{j=1}^{2} \tau c_{ij} x_{ij},$$

where l_i is the labor requirement of a heterogeneous firm in country i, $f_i = f(s_{ii}, s_{ij})$ is the fixed cost of country i's firms producing heterogeneous goods, $c_{ij} = c(s_{ij})$ is the marginal cost of heterogeneous goods sold in country j, and $\tau > 1$ is the corresponding iceberg trade barrier. 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 homogeneous good is freely traded between the two countries. Note that the cost functions f and c are identical across countries; therefore, no country has a technological advantage.[9]

Product standards can affect both the marginal and the fixed costs of production. If s_{ij} affects the marginal cost of production only, then f_i is constant and c_{ij} is a function of s_{ij}. At the same time, if standards affect the fixed cost of production only, then c_{ij} is a constant and f_i is a function of $\{s_{ij}\}_{j\in\{1,2\},x_{ij}>0}$. Note that product standards in this setup do not directly affect the utility from consumption and hence should not be thought of as qualities. This assumption greatly simplifies the analysis, as there is no need for firms to solve for optimal quality of the product.[10] The demand for heterogeneous goods, therefore, is influenced by standards only indirectly through prices. In this way, heterogeneous goods from each firm in country i selling to country j satisfy s_{ij} exactly, but not any higher standard.

Households maximize their utilities subject to the budget constraint given prices. Solving for the households' utility maximization gives the demand for heterogeneous varieties produced in country i:

$$x_{ij} = \frac{(p_{ij}\tau)^{-\sigma}}{P_j^{1-\sigma}} \mu E_j,$$

where $P_j = [n_i(p_{ij}\tau)^{1-\sigma} + n_j p_{jj}^{1-\sigma}]^{\frac{1}{1-\sigma}}$ is the ideal price index and E_j is the nominal expenditure in country j. I let p_{ij} be the ex-factory price of the varieties from country i sold in country j. Therefore, the corresponding price faced by consumers in country j is τp_{ij}. Given the demand for heterogeneous varieties, each firm from the heterogeneous sector in country i maximizes its profits by charging a constant markup over marginal costs, so $p_{ij} = \frac{\sigma c_{ij} w_i}{\sigma - 1}$.

2.2. *Equilibrium for Given Product Standards.* It is well known that in Krugman (1980)-style environments, trade policy such as tariffs and standards can generate production relocation effects and terms-of-trade effects. As discussed in Ossa (2011), the relative strength of the two effects is determined by the elasticity of labor supply in the heterogeneous sector. In the simple model developed in this section, one sector is assumed to be homogeneous and freely traded. The labor supply curve in the heterogeneous sector is perfectly elastic as a result, thereby shutting down the terms-of-trade effect. In addition, I assume that the heterogeneous sector and the homogeneous sector are active in both countries to eliminate uninteresting corner solutions. I choose the price of the freely traded homogeneous good as the numeraire; wages in both countries are therefore equal to 1.

Throughout the theoretical analysis in this article, I assume that the standards set by the governments within an interval $s \in [0, s^{max}]$ are the only policy instruments available. The

[9] This assumption of symmetry simplifies the algebra involved in the theoretical analysis, but is not crucial to the main results. In Subsection A.1 of the Online Appendix, I show that when marginal and fixed cost functions are asymmetric but linear in standards, the welfare analysis presented in this section still holds.

[10] An alternative approach is to assume that standards affect the quality of products and to analyze policy interactions in an environment similar to the one in Fajgelbaum et al. (2011). In this case, additional structures of asymmetric information are needed to rationalize the need to regulate product standards. Linking regulatory protection to quality is an interesting area for future research (see Macedoni and Weinberger, 2022, for example), but this article will just focus on a more straightforward approach.

equilibrium given product standards is characterized by the free-entry condition

$$f_i = \frac{p_{ii}x_{ii} + \tau p_{ij}x_{ij}}{\sigma} \tag{1}$$

and the market-clearing conditions of heterogeneous goods

$$\begin{aligned} p_{ii}x_{ii} &= \left(\frac{p_{ii}}{P_i}\right)^{1-\sigma} \mu L_i, \\ p_{ij}x_{ij} &= \left(\frac{p_{ij}}{P_j}\right)^{1-\sigma} \tau^{-\sigma} \mu L_j. \end{aligned} \tag{2}$$

Given the set of standards $\{s_{11}, s_{12}, s_{21}, s_{22}\}$, the equilibrium number of firms in the heterogeneous sector is[11]:

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

Alternatively, equilibrium price indices can be solved uniquely by substituting (2) into the free-entry condition (1):

$$P_j = \left(\frac{\sigma}{\mu L_j}\frac{f_j p_{ii}^{1-\sigma} - f_i (p_{ji}\tau)^{1-\sigma}}{(p_{jj}p_{ii})^{1-\sigma} - (p_{ji}p_{ij}\tau^2)^{1-\sigma}}\right)^{\frac{1}{\sigma-1}}. \tag{3}$$

Since wages are fixed by the freely traded numeraire good, U_j depends only on P_j, which is determined by (3) in equilibrium. Before discussing how governments set their welfare-maximizing standards, I formally introduce the following assumptions about 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 heterogeneous goods consumed in country j. This is consistent with the interpretation that Ω_j captures the negative externality from consumption. 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. Moreover, higher product standards always reduce the negative externality and hence should not be considered the type of "red-tape barriers" studied in Maggi et al. (2022). Overall, Assumption 1 is broadly consistent with the role of standards in many GATT/WTO disputes. For example, in the Tuna–Dolphin case, the purse seine nets used by Mexican fishermen to harvest tuna also trap dolphins. The harm inflicted on dolphins creates a negative externality for U.S. consumers, even though the quality of imported tuna is not affected. Adopting fishing techniques that satisfy the dolphin protection standards set by U.S. regulators may raise the marginal or fixed cost of tuna production and simultaneously reduce the consumption externality of U.S. consumers.

[11] A positive n_j requires $\frac{L_j c_{ii}^{1-\sigma}}{f_j c_{ii}^{1-\sigma} - f_i (c_{ji}\tau)^{1-\sigma}} > \frac{L_i (c_{ij}\tau)^{1-\sigma}}{f_i c_{jj}^{1-\sigma} - f_j (c_{ij}\tau)^{1-\sigma}}$ for all combinations of standards within the range $[0, s^{max}]$. In addition, active homogeneous sectors in both countries require $l_i^y > 0$ for $i \in \{1, 2\}$. Combining the definition of ideal price index, Equation (1), and the labor market clearing condition $L_i = l_i^x + l_i^y$ gives $L_i - \sigma f_i > 0$ for all combinations of standards within the range $[0, s^{max}]$.

3. STANDARDS AND PRODUCTION RELOCATION EFFECT

In this section, I analyze the welfare effects of cooperative and noncooperative product standards using the model developed in Section 2. 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 scenarios, I analyze the welfare outcomes in the noncooperative Nash equilibrium and also the Nash equilibrium in which national treatment is imposed. I show that in the noncooperative equilibrium, both countries impose high, discriminatory standards on foreign products, and this equilibrium is always Pareto inefficient. When national treatment is imposed and discrimination against foreign imports is no longer possible, however, the Nash equilibrium becomes efficient only in the marginal cost case. In the fixed cost case, the international inefficiency persists because the partial equilibrium effect on the foreign country's extensive margin is not internalized by national treatment.

3.1. *Standards Affect Marginal Costs Only.* In the remainder of this article, I will refer to the case in which fixed cost f_j does not depend on standards as the marginal cost case. The additional assumptions in this case 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. $c'(s) > 0$ *and* $c''(s) > 0$.

Given these assumptions, (3) 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 large trade cost τ, such that $c(s_{jj}) < \tau c(s_{ij})$ for all s_{jj} and s_{ij} in the range $[0, s^{max}]$. I will assume that this condition is satisfied in the marginal cost case.

In the marginal cost case of the two-sector model, raising s_{ij} generates two welfare effects. The first is the partial equilibrium effect: A higher s_{ij} increases p_{ij}, thereby raising the domestic price index P_j. In addition, the higher p_{ij} also leads to 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 heterogeneous sector and exit from the foreign heterogeneous sector. Note that when the fixed cost is constant, the change in prices as a result of higher standards leads to a relocation of heterogeneous firms from country i to country j. However, the total number of heterogeneous firms in the two countries $(n_1 + n_2)$ remains unchanged.[12] Such production relocation reduces P_j due to the existence of trade cost τ. At the same time, raising s_{jj} will also trigger production relocation, but in the opposite direction, which increases P_j.

Taking partial derivatives of P_j with respect to the standards gives us the following lemma[13]:

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* $\frac{\partial P_j}{\partial s_{ij}} < 0$.

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

[12] To see this, first calculate the total expenditure on heterogeneous goods: $\mu(L_1 + L_2) = n_1(p_{11}x_{11} + \tau p_{12}x_{12}) + n_2(p_{22}x_{22} + \tau p_{21}x_{21})$. Substituting (1) into this equation gives $n_1 + n_2 = \frac{\mu(L_1+L_2)}{f\sigma}$.

[13] Details of the algebra can be found in Subsection A.2 of the Online Appendix.

see this, consider an increase of s_{ij} that raises p_{ij}. Now, country j firms increase sales and earn positive profit. In order to restore equilibrium, there has to be entry in country j that 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 profits, because the exit triggered in country i raises P_i.

3.1.1. *No cooperation.* In the noncooperative Nash equilibrium, country j's government solves the following optimization problem:

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

subject to the equilibrium condition described by (3). When country j sets s_{jj}, it faces a trade-off between the real expenditure and the negative consumption externality. On the one hand, we know from Lemma 1 that a higher s_{jj} reduces real expenditure by raising P_j. On the other hand, a higher s_{jj} also reduces the negative consumption externality. The optimal s_{jj} is pinned down by the first-order condition $\frac{\partial W_j}{\partial s_{jj}} = 0$. 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 standard s_{max} on heterogeneous goods imported from country i.

When country j increases s_{ij} to improve its welfare, production relocation also drives up P_i. This effect does not enter country j's objective function when country j chooses its standards in the noncooperative equilibrium, thereby creating an international inefficiency. Note 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. At the same time, since $\frac{\partial P_i}{\partial s_{jj}} < 0$ from Lemma 1, W_i will increase as a result. The marginal increase in s_{jj} constitutes a Pareto improvement from the Nash equilibrium. Therefore, the Nash equilibrium in which standards are set noncooperatively is Pareto inefficient.

