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Dumping, antidumping duties, and price undertakings

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ABSTRACT

This paper examines which types of firms, from a developed country (DC) or a less developed country (LDC), tend to practice dumping, using a two-market equilibrium analysis of trade in similar products. Specifically, we present a vertical product differentiation model of duopolistic competition between a DC firm and an LDC firm under free trade to show that the DC firm sells a higher-quality product without dumping. In contrast, the LDC firm sells a lower-quality product and practices dumping in the DC market by charging a price lower than the product's price in the LDC's local market. In response to the LDC dumping, the DC government's use of an optimal antidumping duty increases its domestic welfare. The LDC's social welfare may increase if its exporting firm accepts price undertaking rather than dumping. From the perspective of world welfare, defined by aggregating the welfare of the trading countries (DC and LDC), the trade damage measure through imposing antidumping fines on LDC dumping is Pareto-improving compared to free trade (under which dumping takes place) and price undertakings.

1. Introduction

Unfair trade practices such as dumping products into the markets in developed countries continue to make business news headlines. In 2019, American Kitchen Cabinet Alliance petitioned the U.S. International Trade Commission (ITC) against cheap wooden cabinets and vanities imported from China. On April 6, 2020, the ITC documented that Chinese exporters dumped wooden cabinets and vanities of $4.4 billion worth in the U.S. market in 2018. The ITC's findings confirmed that the Chinese exporters' unfair trade practices materially injured the U.S. domestic industry. The ITC imposed antidumping (AD) duties on seven Chinese wooden cabinets and vanities exporters/producers, ranging from 4.37% to 262.18% (US Department of Commerce 2020b). The use of AD duties by the U.S. government is not limited to products such as wooden cabinets and vanities. The U.S. government has been investigating whether aluminum foil from Armenia, Brazil, Oman, Russia, and Turkey is dumped in the U.S. market (US International Trade Commission 2021). Likewise, Wind Tower Trade Coalition filed a petition against India and Malaysia for dumping utility-scale wind towers at the alleged dumping margin of 54% for India and 93% for Malaysia. The U.S. government investigates whether these exports injured the U.S. industry by selling their product at less than fair value (US Department of Commerce, 2020a). These cases exemplify the practices of dumping products at lower prices in developed countries, where governments may impose antidumping duties as unfair trade remedies.

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One crucial concern is whether World Trade Organization (WTO, 2021a, 2021b) does not see dumping as an unfair trade practice and thus does not necessarily support using antidumping duties. WTO provides member states a mechanism to deal with dumping practices known as the "Anti-Dumping Agreement." GATT/WTO (Article 6) allows a member state to take action against dumping when there is material damage to its domestic industry due to a lower price of an imported product than its price in the exporting country's market. In addition to the WTO documentation, scholarly work widely recognizes that dumping is an unfair trade practice. Researchers cautiously remark that WTO does not necessarily prohibit dumping unless it causes a material injury to a trading partner. In this case, the trading partner's imposition of an AD policy makes dumping a costly choice.[1]

From a global perspective, there are significant issues concerning (i) which types of firms, from developed countries (DCs) or less developed countries (LDCs), tend to practice dumping and (ii) whether DC or LDC governments are likely to launch antidumping investigations into imports. How is dumping related to trade in similar products? Given the growing concern over the large-scale dumping of cheap products to DCs, would LDCs be better off if their governments restrained exporters from practicing dumping? Are antidumping duties efficacious in protecting domestic firms and hence proven to be a welfare-improving policy for an importing country? How would the global dumping of lower-quality products affect the Pareto superiority of worldwide free trade? Can world welfare (defined by aggregating the social welfare of DC and LDC as trading partners) be higher under an AD policy than under free trade in the presence of dumping? This paper answers these questions with a two-market equilibrium analysis of international trade between DC and LDC in quality-differentiated products.

In retrospect, voluminous studies have contributed to our understanding of dumping and antidumping regulations.[2] Recognizing the literature's contributions, we follow the GATT/WTO guidelines to derive the conditions under which dumping arises by directly comparing the equilibrium market prices of similar products sold by DC and LDC firms.[3] The equilibrium price comparison for a firm's product sold in both DC and LDC markets helps identify the firm type (DC or LDC) that practices dumping. In characterizing international duopoly under free trade, we use a two-stage game where each competing firm endogenously determines its product quality level before engaging in price competition in the DC and LDC markets. We consider inter-country income differentials, which reflect different degrees of international market competition. Within the two-way trade in quality-differentiated products between DC and LDC firms,[4] we show that the DC firm sells a higher-quality product due to its economic incentive to undertake R&D for quality improvements. In contrast, the LDC firm sells a lower-quality product with no interest in costly R&D for quality up-gradation. These analytical results are consistent with the empirical findings that, on average, a DC firm's strategic choice of product quality is relatively higher than that of an LDC firm (Amiti and Khandelwal, 2013). Moreover, our trade model in quality-differentiated products with inter-country income differentials reveals that the DC firm does not practice dumping under free trade, whereas the LDC firm dumps its lower-quality product into the DC market at a price lower than the LDC's local price.

The framework of trade in similar products (with quality differentiation) permits us to investigate how consumers and producers in two trading countries (DC and LDC) are affected by three different trade regimes: free trade, antidumping (AD), and price undertaking. Facing the LDC dumping of a lower-quality product in the DC market under free trade, the importing country's government (i.e., DC) responds by imposing AD duties. The analysis indicates that DC consumers and producers gain a higher surplus by consuming and producing more of the higher-quality good and less of the lower-quality good. As such, DC's overall welfare is highest under the AD regime. However, DC consumers and producers confront the highest economic costs when their government allows LDC dumping firms the option of price-undertakings. We find that the win-win-win equilibrium by imposing AD duties on LDC dumping may explain why under the auspices of antidumping regulations, the U.S. government favors the use of antidumping policies rather than the offering of price-undertakings to foreign dumpers.[5]

As for the economic effects on LDC, we show that LDC consumers are better off when the DC government imposes AD duties on LDC

[1] See, e.g., Murray and Rousslang (1989, p. 149), Sykes (1996, p. 5), Bloneign and Prusa 2015 (p. 1), and Mankiw and Swagel (2005, p. 107).

[2] Viner (1923) is among the first to define dumping as the practice of international price discrimination. Contemporary studies on dumping include Prusa (1992, 1994, 2001), Anderson, Schmitt, and Thisse (1995), Blonigen and Prusa (2003), Gao and Miyagiwa (2005), Dinlersoz and Dogan (2010), and Wu et al. (2014). For studies that address issues on the political economy of antidumping see, e.g., Finger, Hall, and Nelson (1982), and Nelson (2006). For recent antidumping issues such as the Continued Dumping and Subsidy Offset Act implemented by the U.S. government under which the revenues from AD duties are redistributed to domestic firms alleging harm see, e.g., Collie and Vandenbussche (2006), and Chang and Gayle (2006). For issues concerning antidumping measures and economic effects see, e.g., Vandenbussche and Wauthy (2001), Pauwels and Springael (2002), Belderbos et al. (2004), Moore (2005), and Ishikawa and Miyagiwa (2008). Blonigen and Prusa (2016) present a systematic review of dumping and antidumping activity. For studies addressing the effectiveness of antidumping duties, see Konings and Vandenbussche (2008, 2013) and Veigelahn and Vandenbussche (2018).

[3] The "technical information on dumping" put forth by the GATT/WTO on its official website permits member countries to identify circumstances under which dumping in international trade emerges. It states that: "*Dumping is, in general, a situation of international price discrimination, where the price of a product when sold in the importing country is less than the price of that product in the market of the exporting country. Thus, in the simplest of cases, one identifies dumping simply by comparing prices in two markets* (*WTO, 2021a*)."

[4] Our analytical framework is similar to a North-South trade model where one firm in the North (a developed country) competes with one firm in the South (a less developed country) in both the northern and southern markets. The DC-LDC trade is equivalent to the North-South trade.

[5] It is instructive to mention at the outset that, practically, authorities may not pursuit social welfare maximization as an objective in setting an optimal AD duty. In our study, we aim to see whether authorities' practice or mode of regulation (e.g., free trade, an AD policy, or a price taking) can be explained by the equilibrium outcomes under welfare maximization. One possible reason why AD protection is opposed is that it explicitly ignores *overall welfare*, which means consumers, producers, and government revenue. This promotes us to consider welfare maximization as a country's objective when choosing an optimal policy in response to unfair trade practices such as dumping.

dumping than when there is free trade. The economic intuition behind this result is as follows. Under an AD policy, gains in surplus to LDC consumers by consuming a higher-quality imported product outweigh the loss of consumer surplus resulting from buying the lower-quality domestic product at an increased price. However, the LDC firm enjoys the highest producer surplus by dumping its lower-quality product under free trade. Third, LDC's welfare is the highest when its exporter accepts a price-undertaking, but the welfare is the lowest when the exporter dumps its lower-quality product and pays AD fines.

From the perspective of world welfare, calculated by aggregating the welfare of trading partners (DC and LDC), we show that the trade damage measure of imposing AD duties is Pareto-improving compared to free trade (under which dumping takes place). This result provides a theoretical justification for AD duties in response to foreign dumping.[6]

This paper contributes to the literature by identifying the firm type (DC or LDC) that tends to practice dumping, on the one hand, and showing whether DC or LDC governments are likely to launch AD actions against foreign dumpers, on the other. Prusa (2001) empirically documents that until the 1980s, approximately 95% of the AD disputes were initiated by DCs against imports from LDCs. Vandenbussche and Zanardi (2008) find that the later trend reveals that LDCs are also highly involved in AD actions. Bown (2011a, b) indicates that AD actions are generally concentrated across traditional users (DCs) and new AD users (LDCs).[7] Interestingly, Bown (2013) further remarks that most of the new AD disputes launched by LDCs have targeted imports of cheaper products from other LDCs – the so-called "South-South protectionism."[8] Blonigen and Prusa (2016) document that, based on AD duties' size, DCs remain the most frequently observed AD policy users against the unfair practices of dumping firms from LDCs. Hansen and Neilsen (2009) show that product quality differences lead to higher-quality firms soliciting tariff protection. The authors remark that product differentiation makes AD policy more beneficial to those firms manufacturing and exporting higher quality (i.e., the developed world). Our analysis of LDC dumping deviates from the reciprocal dumping model of Brander and Krugman (1983) in two crucial respects. First, we examine two-way trade in quality-differentiated products, while Brander and Krugman examine two-way trade in identical products without quality differentiation. Second, we look at the DC-LDC trade when there are inter-country income differentials or different degrees of international market competition. Brander and Krugman analyze issues of trade between two DCs with identical economies. The contribution by Flam and Helpman (1987) is among the first to analyze north-south trade in vertically differentiated products. The authors focus on trade issues other than dumping.

Our study complements the contribution of Moraga-González and Viaene (2015) in examining trade between a DC and an LDC. The methodological differences and the economic implications between the two studies are as follows. We examine a fully covered market for products.[9] Moranga-Gonzalez and Viaene analyze dumping issues for a partially covered market. We show that the DC firm produces a higher-quality product and does not practice dumping, but the LDC firm produces a lower-quality product and practices dumping in the DC market. As a consequence, dumping is a result of lower product quality. Moraga-González and Viaene (2015) show that DC firms practice dumping in LDC markets. The authors find that an LDC government opts for a price-undertaking policy toward a DC dumping firm and that the policy benefits the implementing country (i.e., LDC) but negatively affects global welfare. Our model shows that an antidumping policy is welfare-increasing to an implementing country (i.e., DC) and the world (measured by the aggregate welfare of the trading partners).

The remainder of the paper is organized as follows. Section 2 first lays out an analytical framework of trade in quality-differentiated products to analyze competition between a DC firm and an LDC firm in both of their markets. We consider three different trade regimes: free trade with the presence of dumping, an antidumping policy, and a price undertaking. Section 3 compares firm profits, consumer surplus, and social welfare in DC and LDC under alternative trade regimes. Section 4 contains concluding remarks.