3.1.2. *National treatment.* I compare the noncooperative Nash equilibrium with the outcome under national treatment. Throughout this article, national treatment is interpreted as a rule that requires the same standard to be imposed on all heterogeneous goods sold in the same market, regardless of their origin. In other words, the government of country j now faces an additional constraint $s_{jj} = s_{ij}$ when choosing the optimal standards. I use s_j^{NT} to represent the standard imposed on the heterogeneous goods consumed in country j under national treatment. In this case, (3) can be rewritten as:

$$P_j = \tfrac{\sigma}{\sigma-1}\left(\tfrac{f\sigma}{\mu L_j(1+\tau^{1-\sigma})}\right)^{\frac{1}{\sigma-1}} c(s_j^{NT}). \tag{4}$$

Note first that P_j now depends only on s_j^{NT}, but not on 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 that maximizes W_j is independent of the standard imposed by 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. It is the general equilibrium adjustment in the extensive margin that renders the noncooperative Nash equilibrium inefficient. This production relocation effect in the noncooperative equilibrium is brought about by the price differences of the heterogeneous goods. National treatment equalizes p_{ij} and p_{jj}, and therefore standards cannot be used to induce production relocation. Because the remaining 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 noncooperative policies is Pareto inefficient.*
2. *The unique Nash equilibrium with national treatment is Pareto efficient.*

PROOF. See Subsection A.3 in the Appendix. □

3.2. *Standards Affect Fixed Costs Only.* Consider the situation in which standards affect only the fixed cost, but not the marginal cost of production. I will refer to this 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. $f_i = f_0 + f(s_{ii}) + f(s_{ij})$, *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. I also assume that the marginal cost is a constant c in two countries. This assumption will equalize ex-factory prices. Note that in this case, $n_1 f_1 + n_2 f_2 = \frac{\mu(L_1+L_2)}{\sigma}$. Therefore, the total number of heterogeneous firms $(n_1 + n_2)$ is no longer fixed as in the marginal cost case.

Given the combination of standards, (3) is simplified to:

$$P_j = \left(\frac{\sigma p^{\sigma-1}(f_0(1-\tau^{1-\sigma})+f(s_{jj})+f(s_{ji})-\tau^{1-\sigma}(f(s_{ii})+f(s_{ij})))}{\mu L_j(1-\tau^{2(1-\sigma)})}\right)^{\frac{1}{\sigma-1}}, \tag{5}$$

where $p = \sigma c/(\sigma-1)$. For (5) to hold in equilibrium, it must be optimal for firms from both countries to serve both markets. In other words, we need $(p_{jj}x_{jj})/\sigma \geq f(s_{jj})$ and $(\tau p_{ij}x_{ij})/\sigma \geq f(s_{ij})$. In equilibrium, these two conditions are equivalent to

$$f_0(1-\tau^{1-\sigma}) + f(s_{jj})\tau^{2(1-\sigma)} + f(s_{ji}) - \tau^{1-\sigma}(f(s_{ii}) + f(s_{ij})) > 0, \tag{6}$$

$$f_0(1-\tau^{1-\sigma}) + f(s_{jj}) + f(s_{ji}) - \tau^{1-\sigma}\left(f(s_{ii}) + \tau^{2(\sigma-1)}f(s_{ij})\right) > 0, \tag{7}$$

which I assume always hold for all combinations of standards. Similar to the case in which standards affect the marginal cost only, this condition is satisfied when trade cost τ is large. A positive price index P_j in equilibrium also requires $f_0(1-\tau^{1-\sigma}) + f(s_{jj}) + f(s_{ji}) - \tau^{1-\sigma}(f(s_{ii}) + f(s_{ij})) > 0$, which holds automatically given conditions (6) and (7). Analogous to Lemma 1 in the marginal cost case, the following lemma can be derived[14]:

LEMMA 2. *In the fixed 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* $\frac{\partial P_j}{\partial s_{ii}} < 0$.

In the fixed cost case, there is also a partial equilibrium effect and a general equilibrium production relocation effect. However, the partial equilibrium effect of raising s_{ij} directly changes the extensive margin, but does not change product prices. The larger fixed cost faced by country i reduces n_i and hence increases both P_j and P_i. At the same time, 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

[14] The algebraic details of the lemma can be found in Subsection A.3 of the Online Appendix.

exceeded by the negative production relocation effect, 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. Firms in country j, therefore, increase sales and earn positive profits. In order to restore equilibrium, there has to be entry in country j that 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 profits because the direct effect of higher f_i raises P_i. Similarly, raising s_{jj} will also trigger production relocation, but in the opposite direction, which increases P_j.

3.2.1. *No cooperation.* In the fixed cost case, the governments of the two countries solve the same optimization problem as in the marginal cost case. Note that the signs of the partials in Lemma 2 are identical to those in Lemma 1. Therefore, the reasoning presented in the marginal cost case also applies to the fixed cost case. In other words, s^{max} is always imposed on imported heterogeneous goods in the unique Nash equilibrium, and the Nash equilibrium is Pareto inefficient.

3.2.2. *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. The fixed cost for each firm becomes: $f_i = f_j = f_0 + f(s_j^{NT}) + f(s_i^{NT})$. In other words, in the fixed cost case, national treatment equalizes the fixed cost in both countries. This differs from the marginal cost case with national treatment, in which the marginal costs of goods sold in the two countries may still differ. (5) now becomes:

$$P_j = \left(\frac{\sigma p^{\sigma-1}(f_0 + f(s_j^{NT}) + f(s_i^{NT}))}{\mu L_j (1+\tau^{1-\sigma})} \right)^{\frac{1}{\sigma-1}}. \tag{8}$$

Observe that from (8), $\frac{\partial P_j}{\partial s_j^{NT}} > 0$, which is the same as in the marginal cost case. What distinguishes (8) from (4) 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 noncooperatively and when national treatment is followed.*

PROOF. See Subsection A.4 in the Appendix. □

3.3. *Discussion.* In the theoretical analysis presented in this section, I make several assumptions to simplify the characterization of optimal product standards and their welfare effects. First, the negative consumption externality follows a particular functional form: $\Omega_j = \Omega_{jj}(s_{jj}) + \Omega_{ij}(s_{ij})$. The additive separability assumption simplifies the analysis, but is not crucial to the main results. The case in which this assumption is dropped is discussed in Subsection A.1 of the Appendix, where I instead assume $\Omega_j \equiv \Omega_j(s_{ij}, s_{jj}, P_j(s_{jj}, s_{ij}))$, $\frac{\partial \Omega_j}{\partial P_j} < 0$. Since nominal income is fixed by the freely traded homogeneous good, this assumption implies that a larger quantity of heterogeneous goods consumed also increases the negative consumption externality. The results of Proposition 1 and Proposition 2 still hold under this more general assumption of the negative consumption externality.

Assumption 1 also enables us to focus on consumption externalities that are associated with product features and hence motivate standards. In particular, since Ω_j in Assumption 1 does not depend on the quantity of consumption, the usual arguments for Pigouvian taxes do not apply. Grossman et al. (2021) also distinguish spillovers that arise from consumption per se (hence motivating Pigouvian taxes) from those associated with product type, although a different formulation of consumption externality is adopted.[15] In Subsection A.2 of the Appendix, I extend the model by adding consumption taxes into the government's policy set and allow the consumption externality to depend on the quantity of the heterogeneous goods consumed. In the extended model, imposing optimal consumption taxes alone does not eliminate the government's incentive to use product standards to reduce the externality, and the corresponding noncooperative equilibrium with optimal consumption taxes is still inefficient.

In this two-country, two-sector model, product standards only generate an international inefficiency through production relocation. Since the homogeneous good is freely traded, changing product standards does not have any effect on terms of trade. The theoretical analysis concentrates on the production relocation effects because the welfare consequences of domestic policies through terms of trade have been analyzed extensively within the neoclassical trade framework (Bagwell and Staiger, 2001; Ederington, 2001). Nevertheless, I construct a two-country, one-sector model to analyze the terms-of-trade effect of product standards in Section B of the Online Appendix. Without the freely traded numeraire sector, the extensive margin of the heterogeneous sector in both countries is fixed and the production relocation effect disappears. In other words, the only general equilibrium adjustment operates through the terms of trade. Interestingly, this terms-of-trade effect is always weaker than the partial equilibrium effect in both the marginal cost case and the fixed cost case in this one-sector model. In other words, in the noncooperative Nash equilibrium, both countries will impose relatively low standards on foreign products and relatively high standards on domestic products. This result is inconsistent with the fact that almost all WTO disputes over domestic regulations involve excessively stringent regulations by importing nations (Staiger and Sykes, 2011). As shown later in Section 4, the quantitative exercise incorporates both general equilibrium effects when analyzing the welfare outcomes of cooperative and noncooperative product standards.

In the welfare analysis presented in this section, product standards are the only policy instrument available. The quantitative exercise in this article also takes observed tariff rates as given and analyzes the welfare effects of optimal standards only. This is because tariffs among major players in international trade remain low, despite the ongoing U.S.–China trade war. Due to the limited scope for further tariff reductions, recent trade negotiations have largely revolved around domestic regulations such as product standards. In addition, the welfare effects of cooperative and noncooperative tariffs in the Krugman (1980) model have already been discussed in Ossa (2011) and Lashkaripour (2021). Nevertheless, I include tariffs and discuss their welfare implications in Subsection A.4 of the Online Appendix.

The welfare outcomes of domestic regulations with a larger set of policy instruments have been studied by Bagwell and Staiger (2001) and Grossman et al. (2021). Bagwell and Staiger (2001) find that, in a neoclassical framework where an international inefficiency arises from terms-of-trade manipulation, noncooperative standards are efficient when subsidies and tariffs are available. Grossman et al. (2021) also allow governments to use tariffs, trade subsidies, and consumption taxes in addition to product standards. In a Krugman (1980)-style model that features production relocation, they show that noncooperative standards are inefficient even when all other policy instruments are set at efficient levels. This result holds regardless of whether national treatment is followed or whether there is a local consumption externality. Since the main goal of the theoretical analysis in my article is to illustrate how product

[15] As shown in Grossman et al. (2021), such negative externalities may arise "if social norms generate a distaste for certain versions of a good regardless of whether an individual consumes them herself or sees her compatriots doing so."

standards can generate the international inefficiency through the production relocation channel, I only focus on product standards in this section.

In the fixed cost case discussed in this section, the fixed cost function is assumed to be additive separable and convex in product standards. The additive separable functional form simplifies the analysis, whereas the convexity of f eliminates corner solutions. I also consider the case in which $f_i = f(\max[s_{ii}, s_{ij}])$ in Subsection A.5 of the Online Appendix. This functional form assumption reflects another possible way in which vertical standards affect the fixed cost of production: Once a good with a stringent standard is manufactured, producing other inferior goods does not incur additional fixed costs. I show that the main results of the welfare analysis in the fixed cost case discussed in this section still hold.[16]

To summarize, in this section, I construct a two-country, two-sector model to theoretically analyze the welfare effects of product standards in a Krugman (1980) environment. I start by focusing on the case in which standards affect only the marginal cost of production. In the noncooperative Nash equilibrium, countries impose discriminatory standards on foreign products when no other policy instruments are available, creating an international inefficiency via the production relocation effect. National treatment eliminates the price differences between domestic and foreign products and makes production relocation impossible. The resulting Nash equilibrium thus becomes Pareto efficient. Next, I also analyze the case in which product standards affect only the fixed cost of production. Similarly, the noncooperative equilibrium is Pareto inefficient because of the production relocation effect. However, even under national treatment, the Nash equilibrium is still inefficient in the fixed cost case. This is because whereas national treatment shuts down the production relocation channel, the partial equilibrium effect of standards on the other country's extensive margin is still not internalized. Finally, I discuss several extensions of the model and show that the main theoretical results still hold with alternative assumptions. Since the main goal of this section is to theoretically illustrate the welfare effects of product standards through the production relocation channel, I abstract from other policy instruments such as consumption taxes and production subsidies.

4. QUANTITATIVE EXERCISE

In previous sections, I have explored the welfare consequences of cooperative and noncooperative product standards in a simple model that features a production relocation effect. In this section, I extend the model to a richer multicountry, multisector environment that incorporates both production relocation and terms-of-trade effects.

4.1. *General Environment.* Consider a generalized version of the model developed in Section 2. The economy now consists of M countries and R industries. I denote countries by i and j and sectors by r. The utility derived from consumption becomes

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

In addition, the inverse production function of sector r firms in country i is:

$$l_{ir} = f_{ir} + \textstyle\sum_{j=1}^{M} \tau_{ijr} c_{ijr} x_{ijr}.$$

Note that in this more generalized model, the costs of production and the iceberg trade barrier are allowed to be asymmetric.

[16] I do not consider this functional form of fixed cost in the quantitative exercise because it is not a smooth function. The optimization algorithm I rely on is ineffective when the optimization problem involves kinks in the constraint equations.

Governments also impose tariffs in addition to standards. Let t_{ijr} denote the *ad valorem* tariff imposed by country j on sector r imports from country i. I assume $t_{ijr} \geq 0$ for all $i \neq j$ and $t_{ijr} = 0$ for all $i = j$. Solving for the households' utility maximization gives the demand for varieties in sector r produced in country i:

$$x_{ijr} = \frac{(p_{ijr}\tau_{ijr}(1+t_{ijr}))^{-\sigma_r}}{P_{jr}^{1-\sigma_r}}\mu_{jr}E_j, \tag{9}$$

where E_j is the total nominal expenditure and $P_{jr} = (\sum_{i=1}^{M} n_{ir}(p_{ijr}\tau_{ijr}(1+t_{ijr}))^{1-\sigma_r})^{\frac{1}{1-\sigma_r}}$ is the ideal price index of sector r in country j. Let p_{ijr} be the ex-factory price of sector r varieties from country i sold in country j. The sector-specific ideal price index in equilibrium can be re-expressed by substituting optimal pricing $p_{ijr} = \frac{\sigma_r c_{ijr} w_i}{\sigma_r - 1}$ back into the definition of P_{jr}:

$$P_{jr} = \left(\sum_{i=1}^{M} n_{ir}\left(\frac{\sigma_r c_{ijr} w_i \tau_{ijr}(1+t_{ijr})}{\sigma_r - 1}\right)^{1-\sigma_r}\right)^{\frac{1}{1-\sigma_r}}. \tag{10}$$

Define $X_{ijr} = n_{ir}p_{ijr}\tau_{ijr}x_{ijr}$ as the value of trade flow from country i to country j in sector r, so that $E_j = \sum_{i=1}^{M}\sum_{r=1}^{R}(1+t_{ijr})X_{ijr}$. Substituting (9) and optimal pricing into the definition of X_{ijr} gives:

$$X_{ijr} = n_{ir}(1+t_{ijr})^{-\sigma_r}\left(\frac{\sigma_r\tau_{ijr}c_{ijr}w_i}{\sigma_r-1}\right)^{1-\sigma_r}(P_{jr})^{\sigma_r-1}\mu_{jr}E_j. \tag{11}$$

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

$$W_j = \frac{(1-\sum_{r=1}^{R}\Omega_{jr})E_j}{\prod_{r=1}^{R}(P_{jr})^{\mu_{jr}}}, \tag{12}$$

where Ω_{jr} represents the negative consumption externality generated in sector r of country j. Ω_{jr} is assumed to have the following functional form:

$$\Omega_{jr} = \omega_{jr}\sum_{i=1}^{M}\frac{(1+t_{ijr})X_{ijr}(1-\tilde{s}_{ijr})}{E_j}, \tag{13}$$

where $\tilde{s}_{ijr} = s_{ijr}/s^{max}$ represents the normalized measure of standards.[17] By definition, $\tilde{s}_{ijr} \in [0,1]$. As will be seen later, this normalization also helps to incorporate the data into the model, because the data on standards are also normalized.

ω_{jr} is a parameter that captures the weight of the externality from the consumption of sector r goods in W_j *conditional on expenditure share*. Including ω_{jr} in (13) allows standards in sectors with smaller expenditure share (food production and crop, for example) to have more than proportional weights in the country's welfare. When $\omega_{jr} = 1$ for all sectors in country j, the consumption externality for each sector is weighted by Cobb–Douglas share μ_{jr}. In this case, imposing the maximum standard s^{max} in all sectors reduces the total consumption externality of country j to zero. In the meanwhile, if $s_{ijr} = 0$ in all sectors, the absolute value of the consumption externality is the same as the nominal expenditure and W_j becomes zero. We can

[17] This formulation of externality is consistent with the additive separable assumption of Ω in Section 2. To see this, substituting (13) into (12) gives $W_j = \frac{E_j}{\prod_{r=1}^{R}(P_{jr})^{\mu_{jr}}} - \frac{\sum_{r=1}^{R}\omega_{jr}(\sum_{i=1}^{M}(1+t_{ijr})X_{ijr}(1-\tilde{s}_{ijr}))}{\prod_{r=1}^{R}(P_{jr})^{\mu_{jr}}}$. Moreover, 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 by 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 relative to the channels discussed in previous sections.

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 2.

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

$$c_{ijr} = \exp(c_r^1 \tilde{s}_{ijr}). \tag{14}$$

For the fixed cost of production, I assume that:

$$f_{ir} = \sum_{j=1}^{M} \mathbb{1}\{X_{ijr} > 0\} \exp(f_r^1 \tilde{s}_{ijr}), \tag{15}$$

where $\mathbb{1}\{X_{ijr} > 0\}$ is an indicator function of positive trade flow.[18] The exponential functional form is chosen because it satisfies the assumptions in the theoretical analysis presented in Section 3 and only two additional parameters, c_r^1 and f_r^1, need to be estimated. c_r^1 and f_r^1 can be interpreted as the elasticity of the marginal and fixed costs of production with respect to normalized standards, respectively.

4.3. *Equilibrium.* The equilibrium given standards and tariffs can be characterized by three equations. The first equilibrium condition describes households' budget constraint:

$$E_i = w_i L_i + \sum_{m=1}^{M} \sum_{r=1}^{R} t_{mir} X_{mir} - B_i, \tag{16}$$

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:

$$w_i n_{ir} f_{ir} = \frac{1}{\sigma_r} \sum_{j=1}^{M} X_{ijr}. \tag{17}$$

Finally, the condition that relates labor income to total revenue is:

$$w_i L_i = \sum_{j=1}^{M} \sum_{r=1}^{R} X_{ijr}. \tag{18}$$

The system of Equations (16)–(18), in which P_{jr} and X_{ijr} are defined by (10) and (11), 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.

Directly solving the system of Equations (16)–(18) is challenging, because the parameters $\{\tau_{ijr}, L_i, f_{ir}\}$ are difficult to estimate empirically. In order to circumvent this problem, I follow the "exact hat algebra" technique popularized by Dekle et al. (2007) and express the equilibrium conditions in changes relative to the factual equilibrium.[19] As discussed in Ossa (2014), the presence of aggregate trade imbalances in the data can generate extreme general equilibrium adjustments in response to trade policy changes. In addition, the assumption of constant nominal transfers implies that the results of counterfactual exercises will depend on the units measured. Accordingly, I follow the exercise in Dekle et al. (2007) to construct a trade flow matrix without trade imbalance. All later calculations of welfare changes given counterfactual standards will treat this purged trade flow data as the factual equilibrium.

4.4. *Welfare Effects of Standard Changes.* Although the theoretical analysis in previous sections has focused on the production relocation channel, the generalized model used for the quantitative exercise incorporates several channels through which product standards affect welfare. To see this, I log-linearize around the equilibrium with zero tariffs and no

[18] In the counterfactual exercises presented in Section 6, $X_{ijr} > 0$ for all countries and sectors. The indicator function $\mathbb{1}\{X_{ijr} > 0\}$ is therefore dropped in the equilibrium equations to simplify the notation.

[19] The algebraic details can be found in Subsection A.5 of the Appendix.

consumption externality to obtain:

$$(19)\quad \frac{dW_j}{W_j} \approx \sum_{i=1}^{M}\sum_{r=1}^{R}\frac{X_{ijr}}{E_j}\left(\frac{dw_j}{w_j}-\frac{dw_i}{w_i}\right)+\sum_{i=1}^{M}\sum_{r=1}^{R}\frac{X_{ijr}}{E_j}\frac{1}{\sigma_r-1}\frac{dn_{ir}}{n_{ir}}-\sum_{i=1}^{M}\sum_{r=1}^{R}\frac{X_{ijr}}{E_j}\frac{dc_{ijr}}{c_{ijr}},$$

where $\frac{dW_j}{W_j}$ and other similar variables represent percentage changes.[20]

The three terms in (19) 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, or 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 production relocation effect that is a consequence of the changes to standards. 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, as there is no partial equilibrium effect on the extensive margin.

In this Krugman (1980)-style model, the partial equilibrium effect of standards on the fixed cost of production included in the second term of (19) 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 (19), depends only on standards set by country j and not on standards set by other countries. When country j sets its standards, the effect on W_j via the third term of (19) is internalized. By contrast, standards set by other countries will directly affect the fixed costs of all countries and consequently W_j via the second term of (19). This effect on W_j is not internalized by decision makers in other countries and thus creates an international inefficiency when standards are set noncooperatively.

5. DATA AND CALIBRATION

In this section, I first present the data used in the quantitative exercise and then discuss the calibration of the model's key parameters.