2. A model of two-way trade in quality-differentiated products

2.1. Basic assumptions

Based on GATT/WTO guidelines and regulations on dumping, we present a two-market analysis for comparing the equilibrium prices of a final consumption good sold in domestic and foreign countries (i.e., DC and LDC due to their income differentials). We first identify conditions under which dumping arises and then evaluate DC and LDC's resulting impacts under different trade regimes. Specifically, we consider a trade model under international duopoly in which a DC firm (denoted by 1) and an LDC firm (denoted by 2) produce similar products with vertical differentiation and compete in their domestic markets and the markets abroad.[10]

[6] Though AD duty is an important policy to deal with dumping under WTO regulations, it is not the only choice to deal with dumping. In the real world, some trading nations might use other policy options such as price undertaking.

[7] Traditional AD users (DCs) include the United States, the European Union, Canada, and Australia, whereas the leading new users include Argentina, Brazil, China, India, and Turkey (Blonigen and Prusa 2016).

[8] We also look at whether our model of a DC-LDC (North-South) trade can be applied to an LDC-LDC (South-South) trade model when two trading LDCs differ in their national incomes and engage in imports and exports of quality-differentiated products. In the case of an LDC-LDC trade, we infer that an LDC firm from a relatively higher-income country sells a higher-quality product and does not practice dumping. In contrast, the other LDC firm from a relatively lower-income country sells a lower-quality product and practices dumping. In terms of initiating AD disputes, we can apply our analysis to predict that there is "LDC-LDC protectionism" or "South-South protectionism" (as addressed in Bown (2013)).

[9] The assumption of a fully covered market in each country is consistent with the literature that uses a vertical product differentiation framework (see, e.g., Wauthy 1996; Andaluz 2000; Chang and Raza 2018).

[10] Our theoretical framework assumes that both markets are of equal size. This assumption allows us to attain reduced-form solutions. Note that some studies consider the difference in market size impact on trade war (e.g., Miyagiwa, Song, and Vandenbussche 2016).

We adopt the plausible assumption that, other things being equal, DC consumers have relatively higher incomes on average than LDC consumers. This assumption allows us to introduce a parameter λ that reflects the degree of inter-country income differential.

(i) ***LDC market***

We first look at the LDC market where consumers are uniformly distributed along the line, denoted as $\theta \in [a, a+1]$ for $a > 0$. Each consumer purchases one unit of a product (either domestic or foreign), which is taken to be a necessity. Let p_1 be the price of the DC firm's product and p_2 be that of the LDC firm's product. Following the literature on vertical product differentiation, we specify the indirect utility function of an LDC consumer located at point θ as

$$V_{LDC}(\theta) = \begin{cases} \theta q_1 - p_1 \text{ if buys the DC firm's product at price } p_1, \\ \theta q_2 - p_2 \text{ if buys the LDC firm's product at price } p_2, \end{cases} \tag{1}$$

where q_i is the quality of the good produced by firm $i(=1,2)$. The preference function in (1) implies that for an LDC consumer at θ, his/her marginal utility of consuming product i is θq_i.[11]

To allow for the possibility of improving product quality through a firm's costly R&D investment, we follow the approach in Chang and Raza (2018) by assuming that

$$q_i = 1 + s_i, \tag{2}$$

where $s_i(\geq 0)$ denotes the level of quality-upgrade resulting from R&D investment by firm $i(=1,2)$. In the absence of quality-upgrades, we have $s_1 = s_2 = 0$ which implies the case of no product differentiation $(q_1 = q_2 = 1)$. As several studies in the R&D investment literature, each firm's quality-upgrading expenditure is taken to a quadratic form: $E_i = \gamma_i s_i^2/2$, where the parameter $\gamma(>0)$ denotes the cost-effectiveness of investment by firm $i(=1,2)$.[12] We consider the levels of quality-upgrades, $\{s_1, s_2\}$, as endogenous variables optimally chosen by the DC and LDC firms. We shall show that the optimal quality-upgrades vary across different trade regimes.

It follows from the preference structure in (1) and the quality up-gradation equation in (2) that the LDC's marginal consumer (located at $\widehat{\theta}$) is indifferent between the two products. That is, $\theta(1+s_1) - p_1 = \theta(1+s_2) - p_2$. For $0 < \widehat{\theta} < 1$, market demands for the DC firm's product and the LDC firm's product are:[13]

$$D_2(p_1, p_2) = \widehat{\theta} = \frac{p_1 - p_2}{s_1 - s_2} \text{ and } D_1(p_1, p_2) = 1 - \widehat{\theta} = 1 - \frac{p_1 - p_2}{s_1 - s_2}, \tag{3}$$

where $D_1(p_1, p_2)$ defines the LDC's import demand.

(i) ***DC market***

We use a superscript "$*$" to denote all the related variables for the DC market. We assume a uniform distribution of DC consumers over the line with $\theta^* \in [a, a+1]$, where each consumer purchases one unit of a product which is a necessity. In the DC market, we denote p_1^* as the price of the DC firm's product and p_2^* as that of the LDC firm's product.

As addressed earlier, there is an inter-country income differential between DC and LDC, which is captured by the parameter λ, where $\lambda \in (0,1)$. We thus specify the indirect utility function of a DC consumer located at point θ^* as

$$V_{DC}(\theta^*) = \begin{cases} \lambda\theta^* q_1 - p_1^* \text{if buys the DCfirm's product at } p_1^*, \\ \lambda\theta^* q_2 - p_2^* \text{if buys the LDC firm's product at } p_2^*, \end{cases} \tag{4}$$

where q_i is the quality of product by firm $i(=1,2)$. The preference function in (4) implies that for a DC consumer located at θ^*, his/her marginal utility of consuming product i is $\lambda\theta^* q_i$.[14]

It is plausible to assume that, other things being equal, wealthier consumers in DC have *lower* marginal utility relative to less wealthy consumers in LDC. This assumption is consistent with *the law of diminishing marginal utility* as income rises.[15] Based on the preference structures in (1) and (4), the income differential between DC and LDC implies that the marginal utility is *lower* in DC than

[11] To guarantee the marginal utility of consumption is strictly positive for all consumers in a fully covered market, we assume the parameter θ is greater than zero. This explains why we consider the unit line interval $\theta \in [a, a+1]$ with $a > 0$. See, e.g., Karakosta (2018) for the same methodology in treating a consumer's marginal willingness to pay to be strictly positive when the consumer is located at point $\theta = a(>0)$ in a fully covered market (pp. 696-697).

[12] We borrow the assumption that $\gamma_1 > \gamma_2$from previous studies on R&D investment and its cost-effectiveness (see, e.g., Motta, Thisse, Cabrales (1997), Kováč and Žigić (2014), and Chang and Raza (2018)).

[13] There are two possibilities: either (a) $p_1 > p_2 > 0$ and $s_1 > s_2 \geq 0$ or (b) $p_2 > p_1 > 0$ and $s_2 > s_1 \geq 0$. It remains to determine if (a) or (b) holds in equilibrium.

[14] The inequality condition that $0 < \lambda < 1$is consistent with the law of diminishing marginal utility of income.

[15] Note the assumption that we do not consider a Giffen good.

that in LDC. That is,

$$\lambda\theta^* q_i < \theta q_i$$

for DC and LDC consumers located at the same point (i.e., $\theta^* = \theta$) and consuming a given level of product quality q_i. As such, the parameter λ is positive but is less than one. In what follows, we use $\lambda$to denote the degree of DC-LDC income inequality. The parameter λ reflects the degree of market similarity/dissimilarity between the trading partners. There are two cases of interest: (i) If λ is greater and closer to 1, the DC and LDC markets closely resemble each other. In this case, the degree of market competition between DC and LDC is *higher*. (ii) If λ is lower and closer to 0, the DC and LDC markets are becoming dissimilar. In this case, the degree of market competition is *lower*.[16]

Based on the preference structure in (4) and the quality up-gradation equation in (2), the DC's marginal consumer (located at $\widetilde{\theta}^*$) is indifferent between the two products such that $\lambda\widetilde{\theta}^*(1+s_1) - p_1^* = \lambda\widetilde{\theta}^*(1+s_2) - p_2^*$. For $0 < \widetilde{\theta}^* < 1$, market demands for the LDC firm's product and the DC firm's product are:[17]

$$D_2^*(p_1^*, p_2^*) = \widetilde{\theta}^* = \frac{p_1^* - p_2^*}{\lambda(s_1 - s_2)} \text{ and } D_1^*(p_1^*, p_2^*) = 1 - \widetilde{\theta}^* = 1 - \frac{p_1^* - p_2^*}{\lambda(s_1 - s_2)}, \tag{5}$$

where $D_2^*(p_1^*, p_2^*)$, defines the DC's import demand.

Based on the trade framework in quality-differentiated products between a higher-income country (DC) and a lower-income country (LDC), our next step is to identify the types of firms that tend to practice dumping under free trade. We analyze and compare equilibrium outcomes under three policy options: free trade, trade damage measure of imposing an antidumping duty, and a price undertaking. We begin with the case of free trade.

2.2. Free trade (under which dumping takes place)

Under free trade (denoted by *FT*), we use a two-stage game to characterize the duopolistic competition between DC and LDC firms. At stage one, the firms determine quality upgrades, $s_1^{FT}$and s_2^{FT}, to maximize their respective profits. At stage two, the firms set their profit-maximizing prices,$\{p_1^{FT}, p_1^{*FT}\}$and $\{p_2^{FT}, p_2^{*FT}\}$, respectively, in the DC and LDC markets by engaging in Bertrand competition. Using backward induction, we derive the sub-game perfect Nash equilibrium for the two-stage game.

At the second stage of the game, the DC and LDC firms respectively solve their profit maximization problems as follows:

$$\begin{aligned}
&\underset{\{p_1^{FT}, p_1^{*FT}\}}{\text{Max}}\ \Pi_{DC}^{FT} = p_1^{FT} D_1^{FT}(p_1^{FT}, p_2^{FT}) + p_1^{*FT} D_1^{*FT}(p_1^{*FT}, p_2^{*FT}) - \frac{1}{2}\gamma_1 (s_1^{FT})^2, \\
&\underset{\{p_2^{FT}, p_2^{*FT}\}}{\text{Max}}\ \pi_{LDC}^{FT} = p_2^{FT} D_2(p_1^{FT}, p_2^{FT}) + p_2^{*FT} D_2^{*FT}(p_1^{*FT}, p_2^{*FT}) - \frac{1}{2}\gamma_2 (s_2^{FT})^2,
\end{aligned} \tag{6}$$

where D_1^{FT} and D_2^{FT} are demands in the LDC market as given in (2) while D_1^{*FT} and D_2^{*FT} are demands in the DC market as given in (4). The first-order conditions (FOCs) for the firms imply that the optimal prices of the two firms' products in the DC market are:[18]

$$p_1^{*FT} = \frac{2\lambda(s_1^{FT} - s_2^{FT})}{3} \text{ and } p_2^{*FT} = \frac{\lambda(s_1^{FT} - s_2^{FT})}{3}, \tag{7}$$

and those of the DC firm's product and the LD C firm's product in the LDC market are:

$$p_1^{FT} = \frac{2(s_1^{FT} - s_2^{FT})}{3} \text{ and } p_2^{FT} = \frac{(s_1^{FT} - s_2^{FT})}{3}, \tag{8}$$

Substituting the product prices from (7)–(8) back into (2) and (4), we have the equilibrium demands of the DC firm's and the LDC firm's products in their markets:

$$D_1^{*FT} = \frac{2}{3};\ D_2^{*FT} = \frac{1}{3};\ D_1^{FT} = \frac{2}{3},\ D_2^{FT} = \frac{1}{3}. \tag{9}$$

We move to the first stage of the game at which the DC and LDC firms determine their respective quality-upgrades, $\{s_1^{FT}, s_2^{FT}\}$ To find the solution, we first plug the products' prices from (7)–(8) and their demands from (9) back into the firms' profit functions in (6). The FOCs for the firms with respect to their optimal choices of quality-upgrades imply that

[16] We shall demonstrate that λ plays a role in characterizing price competition for the DC-LDC trade in quality-differentiated products.

[17] There are two possibilities: either (a) $p_1^* > p_2^* > 0$ and $s_1 > s_2 \geq 0$ or (b) $p_2^* > p_1^* > 0$ and $s_2 > s_1 \geq 0$. It remains to determine whether (a) or (b) holds in equilibrium.