5.1. *Data.* Measurement is one of the toughest issues faced in research on nontariff barriers (Goldberg and Pavcnik, 2016), which are broadly defined as measures that are not tariffs but can negatively affect international trade flows. The quantitative exercise in this article relies on data from the Trade Analysis Information System (TRAINS) developed by UNCTAD, a UN agency that collects data on non-tariff measures (NTMs). TRAINS provides information on NTMs at the country and Harmonized System (HS) six-digit level. Since this article focuses on the role of product standards, I only consider the Technical Barriers to Trade (TBT) and the Sanitary and Phytosanitary (SPS) categories of the NTM data and exclude other categories, such as preshipment inspections or licensing requirements. This NTM data set is an unbalanced panel that covers 60 countries from 2010 to 2015.

I follow the approach of coverage ratio used by Essaji (2008) and Disdier et al. (2008) to construct a measure of product standards at the sector level. In particular, the coverage ratio of sector r in country j is defined as the share of its HS six-digit products covered by NTMs, which is available from TRAINS. In other words, the number of products covered by regulations in each sector is interpreted as s_{ir}^{NT}, and therefore the coverage ratio represents the normalized standard under national treatment $\tilde{s}_{jr}^{NT}$. Since all countries involved in the quantitative exercise are members of the WTO, I assume that national treatment is strictly followed in

[20] The algebraic details are presented in Subsection A.6 of the Online Appendix. Log-linearization around positive tariffs would generate another term that captures tariff revenue, which is not the focus of this article. Moreover, log-linearization with the consumption externality generates an additional local effect, which does not contribute to the international inefficiency.

the factual equilibrium.[21] All trade, tariff, and NTM data at HS six-digit level are converted to sectors using a concordance I construct.

Although NTMs data from TRAINS are probably the most widely used data source for nontariff barriers, these data are far from ideal. For example, neither the original data nor the constructed $\tilde{s}_{jr}^{NT}$ assesses the stringency of each recorded NTM or identifies the degree of discrimination (Ederington and Ruta, 2016). Unfortunately, alternative data sources either include only a narrower set of NTMs (Temporary Trade Barriers Database by the World Bank) or rely on surveys of a small number of firms (business surveys conducted by the International Trade Center).[22] The WTO and other international organizations have recognized the issues with existing data sources and initiated several related protects, but TRAINS is still by far the most comprehensive data source for nontariff barriers.

Export data used to estimate the marginal cost parameter c_r^1 are from the CEPII's BACI Database, in which export values are recorded at the HS six-digit level. Distance and various measures of trade frictions are also from the CEPII database and documented in Head and Mayer (2014). Tariff data are from the International Trade Center's Market Access Map database. The trade data I use for the quantitative exercise are from the National Input-Output Tables available at the World Input-Output Database (WIOD), one of the few public databases containing within-country trade flows at the industry level. I use the data for the year 2014, which cover 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, Indonesia, Mexico, Norway, Russia, South Korea, and Switzerland) as one Rest of the World.[23]

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 from 37 OECD countries at industry level in 2012. The industry-level numbers of firms from India, China, Canada, and Japan are also needed for the quantitative exercise. I obtain these numbers from these countries' respective statistics bureaus.[24]

5.2. *Externality Weight.* The calibration of ω_{jr} follows the methodology developed by 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 optimal standard for sector r in country j is larger than the factual standard and decrease ω_{jr} if it is smaller. I then repeat this step and decrease the size of each adjustment in ω_{jr} along the iteration. The iteration continues until the predicted 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 fac-

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

[22] Schmidt and Steingress (2022) use data from the Searle Center Database on Technology Standards, Industry Consortia and Innovation to study the impact of standard harmonization on global trade. Nonetheless, this database only keeps track of voluntary standards, not the regulatory standards that are the focus of my article.

[23] I choose to focus on seven large economies and 21 sectors because the algorithm used for computing optimal tariffs requires the optimization problem to be continuous. Adding more countries or defining sectors at a more disaggregated level would introduce zero trade flows. Solving for optimal tariffs in this case would involve market entry decisions, which would significantly increase the computational burden. Moreover, having more countries or sectors would increase the number of variables and constraints of the optimization problem multiplicatively. The computing time needed to solve that optimization problem, especially in the case of cooperative standards, would be much longer.

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

TABLE 1
CALIBRATED EXTERNALITY WEIGHT ω_{jr}

	Canada	EU	USA	Japan	RoW	India	Brazil	China
Crop and animal production, hunting, etc.	2.31	2.2	2.16	2.17	2.1	2.14	2.14	1.94
Manufacture of electronic products	1.59	1.46	1.42	1.44	1.39	1.42	1.41	1.29
Manufacture of food products, etc.	1.42	1.36	1.3	1.31	1.26	1.29	1.29	1.17
Forestry and logging	1.26	1.18	1.15	1.18	1.11	1.12	1.15	0.99
Manufacture of chemicals and chemical products	0.88	0.82	0.79	0.81	0.77	0.8	0.79	0.72
Manufacture of coke and refined petroleum products	1	1	1	1	1	0.35	0.35	0.32
Manufacture of motor vehicles	0.7	0.69	0.67	0.66	0.57	0.65	0.68	0.69
Manufacture of textiles, wearing apparel, etc.	0.7	0.66	0.64	0.64	0.62	0.63	0.62	0.57
Manufacture of machinery and equipment, etc.	0.71	0.69	0.67	0.66	0.65	0.56	0.56	0.51
Manufacture of fabricated metal products	0.67	0.62	0.62	0.66	0.59	0.61	0.61	0.55
Manufacture of rubber and plastic products	0.71	0.69	0.67	0.66	0.65	0.65	0.36	0.33
Manufacture of other transport equipment	0.7	0.69	0.67	0.4	0.38	0.4	0.39	0.36
Manufacture of other nonmetallic mineral products	0.7	0.69	0.67	0.66	0.25	0.25	0.25	0.23
Fishing and aquaculture	0.7	0.69	0.67	0.66	0.65	0.05	0.05	0.05
Manufacture of furniture; other manufacturing	0.36	0.33	0.33	0.33	0.32	0.33	0.32	0.29
Manufacture of basic metals	0.34	0.32	0.31	0.32	0.3	0.31	0.31	0.27
Printing and reproduction of recorded media	0.32	0.31	0.31	0.31	0.28	0.3	0.3	0.27
Manufacture of electrical equipment	0.16	0.16	0.15	0.15	0.14	0.15	0.14	0.14
Manufacture of wood and of products of wood	0.15	0.15	0.14	0.15	0.14	0.14	0.14	0.12
Manufacture of paper and paper products	0.15	0.14	0.14	0.13	0.12	0.14	0.14	0.12
Mining and quarrying	0.07	0.04	0.04	0.03	0.04	0.03	0.03	0.04
Mean	0.74	0.71	0.69	0.68	0.64	0.59	0.57	0.52

tual standards constitute a Nash equilibrium in which countries unilaterally maximize their welfare under the constraint of national treatment.

The calibrated values of ω_{jr} are presented in Table 1. Sectors and countries are both sorted by average ω_{jr} in descending order. We can see that the developed countries (Canada, EU, and the United States) all have higher average ω_{jr} than the developing countries. This is consistent with the expectation that the stringency of regulations on products is usually positively correlated with a country's income. Furthermore, sectors related to agriculture and food products have higher average weight. This is because since these sectors are closely related to consumers' health, yet their expenditure share is relatively small. Finally, sectors with larger factual standards also tend to have larger ω_{jr} given the assumption behind the iterative procedure used.[25]

In the model, the main function of product standards is to reduce consumption externalities, which is admittedly a bold assumption. In reality, product standards may reflect various political and economic objectives. Some existing works partially address this issue by focusing on a particular sector and providing more direct measures of product standards.[26] However, in this comprehensive quantitative exercise encompassing various sectors and countries, it is challenging to provide direct assessments of standards to accurately reflect their intricate objectives. Nevertheless, in Subsection 6.4, I consider the possibility that a certain share of the product standards is motivated by objectives external to the trade model. When the share of standards used to reduce consumption externalities is smaller, the calibrated ω_{jr} and consequently the magnitude of welfare changes in counterfactual scenarios also decrease.

[25] Note that the calibrated ω_{jr} in "Manufacture of coke and refined petroleum products" is equal to exactly 1 for several countries. This is because the predicted optimal standards under national treatment for these sectors are very close to the respective factual standards when setting $\omega_{jr} = 1$ for the first iteration. In addition, the predicted optimal standards in these sectors are not sensitive to different values of ω_{jr}.

[26] For example, Hejazi et al. (2022) analyze how maximum residue limits for pesticides as a vertical product standard affect the international trade of fruits and vegetables.

5.3. *Marginal Cost Parameter.* The marginal cost parameter c_r^1 is estimated from a gravity equation derived from Equation (11). Specifically, substituting Equation (14) into Equation (11) and taking logs gives:

$$\log X_{ijr} = \log(n_{ir} w_i^{1-\sigma_r}) + \log\left(\frac{\sigma_r^{1-\sigma_r}\mu_{jr}E_j}{(\sigma_r-1)^{1-\sigma_r}(P_{jr})^{1-\sigma_r}}\right) - \sigma_r \log(1+t_{ijr}) + (1-\sigma_r)\log\tau_{ijr} + (1-\sigma_r)c_r^1\tilde{s}_{ijr}.$$

Note that the first two multilateral resistance terms are exporter-sector and importer-sector specific. Regressing this gravity equation separately for each sector r and dividing the coefficient of $\tilde{s}_{ijr}$ by $1-\sigma_r$ gives the estimated value of c_r^1.

The actual regression equation for each sector r is

$$\log X_{ijrt} = b_r^0 + b_r^1 \tilde{s}_{jrt}^{NT} + \mathbf{Z}'_{ijrt}\mathbf{b} + fe_{irt} + fe_{jr} + fe_{rt} + \varepsilon_{ijrt}, \tag{20}$$

where X_{ijrt} is the total value of sector r exports from country i to country j in year t, $\tilde{s}_{jrt}^{NT}$ is the coverage ratio defined as the share of HS six-digit products covered by TBT or SPS in each sector, and $\mathbf{Z}_{ijr}$ captures bilateral trade cost variables such as distance, contiguity, common language, and free trade agreements.[27] For each regression, I also include exporter-year, importer, and year fixed effects. Note that since I run the regression for each sector separately and $\tilde{s}_{jrt}^{NT}$ does not vary by exporter due to national treatment, I cannot add the importer-year fixed effect as suggested by Anderson and van Wincoop (2003). With the estimated coefficient b_r^1 for each sector, the marginal cost parameter c_r^1 can be recovered from $c_r^1 = b_r^1/(1-\sigma_r)$.

5.4. *Fixed Cost Parameter.* Estimating the fixed cost parameter f_r^1 relies on the equilibrium condition (17). Rearranging this equation and expressing 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 the total exports, elasticity of substitution, average income, and number of firms. The data used for the estimation cover 34 countries. Average income is approximated by GDP per capita. All trade and GDP per capita data are 2012 values. Most countries' data on 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 are assumed to impose the sectoral average.

I use a nonlinear least squares approach to estimate f_r^1. Specifically, f_r^1 is computed by solving

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

The estimation is run separately for each sector. Note that for each regression, standards data do not vary across exporters due to national treatment. In addition, all variations are cross-sectional due to data constraints.[28]

[27] Tariffs are not included because the publicly available annual tariff data from TRAINS are an unbalanced panel. Including annual tariffs leads to an insufficient number of observations in nine of the 21 sectors. Omitting tariff controls from the estimation should not be a major concern because significant tariff changes were rare between 2010 and 2015. In addition, since (20) is run separately for each sector, the cross-country variations of most-favored-nation tariffs are captured by the importer fixed effect fe_{jr}. Finally, preferential tariffs are also controlled for by the free trade agreement dummies.

[28] I also experiment with a Poisson pseudo maximum likelihood (PPML) regression to estimate f_r^1, and the quantitative exercise generates very similar results to those presented in Section 6.

TABLE 2
PARAMETERS BY SECTOR

	Coverage Ratio	c_r^1	f_r^1	σ_r
Crop and animal production, hunting, etc.	0.92	2.5	1.83	2.75
Forestry and logging	0.75	1.23	1.83	2.39
Fishing and aquaculture	0.96	−1.06	1.55	3.99
Mining and quarrying	0.56	0.01	0.54	3.01
Manufacture of food products, etc.	0.96	1.57	0.11	2.33
Manufacture of textiles, wearing apparel, etc.	0.6	0.77	0.11	2.73
Manufacture of wood and of products of wood	0.76	0.16	0.16	2.56
Manufacture of paper and paper products	0.72	0.14	0.23	2.56
Printing and reproduction of recorded media	0.43	0.36	0.21	3.38
Manufacture of coke and refined petroleum products	0.9	0.42	0.34	3.65
Manufacture of chemicals and chemical products	0.78	0.95	0.19	2.27
Manufacture of rubber and plastic products	0.84	0.43	0.12	2.77
Manufacture of other nonmetallic mineral products	0.7	0.3	0.15	2.34
Manufacture of basic metals	0.79	0.36	0.23	3.1
Manufacture of fabricated metal products	0.67	0.74	0.07	2.54
Manufacture of electronic products	0.22	1.71	0.25	2.08
Manufacture of electrical equipment	0.93	0.17	0.14	2.72
Manufacture of machinery and equipment, etc.	0.96	0.68	0.13	2.57
Manufacture of motor vehicles	0.91	0.7	0.19	2.73
Manufacture of other transport equipment	0.75	0.47	0.16	2.95
Manufacture of furniture; other manufacturing	0.62	0.39	0.07	3.33
Mean	0.75	0.62	0.41	2.80

Table 2 lists the average coverage ratios, 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. All 21 sectors have positive f_r^1, and the average $\bar{R}^2$ over 21 sectors is 0.97. However, one of the 21 sectors, "Fishing and aquaculture," has a negative c_r^1. The negative coefficient may indicate that product standards in this sector are more horizontal, and therefore regulations over these standards can reduce trade frictions. Because this channel is not the focus of this article, the negative coefficient of this sector is set to zero in the quantitative analysis.

5.5. *Elasticity of Substitution.* 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 the UN's Comtrade database, covering the time period 1999–2015. Instead of focusing on single importers, I use all available trade flows 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 2. The estimates appear plausible, as more homogeneous products such as fishing and dairy products have higher values.[29]

6. COUNTERFACTUAL RESULTS

In this section, I use the calibrated 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 by imposing discriminatingly high standards on imports. 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

[29] The mean of elasticity of substitution is 2.80, which is lower than 3.42 in Ossa (2014). This is because Ossa (2014) uses the GTAP Database, in which the agricultural sectors are disaggregated. Several agricultural sectors such as wheat and rice have a very high elasticity of substitution.

TABLE 3
UNILATERAL STANDARDS: DOMESTIC VERSUS FOREIGN

	Factual Standard	Optimal Standard		
	Mean	Mean	Own	Other
Brazil	0.64	0.78	0.51	0.82
Canada	0.86	0.92	0.64	0.96
China	0.53	0.68	0.4	0.72
India	0.78	0.89	0.49	0.94
Japan	0.86	0.85	0.7	0.87
USA	0.86	0.88	0.69	0.91
EU	0.86	0.87	0.61	0.91
RoW	0.59	0.76	0.45	0.81
Mean	0.75	0.83	0.56	0.87

NOTE: Columns under "Mean" are the average of all standards imposed by the country. Columns under "Own" are averages of each country's unilateral standards imposed on itself. Columns under "Other" are averages of unilateral standards imposed on imports. Columns under "Own" are averages across sectors, whereas those under "Mean" and "Other" are averages across sectors and countries.

loss. Finally, I consider the counterfactual scenario in which all countries follow a Nash bargaining protocol and negotiate efficient standards.

6.1. *Unilateral Optimal Standards.* I first compute the optimal standards and welfare changes when countries unilaterally abandon national treatment and do not fear retaliation. Due to the high dimensionality of the optimization problem, I follow Ossa (2014) and rely on the method of mathematical programming introduced in Su and Judd (2012). This algorithm maximizes $\hat{W}_j$ subject to the equilibrium conditions expressed in changes. I refer to the computed optimal standards in this scenario as unilateral standards.

Table 3 summarizes the averages of the factual standards and computed unilateral standards for all eight countries. Each row represents the counterfactual equilibrium of one country abandoning national treatment. The first two columns list average factual and unilateral standards, respectively. The last two columns of Table 3 further decompose the unilateral standards by market. We can see that for all eight countries, the unilateral standards imposed on domestically produced goods are lower than the average factual standards. However, the average unilateral standards on imported goods are higher than the factual average. These results are consistent with the theoretical analysis presented in previous sections: National treatment constrains the production relocation incentive to impose high standards on imports. Without national treatment, countries will use discriminatingly high standards on imports to improve welfare. This result also corroborates the fact that almost all WTO disputes over domestic regulations involve excessively stringent regulations by importing nations (Staiger and Sykes, 2011).

Table 4 presents the welfare effects of imposing unilateral standards. The first two columns list the welfare change of the country imposing unilateral standards and the average welfare changes of other countries separately. As shown in the table, all countries gain at the expense of other countries. The average welfare gain of the country imposing unilateral standards is 1.2%, whereas the average loss of other countries is 0.6%. To further decompose total welfare changes, the last two columns of Table 4 present percentage changes in real expenditure. We can see that all countries experience an increase in real expenditure when imposing unilateral standards. Note that welfare changes under both of the "Other" columns are the same. This is because, given the functional form of welfare in (12), imposing unilateral standards affects other countries' real expenditure and consumption externality proportionally.

When computing unilateral optimal standards for Table 3 and Table 4, I allow standards to affect both the marginal and fixed costs of production. In order to examine which channel contributes more to the beggar-thy-neighbor nature of unilateral standards, I also conduct

TABLE 4
UNILATERAL STANDARDS: WELFARE CHANGES

	ΔW_j		$\Delta(E_j/P_j)$	
	Own	Other	Own	Other
Brazil	0.9	−0.5	6.3	−0.5
Canada	2.3	−0.4	7.1	−0.4
China	0.8	−0.7	8.1	−0.7
India	1.5	−1	12.3	−1
Japan	0.7	−0.2	6.9	−0.2
USA	1.1	−0.3	9	−0.3
EU	1.4	−1	9.3	−1
RoW	1.1	−0.8	0.4	−0.8
Mean	1.2	−0.6	7.4	−0.6

NOTE: 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	0.9	−0.5	1	0	16.6	−0.6
Canada	2.3	−0.4	2.3	−0.1	7.5	−0.3
China	0.8	−0.7	0.9	−0.3	25.1	−0.7
India	1.5	−1	1.4	−0.4	11.2	−0.5
Japan	0.7	−0.2	0.8	0	12.9	−0.4
USA	1.1	−0.3	1	−0.1	13.2	−0.3
EU	1.4	−1	1.4	−0.7	10.7	−0.4
RoW	1.1	−0.8	1.2	−0.3	25.4	−0.6
Mean	1.2	−0.6	1.2	−0.2	15.3	−0.5

NOTE: All entries are percentage welfare 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.

the same exercise, but this time shutting 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 of Table 4 and are listed for comparison purposes. The two center columns present welfare changes with only the marginal cost channel, whereas the two farthest right columns present welfare changes with only the fixed cost channel. From the columns under "MC Only," we can see that the average of other countries' welfare loss is only 0.2% when the fixed cost channel is shut down. This result suggests that the beggar-thy-neighbor nature of regulatory protection mostly operates through the fixed-cost channel. Note that the welfare gains under "FC Only" are much larger than those listed in the first column. This is because, in this scenario, countries do not worry about the higher prices in the domestic market when they raise standards on imports. In other words, shutting down the marginal cost channel significantly decreases the welfare cost of raising standards through prices.

6.2. *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 are such that each government chooses the standards to maximize its country's welfare, given the optimal 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 reoptimize

TABLE 6
NASH STANDARDS

	Optimal Standard		Welfare Change	
	Own	Other	ΔW_j	$\Delta(E_j/P_j)$
Brazil	0.5	0.83	−2	
Canada	0.62	0.94	−3.8	2.8
China	0.49	0.89	−2.7	4.9
India	0.51	0.95	−2.1	9.9
Japan	0.71	0.9	−2.8	3.6
USA	0.68	0.92	−2.4	6.4
EU	0.61	0.88	−2.9	5.7
RoW	0.45	0.87	−4	−3
Mean	0.57	0.9	−2.8	4.3

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

given other countries' unilateral standards until the welfare change from the previous iteration is less than 10^{-3} 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. 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 a separate equilibrium. We can see that no country enjoys a welfare improvement in this trade war of product standards, and the average welfare loss is 2.8%.

The Nash standards presented in Table 6 display patterns similar to those of the Nash tariffs analyzed in Ossa (2014). For example, comparing the first two columns of Table 6 with the last two columns of Table 3, we see that both the Nash standards on domestic products and those on imports are very close to their counterparts in the unilateral case. Interestingly, Ossa (2014) also finds that the Nash tariffs in the counterfactual trade war scenario are very similar to the unilateral optimal tariffs. Furthermore, the average welfare loss in the trade war of tariffs in Ossa (2014) is 2.9%, which is very close to the average welfare loss of 2.8% shown in Table 6.