[18] If we reverse the order, that is, $s_2^{FT} > s_1^{FT}$ and $p_2^{FT} > p_1^{FT}$, we still have a positive outcome. This is due to the possibility that $p_2^* > p_1^* > 0$ and $s_2 > s_1 \geq 0$. Please see footnotes 13 and 17.

$$s_1^{FT} = \frac{4(1+\lambda)}{9\gamma_1} > 0 \text{ and } s_2^{FT} = 0. \tag{10a}$$

It follows from (2) and (10a) that the equilibrium quality levels for the DC and LDC firms are:

$$q_1 = 1 + \frac{4(1+\lambda)}{9\gamma_1} > 0 \text{ and } q_2 = 1. \tag{10b}$$

Thus, we have $q_1 > q_2$, implying that the DC product is of a higher-quality and the LDC product is of a lower-quality. R&D expenditures on quality improvements by the DC and LDC firms are:

$$E_1^{FT} = \frac{1}{2}\gamma_1\left(s_1^{FT}\right)^2 = \frac{8(1+\lambda)^2}{81\gamma_1} > 0 \text{ and } E_2^{FT} = \frac{1}{2}\gamma_2\left(s_2^{FT}\right)^2 = 0. \tag{10c}$$

These results lead to the first position as follows:

PROPOSITION 1. In the vertical product differentiation model of competition between a DC and an LDC under free trade, the DC firm has an economic incentive to invest in R&D activities for quality improvements and is a higher-quality producer. Nevertheless, the LDC firm does not have any incentive to undertake R&D for quality up-gradation and is a lower-quality producer.[19]

By substituting s_1^{FT} and s_2^{FT} from (10a) back into (7)-(8), we calculate the equilibrium prices of the two products in both the DC and LDC markets:

$$p_1^{*FT} = \frac{8\lambda(1+\lambda)}{27\gamma_1},\ p_2^{*FT} = \frac{4\lambda(1+\lambda)}{27\gamma_1};\ p_1^{FT} = \frac{8(1+\lambda)}{27\gamma_1},\ p_2^{FT} = \frac{4(1+\lambda)}{27\gamma_1}. \tag{11}$$

The equilibrium product prices in (11) permit us to investigate whether any firm sells a product in the foreign market at a price lower than the product's price in its local market. In this case, dumping arises. We first compare p_1^{*FT} and p_1^{FT}, the prices of the DC firm's product sold in both the DC and LDC markets. It follows from (11) that $p_1^{*FT}/p_1^{FT} = \frac{8\lambda(1+\lambda)}{27\gamma_1}/\frac{8(1+\lambda)}{27\gamma_1} = \lambda$, implying that $p_1^{*FT} = \lambda p_1^{FT}$. Given that $0 < \lambda < 1$, we have:

$$p_1^{FT} > p_1^{*FT}. \tag{12}$$

The result in (12) indicates that, in equilibrium, the price of the DC firm's higher-quality product is *higher* in the LDC market than in the DC market. Thus, the DC firm, a higher-quality producer, does not practice dumping in the LDC market.

Next, we compare p_2^{*FT} and p_2^{FT}, the prices that the LDC firm charges for its lower-quality product in both the DC and LDC markets. We have from (11) that $p_2^{*FT}/p_2^{FT} = \frac{4\lambda(1+\lambda)}{27\gamma_1}/\frac{4(1+\lambda)}{27\gamma_1} = \lambda$, implying that $p_2^{*FT} = \lambda p_2^{FT}$. Given that $0 < \lambda < 1$, we have:

$$p_2^{*FT} < p_2^{FT}. \tag{13}$$

The result in (13) indicates that the LDC firm's lower-quality product price is *lower* in the DC market than in the LDC market. Based on the WTO/GATT guidelines, dumping arises. The LDC firm, a lower-quality producer, takes advantage of free trade and practices dumping in the DC market under this regime.

Substituting market demands in (9), R&D investment in (10a), and product prices in (11) back into the profit function in (6), we calculate the DC firm's total profit:

$$\Pi_{DC}^{FT} = \frac{8(1+\lambda)^2}{81\gamma_1}. \tag{14a}$$

We use a general formula to calculate the surplus of DC consumers for the three different regimes (free trade (*FT*), antidumping (*AD*), or price undertaking (*PU*)). This formula is:

$$CS_{DC}^i = \underbrace{\int_a^{\tilde{\theta}^{*i}} \left[\lambda\theta^{*i}\left(1+s_2^i\right) - p_2^{*i}\right] dF(\theta)}_{CS_2^i \text{ in DC}} + \underbrace{\int_{\tilde{\theta}^{*i}}^{a+1} \left[\lambda\theta^{*i}\left(1+s_1^i\right) - p_1^{*i}\right] dF(\theta)}_{CS_1^i \text{ in DC}}, \tag{14b}$$

where i stands for regime $i(= FT, AD, \text{or } PU)$, and CS_2^i and CS_1^i represent respectively economic benefits to DC consumers from buying the lower- and higher-quality products.

For the free trade regime, we have $CS_{DC}^{FT} = CS_2^{FT} + CS_1^{FT}$. Substituting the product prices, market demands, and quality-upgrades from (7)-(11) into the CS measure in (14b) yields

[19] One of the reasons for an LDC's lack of incentive to invest in R&D is Global South R&D inefficiency and failure to enforce intellectual property rights. For details, see Miyagiwa et al. (2016).

$$CS_{DC}^{FT} = \frac{\lambda[(81\gamma_1 - 8\lambda - 8) + a(48 + 48\lambda + 162\gamma_1 + 36a + 36a\lambda)]}{162\gamma_1}. \tag{14c}$$

Defining DC's social welfare as $SW_{DC}^{FT} = CS_{DC}^{FT} + \Pi_{DC}^{FT}$, we substitute CS_{DC}^{FT} and Π_{DC}^{FT} from (14a) and (14c) into the welfare expression. We have:

$$SW_{DC}^{FT} = \frac{\left(24\lambda + 81\lambda\gamma_1 + 8\lambda^2 + 16\right) + a\left(48\lambda + 48\lambda^2 + 162\lambda\gamma_1 + 36a\lambda + 36a\lambda^2\right)}{162\gamma_1}. \tag{14d}$$

Turning to LDC, we compute total profit for the LDC firm by plugging the equilibrium demands, prices, and quality-upgrades from (7)-(11) back into (6). The LDC firm's profit is:

$$\pi_{LDC}^{FT} = \frac{4(1+\lambda)^2}{81\gamma_1}. \tag{15a}$$

The general formula to measure the surplus of LDC consumers under regime i is: $CS_{LDC}^{i} = CS_2^i + CS_1^i$, where CS_2^i and CS_1^i represent economic benefits to LDC consumers from buying the competing products. That is,

$$CS_{LDC}^{i} = \underbrace{\int_{a}^{\widehat{\theta}^i} \left[\theta^i\left(1+s_2^i\right) - p_2^i\right] dF(\theta)}_{CS_2^i \text{ in LDC}} + \underbrace{\int_{\widehat{\theta}^i}^{a+1} \left[\theta^i\left(1+s_1^i\right) - p_1^i\right] dF(\theta)}_{CS_1^i \text{ in LDC}}. \tag{15b}$$

For the free trade regime, we substitute the product prices, market demands, and quality-upgrades from (7)-(11) into the CS measure in (15b) with $i = FT$. This exercise yields

$$CS_{LDC}^{FT} = \frac{(81\gamma_1 - 8\lambda - 8) + a(48 + 48\lambda + 162\gamma_1 + 36a + 36a\lambda)}{162\gamma_1}. \tag{15c}$$

The LDC's social welfare is: $SW_{LDC}^{FT} = CS_{LDC}^{FT} + \pi_{LDC}^{FT}$, where CS_{LDC}^{FT} and π_{LDC}^{FT} are given by (15a) and (15c). It is easy to verify that

$$SW_{LDC}^{FT} = \frac{\left(8\lambda + 81\gamma_1 + 8\lambda^2\right) + a(48 + 48\lambda + 162\gamma_1 + 36a + 36a\lambda)}{162\gamma_1}. \tag{15d}$$

The results of the above analyses permit us to establish the first proposition:

PROPOSITION 2. *In two-way free trade, where the DC firm produces a higher-quality product and the LDC firm produces a lower-quality product, the DC firm does not practice dumping. Nevertheless, the LDC firm practices dumping by selling its lower-quality product at a lower price than its price in the LDC local market.*

Proposition 2 has important policy implications for the WTO guidelines to identify the conditions when dumping arises. Generally speaking, DC firms are likely to sell higher-quality products and do not find it profitable to dump their products at lower prices. However, LDC firms are likely to sell lower-quality products and practice dumping. The dumping behavior of lower-quality products arises since the inter-country income differential (or a differing degree of market competition) gives LDC firms incentives to charge a lower price than the price in their local market. These results explain why we frequently observe the large-scale dumping of cheap, lower-quality products by LDC firms in international markets.

Dumping by LDC firms is a severe problem in the import-competing markets of the developed world. Our analysis supports several empirical findings showing that DCs had been the dumping target by exporting firms from LDCs. For instance, Prusa (2001) finds that, till the 1980s, about 95% of the antidumping actions were taken by DCs against LDC dumping. This finding is consistent with our Preposition 2 suggesting unilateral protection by the DC. Neufeld (2001) indicates that the AD duties as a trade remedy rose to 42% from 38% due to the LDC dumping over the 1994–1999 period. Blonigen and Prusa (2016) document that DCs are the most significant AD policy users against the practice of dumping by firms from LDCs.[20]

The empirical findings prompt us to examine the following question of policy importance. In response to the dumping of lower-quality products by LDC firms, how would the importing country's government (i.e., DC) determine its antidumping fines? We proceed to the next section of our analysis to examine antidumping regulation and the resulting equilibrium outcome.

[20] This empirical evidence connected with using an AD to support Proposition 1 refers to the fact that dumping exists under free trade (without dumping regulation), where LDC firm dumps its lower-quality product in DC markets. The importing government (i.e., DC) responds by imposing an AD duty against LDC dumping. DC could indeed use AD duty as a protectionism tool under free trade; however, it still needs evidence of dumping behavior under WTO guidelines to contain LDC firm's dumping behavior. Moreover, the empirical evidence we mention supporting Proposition 1 reflects that DC took more action against LDC through AD duty. However, this behavior declined after WTO's formation when tariffs were no longer an option (for details, see Moraga-González Viaene 2015, Table 1 on page 778). Recently, we started seeing a surge in DC initiation of AD duty against LDC dumping.

2.3. Antidumping policy

We have shown in Section 2.2 that, under free trade, the LDC firm dumps its lower-quality product in the DC market at a price lower than its local price. That is, $p_2^{*FT} < p_2^{FT}$ (see Eq. (13)). To deal with the LDC dumping, we consider that the DC government sets an AD duty rate, t, identical to the dumping margin. That is,

$$t = \frac{p_2^{FT} - p_2^{*FT}}{p_2^{FT}},$$

which is the price difference between p_2^{FT} and p_2^{*FT} as a proportion of the LDC local price p_2^{FT}. The above dumping margin equation implies that $p_2^{FT} - p_2^{*FT} = tp_2^{FT}$, which is re-written as:

$$p_2^{FT} = \frac{1}{(1-t)} p_2^{*FT}.$$

With the AD policy, the DC government elevates the lower-quality product's price in the DC market to the level p_2^{FT}, the product's free-trade price in the LDC market. We re-define p_2^{FT} as p_2^{*AD}, which is the lower-quality product's price in the DC market after the AD duty rate, t, is imposed. That is, $p_2^{*AD} = p_2^{FT}$. It follows that

$$p_2^{*AD} = \left(\frac{1}{1-t}\right) p_2^{*FT},$$

which is equivalent to $p_2^{*FT} = (1-t)p_2^{*AD}$.