6.3. *Cooperative Standards.* The analysis presented in Section 3 shows that the WTO's shallow integration approach cannot lead to an efficient equilibrium when standards can affect the fixed cost of production. A natural question that arises is to what extent could deeper integration improve welfare outcomes? I now turn to analyze the welfare effects of different approaches to international cooperation over product standards. In order to construct a path from the factual equilibrium to any point on the efficiency frontier, I need to specify a particular bargaining protocol. I adopt the Nash bargaining protocol that improves all countries' welfare symmetrically from the factual equilibrium. In other words, the cooperative standards solve $\max \hat{W}_1$ such that $\hat{W}_j = \hat{W}_1 \forall j$. Given the Nash bargaining protocol, I quantify the welfare effects of cooperative standards under the constraint of national treatment. In addition, I report results with two alternative approaches to international cooperation, namely, mutual recognition and harmonization. Finally, I also consider the scenario with no constraint on cooperative standards.

Table 7 presents cooperative standards and corresponding welfare changes under national treatment and mutual recognition, respectively. Comparing the first two columns, we can see that cooperative standards under national treatment are significantly lower than the factual

TABLE 7

COOPERATIVE STANDARDS UNDER NATIONAL TREATMENT AND MUTUAL RECOGNITION

	Standard			ΔW_j		$\Delta(E_j/P_j)$	
	Factual	NT	MR	NT	MR	NT	
Brazil	0.64	0.3	0.55	7.5	8.2	52.7	31
Canada	0.86	0.53	0.52	7.5	8.2	34.5	34.8
China	0.53	0.17	0.49	7.5	8.2	52.8	15.6
India	0.78	0.37	0.58	7.5	8.2	50.3	33.1
Japan	0.86	0.42	0.67	7.5	8.2	96.3	70.6
USA	0.86	0.64	0.51	7.5	8.2	17.5	29.3
EU	0.86	0.52	0.54	7.5	8.2	31.7	29.2
RoW	0.59	0.4	0.58	7.5	8.2	36.3	20.5
Mean	0.75	0.42	0.55	7.5	8.2	46.5	33

NOTE: Columns under "Factual" are averages of each country's standards in the factual equilibrium. Columns under "NT" and "MR" refer to the cooperative equilibrium following national treatment and mutual recognition, respectively. Entries under ΔW_j and $\Delta(E_j/P_j)$ are percentage changes relative to the factual equilibrium.

standards (Nash standards under national treatment) for all countries. This is because the calibrated weight of consumption externalities is in general smaller than the real expenditure. As shown in Table 1, the average weight of consumption externalities is less than 1 in all countries, and only a few sectors have externality weights greater than 1. Lowering standards reduces the welfare of the importing country through the negative consumption externality, but benefits other countries' real expenditure to a greater extent. In addition, we can see that countries with lower weights of consumption externalities tend to impose lower cooperative standards. This is to be expected in the cooperative equilibrium, as the welfare loss of imposing lower standards is smaller in these countries.

The EU adopts a mutual recognition principle to discipline technical rules imposed at the national level that may create unnecessary obstacles to intra-EU trade. According to the website of the European Commission, mutual recognition requires that "EU countries accept products lawfully sold in another EU country, unless very specific conditions are met." Although the principle of mutual recognition can be interpreted in many ways, I follow the assessment introduced in Costinot (2008), considering mutual recognition to be 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. The efficiency outcomes of standards under mutual recognition are theoretically analyzed in Subsection A.7 of the Online Appendix.

Entries under "MR" in Table 7 are cooperative standards along with the corresponding welfare and real expenditure changes under mutual recognition, following the interpretation of Costinot (2008). In other words, now $s_{ijr} = s_{ir}^{MR}$ and the regulatory power of product standards is in the hands of exporting countries. Comparing entries under column 2 and column 3, we can see that cooperative standards under mutual recognition are higher than those under national treatment for all countries. This is because whereas $\frac{\partial P_j}{\partial s_i^{NT}} > 0$ in the two-country, two-product model in Section 3, $\frac{\partial P_j}{\partial s_i^{MR}} < 0$, as shown in Subsection A.7 of the Online Appendix. In the cooperative equilibrium, therefore, exporting countries have greater incentives to impose higher standards in the case of mutual recognition.

The last four columns of Table 7 present the welfare changes and changes in real expenditure in the cooperative equilibrium under national treatment and mutual recognition. We see that the total welfare gain is substantial in both cases: All countries improve their total welfare by 7.5% under national treatment and by 8.2% under mutual recognition. In addition, all countries experience an improvement in real expenditure. However, the increase in real expenditure is larger in the case of national treatment. In this case, international cooperation in product standards raises all countries' real expenditure at the expense of larger negative consumption externalities. On the contrary, cooperative standards under mutual recognition improve welfare by both increasing the real expenditure and reducing negative consumption externalities.

The significant improvement in real expenditure and welfare gain from cooperative standards shown in Table 7 can be attributed to the inclusion of the negative consumption externality in each country's welfare function. In the cooperative equilibrium, countries can jointly reduce product standards to improve real expenditure. At the same time, the welfare loss due to the rising negative externality is smaller since the average weight of consumption externalities is less than 1 in all countries. Given the high factual standards, there is substantial room for welfare improvement by reducing standards jointly in the cooperative equilibrium. By contrast, cooperative tariffs in Ossa (2014) can only improve welfare by raising real expenditure in all countries. Moreover, product standards can directly affect the welfare of other countries through the extensive margin, as shown in Section 3, a channel that is absent in the case of tariffs. This effect is internalized in the cooperative setting, thereby generating a greater welfare improvement than in Ossa (2014).

The welfare changes presented in Table 6 and Table 7 can be used to infer the progress of international cooperation on product standards. In Ossa (2014), the average welfare loss with noncooperative tariffs is 2.9%, whereas the average welfare gain from cooperative tariffs is 0.5%. Comparing the results in that paper with those presented in this section, we can see that factual tariffs are much closer to the efficient frontier compared to the factual standards. This result is sensible: Tariff cuts from multilateral and bilateral trade policy negotiations have made much more progress than international cooperation on product standards. This result also rationalizes why recent trade agreements have emphasized the importance of reducing regulatory barriers to trade.

In addition to international cooperation under national treatment and mutual recognition, I also consider the scenario of harmonized standards: All countries negotiate one cooperative standard for each sector. In the cooperative equilibrium with harmonization, all countries improve their welfare by 1.4%. Compared to the cooperative equilibrium under national treatment or that under mutual recognition, the magnitude of welfare gain from harmonization is much smaller. This is because the quantitative framework used in this article does not incorporate the cost of learning and adapting heterogeneous standards from the consumer side (as suggested in Toulemonde, 2013) or the potential cost complementarities in the production function. In other words, the benefits of harmonization is muted to a large extent. As a result, harmonization in this framework only constrains individual countries' ability to cooperate.

I also explore the cooperative equilibrium with no institutional constraints to quantify the maximum possible welfare gain from cooperative standards. The first two columns of Table 8 list cooperative standards in this scenario, whereas the last two present changes in total welfare and real expenditure. We can see that all countries impose relatively high standards on domestic products and low standards on imports. This result provides an opposite pattern compared to those of unilateral standards in Table 3 and Nash standards in Table 6. This is again because the weight of consumption externalities is less than the real expenditure for all countries. Lowering standards reduces the welfare of the importing country through the negative consumption externality, but benefits other countries' real expenditure to a greater extent.

The last two columns of Table 8 present the welfare changes and changes in real expenditure in the cooperative equilibrium. We see that the total welfare gain is even higher at 11.8%. In addition, all countries experience a larger percentage gain in real expenditure. Similar to the two cases of cooperation under national treatment, international cooperation on standards in this scenario raises all countries' real expenditure at the expense of larger negative consumption externalities. Since all countries essentially subsidize imported goods, the cooperative standards computed here are less politically feasible. For this reason, the corresponding welfare changes should only be considered as a theoretical upper bound of potential welfare gains from cooperative product standards.

TABLE 8
UNCONSTRAINED COOPERATIVE STANDARDS

	Optimal Standard		Welfare Change	
	Own	Other	ΔW_j	$\Delta(E_j/P_j)$
Brazil	0.74	0.05	11.8	39.4
Canada	0.68	0.22	11.8	45.1
China	0.61	0.07	11.8	23.6
India	0.74	0.26	11.8	37
Japan	0.91	0.01	11.8	47.4
USA	0.66	0.25	11.8	31.2
EU	0.7	0.41	11.8	28.5
RoW	0.71	0.27	11.8	24.4
Mean	0.72	0.19	11.8	34.6

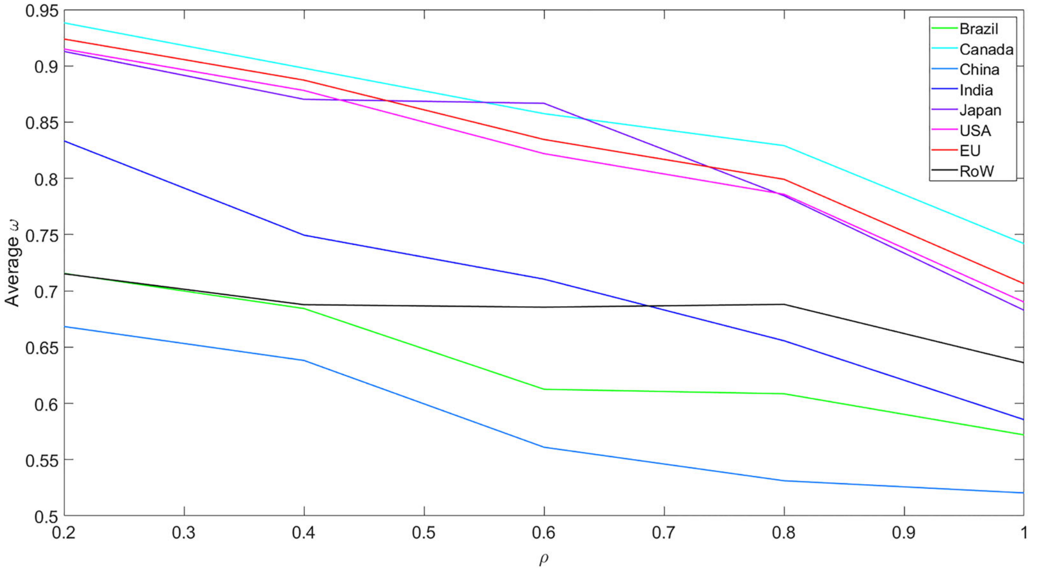
NOTE: Columns under "Own" are averages of each country's cooperative standards imposed on itself. Columns under "Other" are averages of cooperative standards imposed on other countries' goods. Columns under "Own" are averages across sectors, whereas those under "Other" are averages across sectors and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

6.4. *Extensions.* As discussed in Subsection 5.2, the main goal of product standards in the model is to reduce consumption externalities. As a result, governments can adjust product standards to the full extent in the counterfactual scenarios analyzed in this section. In reality, however, product standards are motivated by various political and economic objectives. In order to address this concern, I consider the possibility that a certain share of product standards is not adjustable in counterfactual scenarios because these standards are imposed for reasons external to the model. In particular, I let $\rho \in [0, 1]$ denote the share of product standards that are imposed to reduce the negative consumption externalities, and are hence adjustable in the counterfactual scenarios. The main analysis discussed in Subsections 6.1–6.3 thus corresponds to scenarios with $\rho = 1$ for all countries.

Since ρ denotes the share of standards motivated by the consumption externalities, I need to repeat the procedure described in Subsection 5.2 and recalibrate all externality weights ω_{jr} for different values of ρ. Figure 1 shows each country's average ω_{jr} for $\rho \in [0.2, 1]$.[30] From the figure, we can observe a descending trend in the calibrated ω_{jr} as ρ increases. This pattern can be explained by the crucial assumption in the calibration procedure: The factual standards constitute a Nash equilibrium in which countries unilaterally maximize their welfare under the constraint of national treatment. When the share of standards motivated by the consumption externalities is smaller, a larger weight of the consumption externalities is needed to rationalize the observed factual standards. We also observe from Figure 1 that the rank of each country's average ω_{jr} remains relatively stable. Regardless of the value of ρ, developed countries have higher externality weights, whereas China always ranks last.

Figure 2 illustrates how welfare changes from unilateral optimal standards vary with ρ. In the figure, "Own" represents the average of each country's own welfare change when setting standards unilaterally for various values of ρ. Meanwhile, "Other" represents the average of other countries' welfare changes. We can see that the magnitude of both the average welfare gain of the country imposing unilateral standards and the average welfare loss of other countries increases with ρ. As Table 4 shows, the average welfare gain of the country imposing unilateral standards is 1.2% when $\rho = 1$, whereas the average loss of other countries is 0.6%. At the same time, the corresponding average welfare gain and loss when $\rho = 0.2$ are 0.7% and 0.2%, respectively. I also compute the average welfare loss in the trade war scenario for various values of ρ. When ρ is set to 0.2, the welfare loss averages 0.4%. In comparison, the average welfare loss when $\rho = 1$ is 2.8%, as shown in Subsection 6.2.

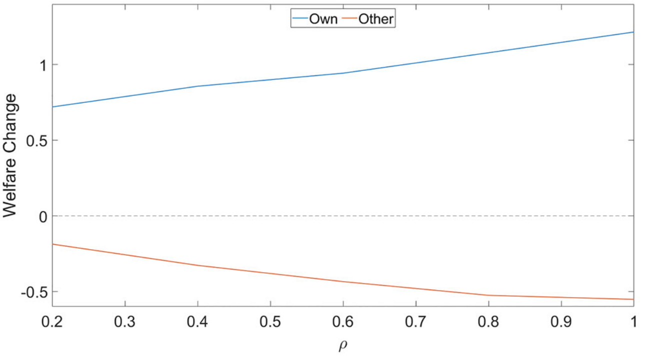
[30] Product standards are fixed when $\rho = 0$, resulting in no welfare change in the counterfactual analysis. For this reason and the fact that the calibration of ω_{jr} is time consuming, I only consider $\rho = 0.2, 0.4, 0.6, 0.8$, and 1 in this exercise.



NOTES: This figure shows the average calibrated ω_{jr} for each country given different values of $\rho \in [0.2, 1]$. When $\rho = 1$, the calibrated ω_{jr} values are the same as those shown in Table 1.

FIGURE 1

CALIBRATED EXTERNALITY WEIGHT ω_{jr} WITH VARYING ρ



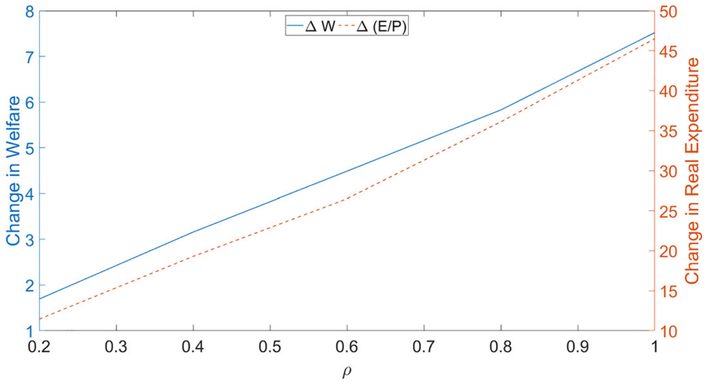
NOTES: "Own" represents the average of each country's own percentage welfare change when setting product standards unilaterally given different values of $\rho \in [0.2, 1]$. "Other" represents the average of other countries' percentage welfare changes.

FIGURE 2

WELFARE CHANGE FROM UNILATERAL STANDARDS WITH VARYING ρ

I also analyze how the welfare outcomes of cooperative standards presented in Subsection 6.3 vary with ρ. Figure 3 plots each country's percentage welfare change ΔW_j and the average percentage change in real expenditure $\Delta(E_j/P_j)$ with various values of ρ when cooperative standards are set to maximize all countries' welfare equally under national treatment.[31] We can see that when ρ decreases from 1, both ΔW_j and average $\Delta(E_j/P_j)$ in the computed cooperative equilibrium also decrease at a similar pace. As discussed in Subsection 6.3, low standards are set in the cooperative equilibrium to improve real expenditure at the expense

[31] When $\rho < 1$, I cannot follow the interpretation discussed in Subsection 6.3 and compute cooperative standards under mutual recognition. This is because the range of optimal standards depends on factual standards, which can be very different across importing countries. As a result, the additional constraint $s_{ijr} = s_{ir}^{MR}$ cannot be satisfied in some sectors when computing the cooperative standards under mutual recognition for $\rho < 1$.



NOTES: The solid line represents the percentage welfare change of cooperative standards under national treatment given different values of $\rho \in [0.2, 1]$. The dashed line represents the corresponding average percentage change in real expenditure.

FIGURE 3

WELFARE CHANGE FROM COOPERATIVE STANDARDS WITH VARYING ρ

of larger consumption externalities when $\rho = 1$. From Figure 3, we can see that this pattern also holds when $\rho < 1$. This is again because the calibrated weights of consumption externalities, although increasing in magnitude when ρ decreases, are still less than 1 on average. As a result, lowering cooperative standards reduces the welfare of the importing country due to the worse negative consumption externality, but simultaneously benefits other countries' real expenditure to a greater extent.

The generalized model used for the quantitative exercise incorporates the production relocation effect and terms-of-trade effect, both of which are sources of international inefficiency in the noncooperative equilibrium. In order to quantify the relative importance of the two channels, I compute unilateral standards when countries abandon national treatment with an additional constraint that wage ratios are fixed. Since the terms-of-trade effect is shut down in this case, the international inefficiency arising from noncooperative product standards can only operate through production relocation and the direct effect of fixed costs on the extensive margin. As shown in Subsection C.1 of the Online Appendix, the average welfare improvement of abandoning national treatment when terms of trade are fixed is 0.9%, or around 70% of the average welfare improvement in the case of unconstrained unilateral standards.

Note that since σ_r used in the quantitative exercise varies by sector, it is possible for the government to use product standards to correct domestic misallocation across sectors. In Subsection C.2 of the Online Appendix, I explore an alternative approach to calibrating ω_{jr}, which arguably controls for a government's incentive to correct sectoral misallocation. The resulting unilateral optimal standards display a similar pattern. At the same time, the average welfare gain from abandoning national treatment is larger because I no longer assume that factual standards maximize domestic welfare under national treatment. In addition, I also compute the unilateral standards with a uniform elasticity of substitution equal to the simple average of the estimated σ_r used in the main analysis. The resulting standards and welfare changes when national treatment is abandoned unilaterally are very similar to those presented in Table 4. Such resemblance implies that the role of sectoral misallocation is limited in the quantitative analysis presented in this section.

7. CONCLUSION

I develop a flexible framework to study regulatory protection and international cooperation on 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. I show that the WTO's principle of national treatment cannot lead to an efficient equilibrium when standards affect the fixed cost of production and no other policy instruments are available. I then use the full model to quantitatively analyze cooperative and noncooperative standards. In the scenario of global trade war in which all countries abandon national treatment, the average welfare loss is 2.8%. However, when countries engage in various forms of efficient multilateral cooperation, the potential welfare gain ranges from 1.4% to 11.8%.

The contribution of this article is twofold. From a theoretical perspective, I incorporate product standards into a Krugman (1980)-style "new trade" model. My model not only incorporates the forces found in earlier papers, but also identifies a novel and important channel through which standards affect welfare: adjustment in the number of varieties. From a quantitative perspective, this article provides the first comprehensive analysis of the welfare effects of cooperative and noncooperative standards. The results of the quantitative exercise indicate that international cooperation on standards is still in its early stages, which is consistent with the focus on regulatory protection observed in recent trade negotiations.

My analysis can be extended in several meaningful ways. For instance, in both the theoretical and quantitative analyses of this article, product standards as a regulatory policy are motivated by the consumption externality. Future studies can explore an alternative approach in which standards affect demand directly through product quality. Furthermore, as discussed in recent works such as Lashkaripour and Lugovskyy (2023) and Bartelme et al. (2021), external economies of scale play an important role in determining optimal industrial policy. Future research can allow industry-level scale elasticities to differ from trade elasticities and analyze the effect of product standards in correcting domestic misallocation. It would also be interesting to expand the policy set to include domestic industrial policies and analyze their interactions with product standards.

Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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APPENDIX

A.1 *Alternative Assumption about Externality.* The analysis in Section 3 assumes additive separability of the negative consumption externality. When this assumption is dropped, the interaction between standards on domestic and imported products also affects 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 either the variable cost or the fixed cost case presented in Section 3. This is because this externality is local and does not depend on foreign standards. Regardless of the functional form of Ω_j, country j fully internalizes the impact of standards on Ω_j in both the noncooperative equilibrium and the equilibrium under national treatment.