Under the AD regime, with the duty rate being set by the DC government, we have different demands for the two competing products in the DC market. We derive these demand equations by replacing the free-trade price, p_2^{*FT}, in (5) with $(1-t)p_2^{*AD}$. This yields

$$D_2^{*AD}\left(p_1^{*AD}, p_2^{*AD}\right) = \widetilde{\theta}^{*AD} = \frac{p_1^{*AD} - (1-t)p_2^{*AD}}{\lambda(s_1^{AD} - s_2^{AD})}; \; D_1^{*AD}\left(p_1^{*AD}, p_2^{*AD}\right) = 1 - \widetilde{\theta}^{*AD} = 1 - \frac{p_1^{*AD} - (1-t)p_2^{*AD}}{\lambda(s_1^{AD} - s_2^{AD})}. \tag{16a}$$

The demand equations for the two competing products in the LDC market remain unchanged:

$$D_2^{AD}\left(p_1^{AD}, p_2^{AD}\right) = \widehat{\theta}^{AD} = \frac{p_1^{AD} - p_2^{AD}}{s_1^{AD} - s_2^{AD}}; \; D_2^{AD}\left(p_1^{AD}, p_2^{AD}\right) = 1 - \widehat{\theta}^{AD} = 1 - \frac{p_1^{AD} - p_2^{AD}}{s_1^{AD} - s_2^{AD}}. \tag{16b}$$

Given that $p_2^{*FT} = (1-t)p_2^{*AD}$, re-writing this equation yields $p_2^{*AD} - p_2^{*FT} = tp_2^{*AD}$. Multiply both sides of the above equation by D_2^{*AD}, the quantity of the lower-quality product imported by DC under the AD regime, we have the total amount of *duty revenue*:

$$\left(p_2^{*AD} - p_2^{*FT}\right) D_2^{*AD} = tp_2^{*AD} D_2^{*AD}.$$

We consider a three-stage game to determine the optimal value of t and the resulting two-market equilibrium solution under the AD regime. At stage one, the DC and LDC firms undertake R&D investments for quality upgrades, s_1^{AD} and s_2^{AD}, that maximize their respective profits. At stage two, the DC government imposes a socially optimal duty rate on the lower-quality product to deal with the LDC dumping as discussed earlier. At stage three, the competing firms determine profit-maximizing prices for their products in the DC and LDC markets by engaging in Bertrand competition. To solve for the sub-game perfect Nash equilibrium, we use backward induction.

At the third and last stage of the game, the DC and LDC firms set their product prices by solving the following profit maximization problems:

$$\begin{aligned} &\underset{\left\{p_1^{AD}, p_1^{*AD}\right\}}{\text{Max}} \; \Pi_{DC}^{AD} = p_1^{AD} D_1^{AD}\left(p_1^{AD}, p_2^{AD}\right) + p_1^{*AD} D_1^{*AD}\left(p_1^{*AD}, p_2^{*AD}\right) - \frac{1}{2}\gamma_1 \left(s_1^{AD}\right)^2, \\ &\underset{\left\{p_2^{AD}, p_2^{*AD}\right\}}{\text{Max}} \; \pi_{LDC}^{AD} = p_2^{AD} D_2^{AD}\left(p_1^{AD}, p_2^{AD}\right) + p_2^{*AD} D_2^{*AD}\left(p_1^{*AD}, p_2^{*AD}\right) - \frac{1}{2}\gamma_2 \left(s_2^{AD}\right)^2, \end{aligned} \tag{16c}$$

where demands D_1^{AD},D_1^{*AD},D_2^{AD}, and D_2^{*AD} are given in (16a)-(16b). The FOCs for the firms imply that the optimal prices of their products in the DC and LDC markets are:

$$p_1^{*AD} = \frac{2\lambda\left(s_1^{AD} - s_2^{AD}\right)}{3}, \; p_2^{*AD} = \frac{\lambda\left(s_1^{AD} - s_2^{AD}\right)}{3(1-t)}, \; p_1^{AD} = \frac{2\left(s_1^{AD} - s_2^{AD}\right)}{3}, \; \textit{and} \; p_2^{AD} = \frac{\left(s_1^{AD} - s_2^{AD}\right)}{3}. \tag{17a}$$

Substituting the prices from (17a) back into (16a)-(16b) yields product demands (or market shares) in DC and LDC:

$$D_2^{*AD} = \widetilde{\theta}^{*AD} = \frac{2t-1}{3t-3}, \; D_1^{*AD} = 1 - \widetilde{\theta}^{*AD} = \frac{2-t}{3(1-t)}, \; D_2^{AD} = \widehat{\theta}^{AD} = \frac{1}{3}, \; \textit{and} \; D_1^{AD} = 1 - \widehat{\theta}^{AD} = \frac{2}{3}. \tag{17b}$$

A comparison between p_2^{*AD} and p_2^{AD} in (17a), which are the prices of the lower-quality product sold in the DC and LDC markets,

allows one to see the impact of the AD policy. That is, $\frac{p_2^{*AD}}{p_2^{AD}} = \frac{\lambda}{1-t}$, which implies that

$$p_2^{*AD}\left(=\frac{\lambda p_2^{AD}}{1-t}\right)\rangle p_2^{*FT}\left(=\lambda p_2^{FT}\right). \tag{17c}$$

The imposition of an *ad valorem* duty, t, raises the price of the lower-quality product, compared to the product's price under free trade. The result in (17c) thus indicates that the AD policy of imposing duties on foreign dumping is efficacious in promoting "fair" price competition.

At the second stage of the game, the DC government determines an optimal *ad valorem* duty that maximizes its overall welfare, $SW_{DC}^{AD} = (CS_2^{AD} + CS_1^{AD}) + \Pi_{DC}^{AD} + tp_2^{*AD}D_2^{*AD}$, which is the sum of consumer surplus (from purchasing the two products), firm profit (net of R&D cost), and duty revenue. That is, the DC government solves the following welfare maximization problem:

$$\begin{aligned}\underset{\{t\}}{\text{Max}} SW_{DC}^{AD} = &\underbrace{\int_0^{\tilde{\theta}^{*AD}} \left[\lambda\theta^{*AD}\left(1+s_2^{AD}\right) - p_2^{*AD}\right]dF(\theta)}_{CS_2^{AD}\text{ in DC}} + \underbrace{\int_{\tilde{\theta}^{*AD}}^{1} \left[\lambda\theta^{*AD}\left(1+s_1^{AD}\right) - p_1^{*AD}\right]dF(\theta)}_{CS_1^{AD}\text{ in DC}} \\ &+ \underbrace{\left[p_1^{AD}D_1^{AD} + p_1^{*AD}D_1^{*AD} - \frac{1}{2}\gamma_1\left(s_1^{AD}\right)^2\right]}_{\Pi_{DC}^{AD}} + \underbrace{tp_2^{*AD}D_2^{*AD}}_{\text{Duty Revenue}},\end{aligned} \tag{17d}$$

where the prices and demands are given in (17a)-(17b). Note that duty revenue in the last term of the welfare function is: $tp_2^{*AD}D_2^{*AD} = (p_2^{*AD} - p_2^{*FT})D_2^{*AD}$. The DC government's FOC implies that its optimal AD duty is:[21]

$$t^{AD} = \frac{a+2}{a+3}. \tag{17e}$$

Substituting t^{AD} from (17e) back into (17a)-(17b), we calculate the equilibrium prices and demands in the DC market:[22]

$$p_1^{*AD} = \frac{2\lambda(s_1 - s_2)}{3}, p_2^{*AD} = \lambda(s_1 - s_2),\ D_2^{*AD} = \theta^{*AD} = 0,\ \text{and}\ D_1^{*AD} = 1 - \theta^* = 1. \tag{17f}$$

At the first stage of the three-stage game, the DC and LDC firms decide on their quality-upgrades. The LDC firm determines an optimal level s_2^{AD} to maximize its profits. It follows from π_{LDC}^{AD} in (16c), where prices and demands are given in (17a), (17b), and (17f), that we have

$$\frac{\partial \pi_{LDC}^{AD}}{\partial s_2^{AD}} = \gamma_2 s_2^{AD} - \gamma_2 s_2^{AD} - \frac{1}{9} = -\frac{1}{9} < 0,$$

which implies there is a corner solution:

$$s_2^{AD} = 0. \tag{18a}$$

Quality upgradation is thus economically unattractive to the LDC firm since its R&D expenditure is zero ($E_2^{AD} = \gamma_2(s_2^{AD})^2/2 = 0$). This result is consistent with the observations that LDC firms producing lower-quality products may have no incentives to undertake costly R&D for quality improvements.[23]

The DC firm decides on an optimal quality-upgrade s_1 that maximizes its profits. Substituting the prices and demands from (17f) back into (16c), we have the DC firm's profit maximization problem:

$$\underset{\left\{s_1^{AD}\right\}}{\text{Max}} \Pi_{LDC}^{AD} = \frac{2\left(s_1^{AD} - s_2^{AD}\right)(3\lambda+2)}{9} - \frac{1}{2}\gamma_1\left(s_1^{AD}\right)^2. \tag{18b}$$

The FOC for the DC firm implies that its optimal quality-upgrade is:

$$s_1^{AD} = \frac{2(3\lambda+2)}{9\gamma_1} > 0. \tag{18c}$$

Following from (18c), the DC firm's optimal R&D expenditure on quality improvement is:

[21] See Appendix A1 for a detailed derivation of the optimal AD duty.

[22] Although the finding that $D_2^{*AD} = 0$ makes DC firm a monopolist in the DC market, a foreign competitor (i.e., an LDC firm) will not set its production to zero. The LDC firm continues to produce a lower-quality product for its home market.

[23] The LDC has no incentive due to the lack of IPRs enforcement mechanisms and R&D inefficiencies in the Global South as opposed to the North Miyagiwa et al. (2016a, 2016b).

$$E_1^{AD} = \frac{1}{2}\gamma_1 \left(s_1^{AD}\right)^2 = \frac{2(3\lambda+2)^2}{81\gamma_1} > 0. \tag{18d}$$

Substituting s_1^{AD} and s_2^{AD} from (18a)-(18c) back into (17f), we obtain the equilibrium prices and demands of the higher- and lower-quality products in the DC market:

$$p_1^{*AD} = \frac{4\lambda(3\lambda+2)}{27\gamma_1}, p_2^{*AD} = \frac{2\lambda(3\lambda+2)}{9\gamma_1}, D_1^{*AD} = 1 - \widetilde{\theta}^{*AD} = 1, \text{ and } D_2^{*AD} = \widetilde{\theta}^{*AD} = 0. \tag{18e}$$

Similarly, substituting s_1^{AD} and s_2^{AD} from (18a)-(18c) back into (17a), (17b), we have the equilibrium prices and demands of the higher- and lower-quality products in the LDC market:

$$p_1^{AD} = \frac{4(3\lambda+2)}{27\gamma_1}, p_2^{AD} = \frac{2(3\lambda+2)}{27\gamma_1}, D_1^{AD} = 1 - \widehat{\theta}^{AD} = \frac{2}{3}, \text{and } D_2^{AD} = \widehat{\theta}^{AD} = \frac{1}{3}. \tag{18f}$$

The final step of the analysis is to calculate profits, consumer surplus, and social welfare under the AD regime. First, substituting (18f) back into (16c) yields the DC firm's profit:

$$\Pi_{DC}^{AD} = \frac{2(3\lambda+2)^2}{81\gamma_1}. \tag{19a}$$

Using the formula (see Eq. (14b)) for measuring consumer surplus in the DC market under the AD regime, we set $i = AD$ and have $CS_{DC}^{AD} = CS_2^{AD} + CS_1^{AD}$. Substituting the results from (18c)-(18f), (19b) into the formula in (14) yields the DC's consumer surplus:

$$CS_{DC}^{AD} = \frac{\left(27\lambda\gamma_1 - 6\lambda^2 - 4\lambda\right) + a\lambda(32 + 48\lambda + 54\gamma_1 + 36a + 54a\lambda)}{54\gamma_1}. \tag{19b}$$

The DC's social welfare is: $SW_{DC}^{AD} = CS_{DC}^{AD} + \Pi_{DC}^{AD} + t^{AD}p_2^{*AD}D_2^{*AD}$, where the terms on the RHS of the equation are given in (17e), (18e), and (19a)-(19c). After calculating, we have:

$$SW_{DC}^{AD} = \frac{\left(81\lambda\gamma_1 + 18\lambda^2 + 36\lambda + 16\right) + a\lambda(96 + 144\lambda + 162\gamma_1 + 108a + 162a\lambda)}{162\gamma_1}. \tag{19c}$$

We turn to the LDC case for determining firm profits, consumer surplus, and social welfare. Plugging the product prices and demands from (18a) and (18f) back into the LDC firm's profit function in (16c) yields

$$\pi_{LDC}^{AD} = \frac{6\lambda+4}{81\gamma_1}. \tag{20a}$$

Using the formula (see Eq. (15b)) for measuring consumer surplus in the LDC market, we set $i = AD$ and have $CS_{LDC}^{AD} = CS_2^{AD} + CS_1^{AD}$. Substituting the results from (18a)-(18f) into the formula yields the LDC's consumer surplus:

$$CS_{LDC}^{AD} = \frac{(81\gamma_1 - 12\lambda - 8) + a(48 + 72\lambda + 162\gamma_1 + 36a + 54a\lambda)}{162\gamma_1}. \tag{20b}$$

The LDC's social welfare is: $SW_{LDC}^{AD} = CS_{LDC}^{AD} + (\pi_{LDC}^{AD} - t^{AD}p_2^{*AD}D_2^{*AD})$, where the terms on the RHS of the equation are given in (17e)-(17f) and (20a)-(20b). After calculating, we have

$$SW_{LDC}^{AD} = \frac{27\gamma_1 + a(16 + 24\lambda + 54\gamma_1 + 12a + 18a\lambda)}{54\gamma_1}. \tag{20c}$$

The results in (17f), showing that $D_2^{*AD} = \widetilde{\theta}^{*AD} = 0$ and $D_1^{*AD} = 1 - \widetilde{\theta}^{*AD} = 1$, have important implications for the AD policy as summarized in the following proposition:

PROPOSITION 3. *In the model of trade in quality-differentiated products where LDC firm practices dumping, the imposition of an optimal AD duty by the DC government causes the dumper to leave the DC market* (*i.e.*, $\widetilde{D}_2^{*AD} = 0$).

Several studies analyzing the impact of antidumping duty through partial and general equilibrium approaches suggest that AD duties remarkably reduce imports (e.g., Murray and Rousslang, 1989; Gallaway et al., 1999; Bloneign, 2016; Besedeš and Prusa, 2017). Particularly, Besedeš and Prusa (2017) empirically investigate how AD duties affect US imports regarding the timings of antidumping actions. This study finds that firms negatively affected by AD investigations tend not to return to the market even after the AD order is no longer in effect. Besedeš and Prusa (2017) further remark that AD actions are likely to "cause exporters to abandon the US market." Likewise, evidence from the Sunset Review process indicates that the antidumping duty level decreases the subject imports (Nye, 2006).[24] Proposition 2 is consistent with the empirical observation that market demand for a dumped product is likely to be zero when

[24] Other studies also examined the impact of anti-dumping duties on imports and showed that findings remain consistent. For details see, e.g., Asche (2001), Staiger and Wolak (1994), and Prusa (1991,1992, 2001).

a convicted LDC dumper quits the DC market under the AD regime.[25]

2.4. Price undertaking

When an LDC firm's product is placed on antidumping order because it dumps the product at a price less than that in its local market, the firm may consider the option of accepting a price undertaking (*PU*). This option serves as a business strategy for a foreign dumping firm to evade an AD fine. This section analyzes the economic effects of a price undertaking regime under which an LDC firm sets its product price identical to that in the firm's local market.

Within the two-market framework of trade between DC and LDC, the LDC firm agrees to set p_2^{PU} identical to p_2^{*PU} when making its profit maximization decision. Demands for the higher- and lower-quality products in the DC and LDC markets in (2) and (4) become the following:

$$D_1^{*PU} = 1 - \frac{p_1^{*PU} - p_2^{*PU}}{\lambda(s_1^{PU} - s_2^{PU})}, D_1^{*PU} = \frac{p_1^{*PU} - p_2^{*PU}}{\lambda(s_1^{PU} - s_2^{PU})}; \overline{D}_1^{PU} = 1 - \frac{p_1^{PU} - p_2^{*PU}}{s_1^{PU} - s_2^{PU}}, \overline{D}_2^{PU} = \frac{p_1^{PU} - p_2^{*PU}}{s_1^{PU} - s_2^{PU}}. \tag{21}$$

We solve the price undertaking regime as a two-stage game. At stage one, the DC and LDC firms determine their optimal quality-upgrades, $\{s_1^{PU}, s_2^{PU}\}$ At stage two, the firms set their product prices in both the DC and LDC markets by engaging in Bertrand competition.

Starting at the second stage of the game, the DC firm's profit maximization problem is:

$$\underset{\{p_1^{*PU}, p_1^{PU}\}}{\text{Max}} \Pi_{DC}^{PU} = p_1^{PU}\overline{D}_1^{PU} + p_1^{*PU}D_1^{*PU} - (1/2)\gamma_1\left(s_1^{PU}\right)^2, \tag{22a}$$

where $\overline{D}_1^{PU}$ and D_1^{*PU} are given in (21). The LDC firm's profit maximization problem is:

$$\underset{\{p_2^{*PU}\}}{\text{Max}} \pi_{LDC}^{PU} = p_2^{*PU}\overline{D}_2^{PU} + p_2^{*PU}D_2^{*PU} - (1/2)\gamma_2\left(s_2^{PU}\right)^2, \tag{22b}$$

where $\overline{D}_2^{PU}$ and D_2^{*PU} are given in (21). Using (22a)-(22b), we derive FOCs for the firms and solve for the optimal product prices in both the DC and LDC markets. This yields

$$p_1^{*PU} = \frac{\lambda(5+3\lambda)\left(s_1^{PU} - s_2^{PU}\right)}{6(1+\lambda)},\ p_1^{PU} = \frac{(3+5\lambda)\left(s_1^{PU} - s_2^{PU}\right)}{6(1+\lambda)},\ \textit{and}\ p_2^{PU} = \frac{2\lambda\left(s_1^{PU} - s_2^{PU}\right)}{3(1+\lambda)} = p_2^{*PU}. \tag{22c}$$

Substituting the prices from (22c) back into (21), we calculate demands for the higher- and lower-quality products in the DC and the LDC markets:

$$D_1^{*PU} = \frac{3\lambda+1}{6(1+\lambda)}, D_1^{*PU} = \frac{3\lambda+5}{6(1+\lambda)}; \overline{D}_2^{PU} = \frac{\lambda+3}{6(1+\lambda)}, \overline{D}_2^{PU} = \frac{5\lambda+3}{6(1+\lambda)}. \tag{22d}$$

At the first stage of the game, the DC and LDC firms determine their optimal quality-upgrades, $\{s_1^{PU}, s_2^{PU}\}$ Plugging the prices and demands from (22c)-(22d) back into the profit functions in (22a)-(22b), we have the profit maximization problems for the DC and LDC firms:

$$\underset{\{s_1^{PU}\}}{\text{Max}} \Pi_{DC}^{PU} = \frac{\left(s_1^{PU} - s_2^{PU}\right)\left(9\lambda^2 + 46\lambda + 9\right)}{36(1+\lambda)} - \frac{1}{2}\gamma_1\left(s_1^{PU}\right)^2; \underset{\{s_2^{PU}\}}{\text{Max}} \pi_{LDC}^{PU} = \frac{4\lambda\left(s_1^{PU} - s_2^{PU}\right)}{9(1+\lambda)} - \frac{1}{2}\gamma_2\left(s_2^{PU}\right)^2. \tag{23a}$$

Using (23a), we derive FOCs for the firms and solve for their optimal quality-upgrades:

$$s_1^{PU} = \frac{46\lambda + 9\lambda^2 + 9}{36\gamma_1(1+\lambda)} > 0 \text{ and } s_2^{PU} = 0. \tag{23b}$$

These results imply that $q_1^{PU} > q_2^{PU}$. Substituting s_1^{PU} and s_2^{PU} from (23b) back into (22c)-(22d), we calculate the equilibrium prices and demands of the higher- and lower-quality products in the DC and LDC markets. They are:

$$p_1^{*PU} = \frac{\lambda(3\lambda+5)\left(9\lambda^2+46\lambda+9\right)}{216\gamma_1(1+\lambda)^2}, p_2^{*PU} = \frac{\lambda\left(9\lambda^2+46\lambda+9\right)}{54\gamma_1(1+\lambda)^2}; D_1^{*PU} = \frac{3\lambda+5}{6(1+\lambda)}, D_2^{*PU} = \frac{3\lambda+1}{6(1+\lambda)}; \tag{23c}$$

[25] Prusa (1997) indicates that AD duty reduces the imports from the targeted country but increases total imports through trade diversion. Choi (2017) empirically test the impact of AD duties on imports by focusing on the United States, the European Union, China, and India from 1996 to 2015. The findings demonstrate that AD duties reduce imports in the short term, while such a relationship disappears in the long run and may become positively related.

$$p_1^{PU}=\frac{(5\lambda+3)\left(9\lambda^2+46\lambda+9\right)}{216\gamma_1(1+\lambda)^2}, p_2^{PU}=\frac{\lambda\left(9\lambda^2+46\lambda+9\right)}{54\gamma_1(1+\lambda)^2}; D_1^{PU}=\frac{5\lambda+3}{6(1+\lambda)}, D_2^{PU}=\frac{\lambda+3}{6(1+\lambda)}. \tag{23d}$$

Note that under a price undertaking, we have $p_2^{PU}=p_2^{*PU}$.

A comparison of equilibrium demands for the two products in the DC market reveals that

$$D_2^{*FT}>D_2^{*PU}>D_2^{*AD}=0 \text{ and } D_1^{*AD}>D_1^{*PU}>D_1^{*FT}>0. \tag{23e}$$

PROPOSITION 4. *Unlike the optimal AD policy that causes an LDC dumper to leave the DC market, a price-undertaking policy allows the LDC firm to have a positive market share in the DC market.*[26] *The DC firm's market share is higher under a price undertaking than under free trade (with LDC dumping).*

Proposition 4 has economic implications for competing firms in international markets. LDC firms engaging in dumping are better off by accepting price undertaking rather than facing AD duties. Looking at the European Economic Community as an example, 40.6 percent of the 578 affirmative AD actions were terminated between 1981 and 2001 because foreign firms accepted price undertakings (Zanardi, 2006). This policy option allowed the dumping firms to stay in the importing market (Konings et al., 1998). Moreover, the price undertaking allowed exporting firms to avoid the reputational damage caused by the AD duty.

Having determined the equilibrium prices and demands, we calculate profits, consumer surplus, and social welfare. First, making use of the prices in (23c), the demands in (23d), and the profit function in (22a), we calculate the DC firm's total profit:

$$\Pi_{DC}^{PU}=\frac{\left(9\lambda^2+46\lambda+9\right)^2}{2592\gamma_1(1+\lambda)^2}. \tag{24a}$$

Using the formula (Eq. (14b)) to measure consumer surplus in the DC market, we set $i=PU$ and have $CS_{DC}^{PU}=CS_2^{PU}+CS_1^{PU}$. Substituting the results from (23c)-(23d) into the formula in (14b) yields the DC's consumer surplus:

$$\begin{aligned}CS_{DC}^{PU}&=\frac{\lambda\left(1296\gamma_1-1220\lambda-954\lambda^2+252\lambda^3+81\lambda^4+3888\lambda\gamma_1+3888\lambda^2\gamma_1+1296\lambda^3\gamma_1-207\right)}{2592\gamma_1(1+\lambda)^3}\\&+\frac{a\lambda\left(540+324a+2304a\lambda+3960a\lambda^2+2304a\lambda^3+324a\lambda^4\right)}{2592\gamma_1(1+\lambda)^3}\\&+\frac{a\lambda\left(3624\lambda+5280\lambda^2+2520\lambda^3+324\lambda^4+2592\gamma_1+7776\lambda\gamma_1+7776\lambda^2\gamma_1+2592\lambda^3\gamma_1\right)}{2592\gamma_1(1+\lambda)^3}.\end{aligned} \tag{24b}$$

The DC's welfare is:$SW_{DC}^{PU}=CS_{DC}^{PU}+\Pi_{DC}^{PU}$, where Π_{DC}^{PU} is in (24a) and CS_{DC}^{PU} is in (24c). Thus,

$$\begin{aligned}SW_{DC}^{PU}&=\frac{702\lambda+1886\lambda^2+2152\lambda^3+1161\lambda^4+162\lambda^5+1296\lambda\gamma_1+3888\lambda^2\gamma_1+3888\lambda^3\gamma_1+1296\lambda^4\gamma_1+81}{2592\gamma_1(1+\lambda)^3}\\&+\frac{a\lambda\left(540+324a+2304a\lambda+3960a\lambda^2+2304a\lambda^3+324a\lambda^4\right)}{2592\gamma_1(1+\lambda)^3}\\&+\frac{a\lambda\left(3624\lambda+5280\lambda^2+2520\lambda^3+324\lambda^4+2592\gamma_1+7776\lambda\gamma_1+7776\lambda^2\gamma_1+2592\lambda^3\gamma_1\right)}{2592\gamma_1(1+\lambda)^3}.\end{aligned} \tag{24c}$$