Another possible change is to include the quantity of heterogeneous goods consumed as an argument of Ω_j. This scenario is more applicable when the externality is associated with environment or health. Because I assume there is no terms-of-trade effect, total expenditure on heterogeneous goods is μL_j. Therefore, the quantity consumed depends only on the ideal price index of the heterogeneous goods P_j. For this reason, I can 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 heterogeneous goods increases the negative consumption externality. Note that there are now two 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:

$$\frac{\mu L_j}{P_j^{\mu+1}} \frac{\partial P_j}{\partial s_{ij}} + \frac{\partial \Omega_j}{\partial s_{ij}} + \frac{\partial \Omega_j}{\partial P_j} \frac{\partial P_j}{\partial s_{ij}} = 0,$$

$$\frac{\mu L_j}{P_j^{\mu+1}} \frac{\partial P_j}{\partial s_{jj}} + \frac{\partial \Omega_j}{\partial s_{jj}} + \frac{\partial \Omega_j}{\partial P_j} \frac{\partial P_j}{\partial s_{jj}} = 0.$$

s_{ij} in the noncooperative Nash equilibrium may no longer equal s^{max}. This is because production relocation increases the consumption of the heterogeneous products, which in turn increases the negative consumption externality. Country j now has less incentive to impose high standards on imported goods. Similar to the analysis in Section 3, the noncooperative Nash equilibrium is still inefficient, as no country internalizes the externality on the other country through international trade.

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

$$\frac{\partial W_j}{\partial s_j^{NT}} = -\frac{\mu L_j}{P_j^{\mu+1}} \frac{\partial P_j}{\partial s_j^{NT}} - \left(\frac{\partial \Omega_j}{\partial s_j^{NT}} + \frac{\partial \Omega_j}{\partial P_j} \frac{\partial P_j}{\partial s_j^{NT}} \right). \tag{A.1}$$

In the marginal cost case, the expression of P_j in equilibrium is still the same as in (4). Note that analogous to the result in Subsection 3.1, $\frac{\partial P_j}{\partial s_i^{NT}} = 0$. Consequently, 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 national treatment, 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 as in the proof for Proposition 1.

In the fixed cost case with national treatment, the expression of P_j in equilibrium is still the same as in (5), and the partial derivative of country j's welfare with respect to s_j^{NT} is still (A.1). However, we know from (8) 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.2 *Externality and Pigouvian Tax.* Assumption 1 enables us to focus on consumption externalities that are associated with product features and hence motivate standards. Since Ω_j in Assumption 1 does not depend on the quantity of consumption, the usual arguments for Pigouvian taxes do not apply. To see this, I can additionally allow country j's government to impose a consumption tax t_j^c on all heterogeneous goods sold to market j. The real expenditure component U_j of W_j is now a function of t_j^c, but Ω_j still only depends on s_{ji} and s_{jj}. Therefore, Assumption 1 does not motivate Pigouvian taxes to reduce the consumption externality.

Even if I introduce Pigouvian taxes and allow the negative consumption externality to depend on quantity, there are still incentives to use product standards to reduce the negative externality. To see this, let t_j^c denote a consumption tax on heterogeneous goods sold in market j and define $\mathbf{T} = \{t_1^c, t_2^c\}$. In addition, define $\mathbf{S} = \{s_{11}, s_{12}, s_{21}, s_{22}\}$. If I_j denotes the total nominal income of country j, then by definition $I_j = L_j + t_j^c(\tau p_{ij} x_{ij} + p_{jj} x_{jj})$ and $U_j = \frac{I_j}{P_j^{\mu}}$. Note that $\mathbf{T}$ affects U_j through both nominal income I_j and the price index P_j. Moreover, the negative consumption externality now depends on the quantity of heterogeneous goods consumed, which is measured by the corresponding real expenditure $(\mu I_j)/(P_j)^{\mu} = \mu U_j$. Hence, country j's welfare is

$$W_j = U_j(\mathbf{S}, \mathbf{T}) - \Omega_j(s_{ij}, s_{jj}, \mu U_j(\mathbf{S}, \mathbf{T})),$$

where $\frac{\partial \Omega_j}{\partial U_j}$ is assumed to always be positive. In addition, I assume $\frac{\partial \Omega_j}{\partial s_{jj}} < 0$ and $\frac{\partial \Omega_j}{\partial s_{ij}} < 0$ as in Assumption 1.

Country j's government can now use s_{ij}, s_{jj}, and t_j^c to maximize its welfare W_j. Focusing on interior solutions only, an optimal consumption tax t_j^c requires

$$\frac{\partial U_j}{\partial t_j^c} - \frac{\partial \Omega_j}{\partial U_j} \frac{\partial U_j}{\partial t_j^c} = 0. \tag{A.2}$$

Optimal product standards, meanwhile, require

$$\frac{\partial U_j}{\partial s_{jj}} - \frac{\partial \Omega_j}{\partial s_{jj}} - \frac{\partial \Omega_j}{\partial U_j} \frac{\partial U_j}{\partial s_{jj}} = 0 \qquad \frac{\partial U_j}{\partial s_{ij}} - \frac{\partial \Omega_j}{\partial s_{ij}} - \frac{\partial \Omega_j}{\partial U_j} \frac{\partial U_j}{\partial s_{ij}} = 0. \tag{A.3}$$

Consider, for example, a policy combination $\{t_j^c = t_j^{c*}, s_{ij} = s_{jj} = 0\}$ such that $1 - \frac{\partial \Omega_j}{\partial U_j} = 0$. In this case, the first-order condition for t_j^c (A.2) is satisfied. However, the first-order conditions for product standards (A.3) are not satisfied. From this policy combination, increasing the s_{ij} and s_{jj} will strictly improve country *j*'s welfare. Moreover, Lemma 1 and Lemma 2 still hold in the marginal cost case and fixed cost case, respectively. As a result, raising s_{ij} will improve W_j through both a reduction of Ω_j and production relocation, leading to an inefficient noncooperative equilibrium. This result is consistent with Proposition 2 in Grossman et al. (2021), which shows that the noncooperative equilibrium is inefficient even when trade taxes and consumption subsidies are set at their efficient levels.

A.3 *Proof of Proposition 1.* The following lemma is useful for other parts of the proof.

LEMMA A.1. *Consider the marginal cost case in which Assumption 2 is followed. Then, when two governments choose standards simultaneously to maximize welfare, in the unique Nash equilibrium, s^{max} is always imposed on imported heterogeneous goods.*

PROOF. From Lemma 1, $\frac{\partial W_j}{\partial s_{ij}} > 0$ for all possible combinations of standards. Therefore, $s_{ij} = s_{ji} = s^{max}$ follows immediately. The uniqueness of the Nash equilibrium is due to the convexity of Ω_j and the fact that $\frac{\partial}{\partial s_{jj}}(\frac{L_j}{P_j^{\mu}}) < 0$ for all possible combinations of standards, which also follows directly from Lemma 1. □

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

$$dW_1 = \frac{\partial W_1}{\partial s_{11}} ds_{11} + \frac{\partial W_1}{\partial s_{21}} ds_{21} + \frac{\partial W_1}{\partial s_{12}} ds_{12} + \frac{\partial W_1}{\partial s_{22}} ds_{22}, \tag{A.4}$$

$$dW_2 = \frac{\partial W_2}{\partial s_{11}} ds_{11} + \frac{\partial W_2}{\partial s_{21}} ds_{21} + \frac{\partial W_2}{\partial s_{12}} ds_{12} + \frac{\partial W_2}{\partial s_{22}} ds_{22}. \tag{A.5}$$

Consider the regulatory changes $ds_{22} > 0$ and $ds_{11} = ds_{12} = ds_{21} = 0$. In the noncooperative Nash equilibrium, $\frac{\partial W_2}{\partial s_{22}} = 0$. Therefore, from (A.5), we have $dW_2 = 0$. However, from Lemma 1, we know that $\frac{\partial P_1}{\partial s_{22}} < 0$, which implies $\frac{\partial W_1}{\partial s_{22}} > 0$. Substituting this result into (A.4), we have $dW_1 > 0$. The resulting combination of regulatory changes is Pareto improving.

To prove that the equilibrium with national treatment is unique and Pareto efficient, I first differentiate (4) to have $\frac{\partial P_j}{\partial s_j^{NT}} = \frac{\sigma}{\sigma-1}(\frac{f\sigma}{\mu L_j(1+\tau^{1-\sigma})})^{\frac{1}{\sigma-1}} c'(s_j^{NT}) > 0$. The second-order derivative is: $\frac{\partial^2 P_j}{\partial (s_j^{NT})^2} = \frac{\sigma}{\sigma-1}(\frac{f\sigma}{\mu L_j(1+\tau^{1-\sigma})})^{\frac{1}{\sigma-1}} c''(s_j^{NT}) > 0$. Given the assumptions about Ω_j and the fact that $\frac{\partial}{\partial s_j^{NT}}(\frac{L_j}{P_j^{\mu}}) < 0$ for all $s_j^{NT} \in [0, s^{max}]$, the optimal s_j^{NT} under national treatment 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 combination of (ds_1^{NT}, ds_2^{NT}).

A.4 *Proof of Proposition 2.* Since the signs of the partials in Lemma 2 are identical to those in Lemma 1, I can follow the exact same steps in the proof of Proposition 1 to show that the noncooperative equilibrium is Pareto inefficient. To show that the Nash equilibrium under 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 differentiating dW_j gives:

$$dW_j = -\frac{\mu L_j}{P_j^{\mu+1}} \frac{\partial P_j}{\partial s_j^{NT}} ds_j^{NT} - \frac{\mu L_j}{P_j^{\mu+1}} \frac{\partial P_j}{\partial s_i^{NT}} ds_i^{NT} - \Omega_j'(s_j^{NT}) ds_j^{NT}. \tag{A.6}$$

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

$$-\frac{\mu L_j}{P_j^{\mu+1}}\frac{\partial P_j}{\partial s_j^{NT}} - \Omega_j'(s_j^{NT}) = 0. \tag{A.7}$$

Consider standard changes $ds_1^{NT} = 0$ and $ds_2^{NT} < 0$. From (A.6) and (A.7), we have $dW_2 = 0$. At the same time, because $-\frac{\mu L_1}{P_1^{\mu+1}}\frac{\partial P_1}{\partial s_2^{NT}} < 0$, we have $dW_1 > 0$. Therefore, the standard combination in the Nash equilibrium is Pareto inefficient.

A.5 *Quantitative Exercise: Equilibrium Conditions in Changes.* Assuming that standards are the only possible policy instruments, conditions (16)–(18) can be rewritten as:

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

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

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

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 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 (14) and (15), we have

$$\hat{c}_{ijr} = \exp\left(c_r^1(\tilde{s}_{ijr}' - \tilde{s}_{ijr})\right),$$

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

Finally, in the counterfactual equilibrium, the welfare change of country j 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 $\xi_j = E_j - \sum_{r=1}^{R}\sum_{i=1}^{M} \omega_{jr}(1+t_{ijr})X_{ijr}(1-\tilde{s}_{ijr})$.