As for the LDC, we first calculate total profit for the LDC firm by using the equilibrium prices and demands in (23c)-(23d). This yields

$$\pi_{LDC}^{PU}=\frac{\lambda\left(9\lambda^2+46\lambda+9\right)}{81\gamma_1(\lambda+1)^2}. \tag{25a}$$

Using the formula (Eq. (15b)) to measure consumer surplus in the LDC market, we set $i=PU$ and have $CS_{LDC}^{PU}=CS_2^{PU}+CS_1^{PU}$. Substituting the results from (23c)-(23d) into the formula in (15) yields the LDC's consumer surplus:

$$\begin{aligned}CS_{LDC}^{PU}&=\frac{252\lambda+1296\gamma_1-954\lambda^2-1220\lambda^3-207\lambda^4+3888\lambda\gamma_1+3888\lambda^2\gamma_1+1296\lambda^3\gamma_1+81}{2592\gamma_1(1+\lambda)^3}\\&+\frac{a\left(324+2520\lambda+5280\lambda^2+3624\lambda^3+540\lambda^4+324a+2592\gamma_1\right)}{2592\gamma_h(1+\lambda)^3}\\&+\frac{a\lambda\left(2304a+3960a\lambda+2304a\lambda^2+324a\lambda^3+7776\gamma_1+7776\lambda\gamma_1+2592\lambda^2\gamma_1\right)}{2592\gamma_1(1+\lambda)^3}.\end{aligned} \tag{25c}$$

[26] This finding is supported by the study of Konings et al. (1998) that price undertaking helps foreign firms to maintain their market shares in importing countries.

The LDC's welfare is: $SW_{LDC}^{PU} = CS_{LDC}^{PU} + \pi_{LDC}^{PU}$, where π_{LDC}^{PU} and CS_{LDC}^{PU} are given in (25a) and (25c).

$$\begin{aligned} SW_{LDC}^{PU} &= \frac{540\lambda + 1296\gamma_1 + 806\lambda^2 + 540\lambda^3 + 81\lambda^4 + 3888\lambda\gamma_1 + 3888\lambda^2\gamma_1 + 1296\lambda^3\gamma_1 + 81}{2592\gamma_1(1+\lambda)^3} \\ &+ \frac{a\left(324 + 2520\lambda + 5280\lambda^2 + 3624\lambda^3 + 540\lambda^4 + 324a + 2592\gamma_1\right)}{2592\gamma_1(1+\lambda)^3} \\ &+ \frac{a\lambda\left(2304a + 3960a\lambda + 2304a\lambda^2 + 324a\lambda^3 + 7776\gamma_1 + 7776\lambda\gamma_1 + 2592\lambda^2\gamma_1\right)}{2592\gamma_1(1+\lambda)^3}. \end{aligned} \tag{25d}$$

Having derived the equilibrium outcomes of the three different trade regimes, our next step of the analysis is to see how the regimes affect DC and LDC differently.

3. Regime comparisons and policy recommendations

In this section, we examine how R&D investments affect the product quality decisions of the competing DC and LDC firms under different trade regimes. We then compare the effects on profits, consumer surplus, and welfare between DC and LDC.

3.1. Effects on DC[27]

We first look at quality upgrades optimally chosen by the DC and LDC firms and the resulting quality levels of their products. We have from the results in (10a), (18c), and (23b) that $s_1^{AD} > s_1^{FT} > s_1^{PU}$ which implies that $q_1^{AD} > q_1^{FT} > q_1^{PU}$. To compare the DC firm's profits across different trade regimes, we have from the results in (14a), (19a), and (24a) that $\Pi_{DC}^{AD} > \Pi_{DC}^{FT} > \Pi_{DC}^{PU}$. To see how DC consumers are affected by LDC dumping, we have from the results in (14c), (19c), and (24c) that $CS_{DC}^{AD} > CS_{DC}^{FT} > CS_{DC}^{PU}$.

The policy implications of these results are summarized in the following proposition:

PROPOSITION 5. *In the DC-LDC trade in similar products, we have:*

(i) *The optimal quality upgrade through costly R&D investment is the highest for the DC firm when its government imposes AD duties on LDC dumping but is the lowest when the LDC firm accepts a price undertaking.*
(ii) *DC firm's profit is highest when its government imposes AD duties against dumping. However, the DC firm's profit is the lowest when the LDC firm accepts price undertaking.*
(iii) *DC consumers enjoy the highest surplus when their government imposes antidumping duties against dumping compared to the other two trade regimes. Nevertheless, DC consumers are hurt the most when the LDC firm accepts a price undertaking.*

Proposition 5 suggests that a DC firm's product quality depends on its government's type of trade policies. The DC firm will likely increase R&D investment in product quality under an AD duty regime. This result emerges because AD duty pushes the LDC dumping firms to exit the DC market and helps the DC firm increase its market share and profit. Higher profit enables the DC firm to invest more in product quality, maintaining product quality leadership. Findings from the empirical studies support that price undertaking reduces DC firms' incentives to undertake investment in quality improvement. Specifically, Vandenbussche and Wauthy (2001) investigate the European Union's antidumping measures and find, among other things, that price undertaking negatively affects product quality in an importing country's domestic industries.

The proposition suggests that DC firms that produce higher-quality products have a strong incentive to lobby their government to impose AD duties against the dumping of lower-quality products by LDC firms. The intuition is that AD duties make it possible to expel their competitors (LDC firms), allowing DC firms to increase their market dominance. As such, DC firms can raise the prices of their higher-quality products and make more profits. This finding strongly supports several empirical studies documenting that AD duty increases domestic profits (Kelly and Morkre, 1998; DeVault 1996; Bloneign 2016).

Proposition 5 indicates that, relative to free trade equilibrium in which foreign dumping of lower-quality products occurs, DC consumers are better off by purchasing higher-quality products under an AD policy. This finding has implications for DC consumers' benefits in that it reflects how consumer utility is positively related to product quality. In other words, DC wealthier consumers value a higher-quality product and receive more satisfaction from an improved product quality than a loss due to an increased price under the AD duty. This finding appears consistent with empirical studies (Devault, 1996).

Next, we examine the welfare implications of the three different regimes. Comparing the equilibrium welfare levels as shown in (14d), (19d), and (25d) yields $SW_{DC}^{AD} > SW_{DC}^{FT} > SW_{DC}^{PU}$. We, therefore, have:

PROPOSITION 6. *DC's social welfare is the highest when its government implements an AD policy on LDC dumping but is the lowest when the LDC firm accepts a price undertaking.*

This proposition has interesting economic implications and rationale for dismissing price undertaking as a trade protection instrument. It indicates that AD duty increases social welfare, which is less likely to increase when the targeted LDC firm accepts price-

[27] See Appendix A2 for detailed derivations of the results in this section.

undertaking. This is because AD duty enhances the DC firm's profit and positively affects domestic consumer surplus from enjoying the higher-quality product. Taken together, it illustrates that for the DC government, it is a better choice to impose AD duty in response to dumping. Proposition 8 is consistent with the finding of Pauwels and Springael (2002) that the European Union is better off with an AD policy than accepting a price undertaking from the welfare-enhancing perspective. Accepting price undertakings by foreign firms as a settlement strategy is vital in affecting the termination of antidumping cases in the European Economic Community (EEC). Member countries of the EEC frequently allowed foreign firms to accept price undertakings, but the number of price undertakings accepted varied considerably over time. Tharakan (1991) indicates that out of 249 affirmative case decisions for 1980–1987, about 72% were terminated by accepting undertakings. Zanardi (2006) remarks that, among 578 affirmative AD actions for the EEC between 1981 and 2001, 40.6% of these cases were terminated by price undertakings. Rovegno and Vandenbussche (2011) find that the use of price undertakings in the European Union from 1995 to 2008 has dropped steadily in favor of imposing AD duties.

3.2. Effects on LDC[28]

We proceed to examine how the different trade regimes affect the profits of the LDC firm that sells a lower-quality product. Following the results in (15a), (20a), and (25a), we have

(i) $\pi_{LDC}^{PU} > \pi_{LDC}^{AD}$ when $\lambda > \widehat{\lambda}_{LDC}$ and (ii) $\pi_{LDC}^{AD} > \pi_{LDC}^{PU}$ when $\lambda < \widehat{\lambda}_{LDC}$, where $\widehat{\lambda}_{LDC}(= 0.445)$ is the critical value of the inter-country income differential that makes the LDC firm indifferent between the AD regime and a price undertaking. The comparison between π_{LDC}^{FT} and π_{LDC}^{AD} (or π_{LDC}^{PU}) is straightforward that $\pi_{LDC}^{FT} > \pi_{LDC}^{AD}$and $\pi_{LDC}^{FT} > \pi_{LDC}^{PU}$.

Taking together the rankings of firm profits, as shown above, we have two possibilities.

Case1: When $\lambda > 0.445$ (i.e., when income differential is smaller such that the DC and LDC markets are more competitive), we have: $\pi_{LDC}^{FT} > \pi_{LDC}^{PU} > \pi_{LDC}^{AD}$, where π_{LDC}^{AD} is the LDC firm's profit from its domestic market (due to zero market share in DC).

Case2: When $\lambda < 0.445$ (i.e., when income differential is more substantial such that the DC and LDC markets are less competitive), we have: $\pi_{LDC}^{FT} > \pi_{LDC}^{AD} > \pi_{LDC}^{PU}$.

It is easy to verify that π_{LDC}^{PU} in Case 2 is lower than that in Case 1. We thus have:

PROPOSITION 7. *LDC's firm profit is the highest by dumping its lower-quality product into the DC market under free trade. However, the comparison between an AD policy and a price undertaking depends on the degree of international market competition. When the DC and LDC markets are more (less) competitive, the LDC firm's profit is higher (lower) under a price-undertaking than under an AD policy.*

The results in Proposition 7 suggest that LDC firms are likely to maximize their profits by dumping lower-quality products in DC markets under free trade. Under free trade, since there are no trade barriers and LDC firms have access to international markets. This access motivates LDC firms to dump and have a higher market share through domestic and foreign demands for lower-quality (cheaper) products. In contrast, when LDC dumping firms face AD fines, their losses include lower foreign demands for their products and the exit from the market. Thus, we are more likely to see lower profits for LDC firms when convicted of paying costly AD duties.

As for consumer surplus under the alternative trade regimes, we compare the results in (15c), (20c), and (25c) and find that $CS_{LDC}^{AD} > CS_{LDC}^{FT}$. However, the comparisons between CS_{LDC}^{PU} and CS_{LDC}^{FT} (or CS_{LDC}^{AD}) cannot be determined unambiguously. We thus have:

PROPOSITION 8. *LDC consumers are better off if the DC government imposes AD duties on LDC dumping than under free trade (in the presence of LDC dumping).*

The economic intuition is as follows. Under an AD policy, gains in LDC's consumer surplus by consuming an imported good with a relatively upgraded quality (resulting from DC's R&D investment in quality enhancement) exceed the losses that consumers encounter in consumer surplus through consuming the lower-quality product with an increased price.

To compare the equilibrium levels of social welfare across the trade regimes, we have the results in (15d), (20d), and (25d) that

$$SW_{LDC}^{PU} > SW_{LDC}^{FT} > SW_{LDC}^{AD}.$$

We, therefore, have:

PROPOSITION 9. *LDC's social welfare is the highest when its exporting firm accepts a price-undertaking but is the lowest when the LDC firm practices dumping and pays AD duties.*

Given that price undertaking allows a foreign dumping firm to keep some of the AD rents, an LDC's social welfare is higher under price undertaking than under the AD regime.[29] This finding is consistent with the study of Gao and Miyagiwa (2005). The authors indicate that price undertaking is a more friendly protection policy toward foreign dumpers than AD.

[28] See Appendix A3 for detailed derivations of the results in this section.

[29] It is noted that a firm must be found guilty of dumping under free trade before price undertaking is offered as a soft penalty for dumping.

3.3. Effects on global welfare

It is instructive to investigate how alternative trade regimes affect global welfare, defined by aggregating the social welfare of DC and LDC trading partners. Under free trade in the presence of dumping, global welfare is: $GW^{FT} = SW_{DC}^{FT} + SW_{LDC}^{FT}$, where SW_{DC}^{FT} and SW_{LDC}^{FT} are, respectively, given in (14d) and (15d). Under the AD regime, global welfare is: $GW^{AD} = SW_{DC}^{AD} + SW_{LDC}^{AD}$, where SW_{DC}^{AD} and SW_{LDC}^{AD} are, respectively, given in (19d) and (20d). Under a price-undertaking, global welfare is: $GW^{PU} = SW_{DC}^{PU} + SW_{LDC}^{PU}$, where SW_{DC}^{PU} and SW_{LDC}^{PU} are, respectively, given in (24d) and (25d). Comparing the equilibrium levels of global welfare under the different regimes reveals that[30]

$$GW^{AD} > GW^{FT} > GW^{PU}.$$

We thus have:

PROPOSITION 10. *In two-way trade between DC and LDC, where the DC firm produces a higher-quality product and the LDC firm produces a lower-quality product, global welfare is the highest when the DC government imposes AD duties against the LDC firm's dumping practice. However, global welfare is the lowest when the LDC firm accepts a price undertaking.*

From a global welfare perspective, our two-market equilibrium analysis with endogenous product quality choice by DC and LDC firms implies the antidumping policy's Pareto optimality. The economic intuition behind Proposition 10 is that it diminishes international price discrimination and encourages competition in world markets. The implications of Proposition 10 are consistent with the analysis of Anderson et al. (1995) that imposing an AD duty on foreign dumping affects global welfare positively.

Rovegno and Vandenbussche (2011), using data from 1995 to 2008 in the European Union, find that price undertakings decreased steadily in favor of AD duty. Moreover, Rovegno and Vandenbussche (2011) indicate that the average use of AD duties for the same period in the EU is more than 76%. These empirical findings have interesting welfare implications for DCs and LDCs taken together. This proposition suggests that optimal AD charges against foreign dumping as a trade damage measure are essentially welfare-improving for the world economy.

4. Concluding remarks

This paper presents an imperfect competition model of trade in quality-differentiated products between a DC firm and an LDC firm in which there is a two-market equilibrium. We show that dumping arises when the DC and LDC markets have different degrees of competition (due to the inter-country income differential). Stressing the competing firms' endogenous product quality decisions, we find that the DC firm produces a higher-quality product, whereas the LDC firm produces a lower-quality product. Under free trade, the LDC firm dumps its lower-quality product on the DC market at a price lower than the product's price in its LDC local market. This result explains the frequent observations concerning dumping lower-quality, cheaper products from LDCs into DC countries. Although dumping is profitable to exporters of lower-quality products from an LDC, the country's overall welfare decreases when its exporters pay AD duties. An LDC is better off by restraining its exporters from practicing dumping. In the two-market equilibrium analysis under free trade, AD duties effectively deal with LDC dumping from the perspective of DCs with their firms producing higher-quality products. An AD policy allows domestic firms to regain their market shares. Moreover, AD protection as a trade remedy policy of an importing country improves its domestic welfare and is socially desirable.

The simple trade model in quality-differentiated products indicates that a DC's AD policy in response to an LDC dumping can improve world welfare. Following the WTO/GATT guidelines to identify the price-discriminating behavior of dumping lower-quality products, AD duties' positive welfare effects imply that the policy is not necessarily a protectionist measure. Remarkably, an AD regime constitutes an efficacious measure of remedy to unfair trade practices. Thus, in the face of LDC dumping under free trade, the trade remedy measure of imposing AD duties is Pareto-improving from the world trade perspective.

The limitations of the present study and hence potentially interesting extensions of the model should be mentioned. To capture the dumping phenomenon between DC and LDC and the resulting policy implications, we use a static model of two-way trade for analytical simplicity and model tractability. The static model has restrictions on the technology assumption and the upgrade cost. We recognize that static and dynamic settings may lead to differences in equilibrium outcomes with different policy prescriptions. Moreover, our theoretical result is that an antidumping policy is Pareto-improving because it depends mainly on our model assumptions of unilateral protection by an importing country (DC) without retaliation from an exporting country (LDC). Despite the potential complexity in modeling, the above two issues are interesting extensions for future research.

Compliance with ethical standards

The authors declare that they have no conflict of interest. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

[30] See Appendix A4 for the detailed equations of global welfare and their comparisons.

Mathematical appendix

A1. The determination of an optimal AD duty

Under the AD regime, there is a three-stage game. At the third stage where there is price competition, the DC and LDC firms determine their product prices by solving the profit maximization problems. The FOCs for the DC firm are:

$$\frac{\partial \Pi_{DC}^{AD}}{\partial p_1^{*AD}} = \left(2p_1^{*AD} - p_2^{*AD} + tp_2^{*AD} - \lambda s_1^{AD} + \lambda s_2^{AD}\right) = 0 \text{ and } \frac{\partial \Pi_{DC}^{AD}}{\partial p_1^{AD}} = p_2^{AD} - 2p_1^{AD} + s_1^{AD} - s_2^{AD} = 0. \tag{a.1}$$

Moreover, the FOCs for the LDC firm are:

$$\frac{\partial \pi_{LDC}^{AD}}{\partial p_2^{*AD}} = \left(p_1^{*AD} - 2p_2^{*AD} + 2tp_2^{*AD}\right) = 0 \text{ and } \frac{\partial \pi_{LDC}^{AD}}{\partial p_2^{AD}} = \frac{p_1^{AD} - 2p_2^{AD}}{s_1^{AD} - s_2^{AD}} = 0. \tag{a.2}$$

Simultaneously taking into account the four-equation system in (a.1) and (a.2), we solve for the equilibrium prices of the higher- and lower-quality products in the DC and LDC markets as follows:

$$p_1^{*AD} = \frac{2\lambda\left(s_1^{AD} - s_2^{AD}\right)}{3}, p_1^{AD} = \frac{2\left(s_1^{AD} - s_2^{AD}\right)}{3}, p_2^{*AD} = \frac{\lambda\left(s_1^{AD} - s_2^{AD}\right)}{3(1-t)}, \text{ and } p_2^{AD} = \frac{s_1^{AD} - s_2^{AD}}{3}.$$

We then calculate market demands for the two products in the DC and LDC markets:

$$D_2^{AD} = \theta^{AD} = \frac{1}{3}, D_1^{AD} = 1 - \theta^{AD} = \frac{2}{3}, D_2^{*AD} = \theta^{*AD} = \frac{2t-1}{3(t-1)}, \text{ and } D_1^{*AD} = 1 - \theta^{*AD} = \frac{t-2}{3(t-1)}.$$

To solve for an optimal AD duty set by the DC government, we substitute the above prices and demands into the social welfare function of the DC:

$$SW_{DC}^{AD} = \underbrace{CS_2^{AD} + CS_1^{AD}}_{\text{Consumer surplus}} + \underbrace{\Pi_{DC}^{AD}}_{\text{Producer surplus}} + \underbrace{\left(p_2^{*AD} - p_2^{*FT}\right)D_2^{*AD}}_{\text{Duty revenue}},$$

where the last term measures the total amount of duty revenue. It follows that

$$SD_{DC}^{AD} = \underbrace{\int_a^{\tilde{\theta}^{*AD}} \left[\lambda\theta^{*AD}\left(1 + s_2^{AD}\right) - p_2^{*AD}\right]dF(\theta)}_{CS_2^{AD} \text{ in DC}} + \underbrace{\int_{\theta^{*AD}}^{a+1} \left[\lambda\theta^{*AD}\left(1 + s_1^{AD}\right) - p_1^{*AD}\right]dF(\theta)}_{CS_1^{AD} \text{ in DC}} + \underbrace{\left[p_1^{AD}D_1^{AD} + p_1^{*AD}D_1^{*AD} - \frac{1}{2}\gamma_1\left(s_1^{AD}\right)^2\right]}_{\Pi_{DC}^{AD}}$$
$$+ \underbrace{\left(p_2^{*AD} - p_2^{*FT}\right)D_2^{*AD}}_{\text{Duty Revenue}}.$$

The FOC for the DC government is:

$$\frac{\partial SW_{DC}^{AD}}{\partial t} = \frac{\lambda\left(s_1^{AD} - s_2^{AD}\right)(3a - 3t - 3at + 2)}{9(t-1)^3} = 0,$$

which implies that the optimal AD duty is: $t^{AD} = (a+2)/(a+3)$.

A2. Effects on DC under the alternative trade regimes

The ranking of DC firm's optimal quality-upgrades
Given that the optimal quality-upgrades under the three different regimes are:

$$s_1^{FT} = \frac{4\lambda + 4}{9\gamma_1}, s_1^{AD} = \frac{6\lambda + 4}{9\gamma_1}, \text{ and } s_1^{PU} = \frac{46\lambda + 9\lambda^2 + 9}{36\gamma_1 + 36\lambda\gamma_1}.$$

It follows that

$$s_1^{AD} - s_1^{FT} = \frac{2\lambda}{9\gamma_1} > 0 \Rightarrow q_1^{AD} > q_1^{FT}; s_1^{AD} - s_1^{PU} = \frac{15\lambda^2 - 6\lambda + 7}{36\gamma_1(\lambda+1)} > 0 \Rightarrow q_1^{AD} > q_1^{PU};$$

$$s_1^{FT} - s_1^{PU} = \frac{7(\lambda-1)^2}{36\gamma_1(\lambda+1)} > 0 \Rightarrow q_1^{FT} > q_1^{PU}.$$

We thus have: $s_1^{AD} > s_1^{FT} > s_1^{PU} \Rightarrow q_1^{AD} > q_1^{FT} > q_1^{PU}$.
The ranking of DC firm's profits
Given that the optimal profits for the DC firm under the three different regimes are:

$$\Pi_{DC}^{AD}=\frac{2(3\lambda+2)^2}{81\gamma_1},\ \Pi_{DC}^{FT}=\frac{8(\lambda+1)^2}{81\gamma_1},\ \text{and}\ \Pi_{DC}^{PU}=\frac{\left(9\lambda^2+46\lambda+9\right)^2}{2592\gamma_1(\lambda+1)^2}.$$

It follows that

$$\Pi_{DC}^{AD}-\Pi_{DC}^{FT}=\frac{2\lambda(5\lambda+4)}{81\gamma_1}>0\Rightarrow\Pi_{DC}^{AD}>\Pi_{DC}^{FT};$$

$$\Pi_{DC}^{FT}-\Pi_{DC}^{PU}=\frac{7(\lambda-1)^2\left(25\lambda^2+78\lambda+25\right)}{2592\gamma_1(\lambda+1)^2}>0\Rightarrow\Pi_{DC}^{FT}>\Pi_{DC}^{PU};$$

$$\Pi_{DC}^{AD}-\Pi_{DC}^{PU}=\frac{495\lambda^4+1092\lambda^3+90\lambda^2+452\lambda+175}{2592\gamma_1(\lambda+1)^2}>0\Rightarrow\Pi_{DC}^{AD}>\Pi_{DC}^{PU}.$$

We thus have: $\Pi_{DC}^{AD}>\Pi_{DC}^{FT}>\Pi_{DC}^{PU}$.

The ranking of DC's consumer surplus

Given the equilibrium levels of consumer surplus in (14c), (19c), and (24c), we have

$$CS_{DC}^{FT}-CS_{DC}^{AD}=\frac{\lambda(5\lambda+2)-a\lambda(24+48\lambda+63a\lambda+36a)}{81\gamma_1};$$

$$\begin{aligned}CS_{DC}^{FT}-CS_{DC}^{PU}&=\frac{\lambda(1-\lambda)\left(209\lambda^3+973\lambda^2+787\lambda+79\right)}{2592\gamma_1(\lambda+1)^3}\\&+\frac{a\lambda(1-\lambda)\left(-252a\lambda^3-252a\lambda^2+252a\lambda+252a-444\lambda^3-996\lambda^2-324\lambda+228\right)}{2592\gamma_1(\lambda+1)^3}.\end{aligned}$$

To make a comparison, we need to determine restrictions on the parameter a for utility $V_{DC}(\theta^*)=\lambda\theta^*q_2-p_2^*$ to be strictly positive under any of the trade regimes. Note that $\theta^*\in[a,a+1]$, where $a>0$. The utility of a DC consumer located at point a is:

$$V_{DC}(a)=\lambda\theta^*q_2-p_2^*=\lambda a(q_2)-p_2^*=\lambda a(1+s_2)-p_2^*=\lambda a(1+0)-p_2^*>0.$$

Under free trade, $V_{DC}(a)=\lambda a-p_2^{*FT}=\lambda a-\frac{\lambda(4\lambda+4)}{27\gamma_1}>0$ which implies that $a>\frac{4\lambda+4}{27\gamma_1}$.

Under AD, $V_{DC}(a)=\lambda a-p_2^{*AD}=\lambda a-\frac{\lambda(6\lambda+4)}{9\gamma_1}>0$ which implies that $a>\frac{6\lambda+4}{9\gamma_1}$.

Under PU, $V_{DC}(a)=\lambda a-p_2^{*PU}=\lambda a-\frac{\lambda(9\lambda^2+46\lambda+9)}{54\gamma_1(1+\lambda)^2}>0$ which implies that $a>\frac{(9\lambda^2+46\lambda+9)}{54\gamma_1(1+\lambda)^2}$.

For $V_{DC}(a)>0$ under any of the trade regimes, the constrained condition is: $a>(6\lambda+4)/(9\gamma_1)$. We assume this condition holds. Substituting this condition into the expression $(CS_{DC}^{FT}-CS_{DC}^{AD})$, as shown above, we find that $CS_{DC}^{FT}-CS_{DC}^{AD}<0$ which implies that $CS_{DC}^{AD}>CS_{DC}^{FT}$. Substituting the constrained condition that $a>(6\lambda+4)/9\gamma_1$ into the expression $(CS_{DC}^{FT}-CS_{DC}^{PU})$, we find that $CS_{DC}^{FT}>CS_{DC}^{PU}$. We thus have: $CS_{DC}^{AD}>CS_{DC}^{FT}>CS_{DC}^{PU}$.

The ranking of DC's social welfare

Given the optimal levels of DC welfare under the three regimes in (14d), (19d), and (24d), we have

$$SW_{DC}^{AD}-SW_{DC}^{FT}=\frac{\lambda(5\lambda+6)}{81\gamma_1}+\frac{a\lambda(24+48\lambda+63a\lambda+36a)}{81\gamma_1}\Rightarrow SW_{DC}^{AD}>SW_{DC}^{FT};$$

$$\begin{aligned}SW_{DC}^{FT}-SW_{DC}^{PU}&=\frac{(1-\lambda)\left(34\lambda^4+427\lambda^3+787\lambda^2+625\lambda+175\right)}{2592\gamma_1(\lambda+1)^3}\\&+\frac{a(1-\lambda)\left(-252a\lambda^4-252a\lambda^3+252a\lambda^2+252a\lambda-444\lambda^4-996\lambda^3-324\lambda^2+228\lambda\right)}{2592\gamma_1(\lambda+1)^3}.\end{aligned}$$

Evaluating the above expression under the constrained condition that $a>(6\lambda+4)/9\gamma_1$, we find that $(SW_{DC}^{FT}-SW_{DC}^{PU})>0$ which implies that $SW_{DC}^{FT}>SW_{DC}^{PU}$. We thus have: $SW_{DC}^{AD}>SW_{DC}^{FT}>SW_{DC}^{PU}$.

A3. Effects on DC under the three alternative trade regimes

(i) The ranking of LDC firm's profits

Given that maximum profits under the three different regimes are:

$$\pi_{LDC}^{FT}=\frac{(4\lambda+4)(\lambda+1)}{81\gamma_1},\ \pi_{LDC}^{AD}=\frac{6\lambda+4}{81\gamma_1},\ \text{and}\ \pi_{LDC}^{PU}=\frac{\lambda\left(9\lambda^2+46\lambda+9\right)}{81\gamma_1(\lambda+1)^2}.$$

It follows that

$$\pi_{LDC}^{FT}-\pi_{LDC}^{AD}=\frac{2\lambda(2\lambda+1)}{81\gamma_1}>0\Rightarrow\pi_{LDC}^{FT}>\pi_{LDC}^{AD};$$

$$\pi_{LDC}^{FT}-\pi_{LDC}^{PU}=\frac{(\lambda-1)^2\left(4\lambda^2+15\lambda+4\right)}{81\gamma_1(\lambda+1)^2}>0\Rightarrow\pi_{LDC}^{FT}>\pi_{LDC}^{PU};$$

$$\pi_{LDC}^{PU}-\pi_{LDC}^{AD}=-\frac{-3\lambda^3-30\lambda^2+5\lambda+4}{81\gamma_1(\lambda+1)^2}.$$

We thus have two possibilities:

(1) $\pi_{LDC}^{FT}>\pi_{LDC}^{PU}>\pi_{LDC}^{AD}$when$\lambda>\widehat{\lambda}_{LDC}$ (i.e., when income differential is getting smaller) and
(2) $\pi_{LDC}^{FT}>\pi_{LDC}^{AD}>\pi_{LDC}^{PU}$when$\lambda<\widehat{\lambda}_{LDC}$ (i.e., when income differential is getting greater).

lowerRoman(%1) The ranking of LDC's consumer surplus

Given the equilibrium levels of consumer surplus in (15c), (20b), and (25c), we have

$$CS_{LDC}^{FT}-CS_{LDC}^{AD}=\frac{-\lambda(9a^2+12a-2)}{81\gamma_1};$$

$$\begin{aligned}&CS_{LDC}^{PU}-CS_{LDC}^{AD}\\&=\frac{\left(-15\lambda^4-516\lambda^3+6\lambda^2+828\lambda+209\right)}{2592\gamma_1(\lambda+1)^3}\\&-\frac{a\left(540a\lambda^4+864a\lambda^3+360a\lambda^2+288a\lambda+252a+612\lambda^4+600\lambda^3+480\lambda^2+936\lambda+444\right)}{2592\gamma_1(\lambda+1)^3};\end{aligned}$$

$$\begin{aligned}&CS_{LDC}^{PU}-CS_{LDC}^{FT}\\&=\frac{(1-\lambda)\left(79\lambda^3+787\lambda^2+973\lambda+209\right)}{2592\gamma_1(\lambda+1)^3}\\&+\frac{(1-\lambda)\left(252a^2\lambda^3+252a^2\lambda^2-252a^2\lambda-252a^2+228a\lambda^3-324a\lambda^2-996a\lambda-444a\right)}{2592\gamma_1(\lambda+1)^3}.\end{aligned}$$

Evaluating the above expressions under the constrained condition that $a>(6\lambda+4)/9\gamma_1$, we have, $(CS_{LDC}^{FT}-CS_{LDC}^{AD})<0$ which implies that $CS_{LDC}^{AD}>CS_{LDC}^{FT}$. However, the comparison between CS_{LDC}^{PU} and CS_{LDC}^{AD} or that between CS_{LDC}^{PU} and CS_{LDC}^{FT} cannot be determined unambiguously. So, the only unambiguous ranking of LDC's consumer surplus is: $CS_{LDC}^{AD}>CS_{LDC}^{FT}$.

We present an alternative proof for the result that $CS_{LDC}^{AD}>CS_{LDC}^{FT}$ in the following. Under free trade, the equilibrium prices, demands, and R&D investments in product quality improvement by the DC and LDC firms are shown in (11), (12a), and (13). The LDC's consumer surplus under free trade contains two components:$CS_{LDC}^{FT}=CS_2^{FT}+CS_1^{FT}$, where

$CS_2^{FT}=\int_a^{\widehat{\theta}}[\theta(1+s_2)-p_2]dF(\theta)=(1+s_2)\int_a^{\widehat{\theta}}\theta d\theta-p_2\int_a^{\widehat{\theta}}d\theta=(1+s_2)\frac{1}{2}[(\widehat{\theta})^2-a^2]-p_2(\widehat{\theta}-a)$ and

$$CS_1^{FT}=\int_{\widehat{\theta}}^{a+1}[\theta(1+s_1)-p_1]dF(\theta)=(1+s_1)\int_{\widehat{\theta}}^{a+1}\theta d\theta-p_1\int_{\widehat{\theta}}^{a+1}d\theta=(1+s_1)\frac{1}{2}\left[(a+1)^2-(\widehat{\theta})^2\right]-p_1[(a+1)-\widehat{\theta}].$$

Plugging the results from (11), (12a), and (13) back into the above expressions, we obtain the following:

$CS_2^{FT}=(1+0)\frac{1}{2}\left[\left(\frac{1}{3}\right)^2-a^2\right]-\frac{4(\lambda+1)}{27\gamma_1}\left(\frac{1}{3}-a\right)=\frac{(3a-1)(8\lambda-9\gamma_1-27a\gamma_1+8)}{162\gamma_1}$ and

$$CS_1^{FT}=\left(1+\frac{4(\lambda+1)}{9\gamma_1}\right)\frac{1}{2}\left[(a+1)^2-\left(\frac{1}{3}\right)^2\right]-\frac{8(\lambda+1)}{27\gamma_1}\left[(a+1)-\frac{1}{3}\right]=\frac{(3a+2)(4a+12\gamma_1+4a\lambda+9a\gamma_1)}{54\gamma_1}.$$

We thus have the following result:

$$CS_{LDC}^{FT}=CS_2^{FT}+CS_1^{FT}=\frac{48a-8\lambda+81\gamma_1+48a\lambda+162a\gamma_1+36a^2\lambda+36a^2-8}{162\gamma_1}.$$

Whereas under an AD policy, the optimal duty is shown in (17e), R&D investments in product quality improvement by the DC and

LDC firms are shown in (18a) and (18c), and the equilibrium prices and demands are shown in (17f), (18e), and (18f). The LDC's consumer surplus under the AD policy contains two components: $CS_{LDC}^{AD} = CS_2^{AD} + CS_1^{AD}$, where

$$CS_2^{AD} = \int_a^{\widehat{\theta}} [\theta(1+s_2) - p_2] dF(\theta) = (1+s_2) \int_a^{\widehat{\theta}} \theta d\theta - p_2 \int_a^{\widehat{\theta}} d\theta = (1+s_2) \frac{1}{2} \left[(\widehat{\theta})^2 - a^2 \right] - p_2(\widehat{\theta} - a);$$

$CS_1^{AD} = \int_{\widehat{\theta}}^{a+1} [\theta(1+s_1) - p_1] dF(\theta) = (1+s_1) \int_{\widehat{\theta}}^{a+1} \theta d\theta - p_1 \int_{\widehat{\theta}}^{a+1} d\theta = (1+s_1) \frac{1}{2} [(a+1)^2 - (\widehat{\theta})^2] - p_1[(a+1) - \widehat{\theta}]$Plugging the equilibrium results under an AD policy into the above expressions, we have:

$CS_2^{AD} == (1+0) \frac{1}{2} \left[\left(\frac{1}{3}\right)^2 - a^2 \right] - \frac{2(3\lambda+2)}{27\gamma_1} \left(\frac{1}{3} - a\right) = \frac{(3a-1)(12\lambda - 9\gamma_1 - 27a\gamma_1 + 8)}{162\gamma_1}$ and

$$CS_1^{AD} = \left(1 + \frac{2(3\lambda+2)}{9\gamma_1}\right) \frac{1}{2} \left[(a+1)^2 - \left(\frac{1}{3}\right)^2 \right] - \frac{2(3\lambda+2)}{27\gamma_1} \left((a+1) - \frac{1}{3} \right) = \frac{(3a+2)(4a + 12\gamma_1 + 6a\lambda + 9a\gamma_1)}{54\gamma_1}.$$

It follows that

$$CS_{LDC}^{AD} = CS_2^{AD} + CS_1^{AD} = \frac{48a - 12\lambda + 81\gamma_1 + 72a\lambda + 162a\gamma_1 + 54a^2\lambda + 36a^2 - 8}{162\gamma_1}.$$

Next, we look at the difference in surplus that LDC consumers obtain through consuming the higher-quality product and the lower-quality product, separately, between the two alternative regimes. We have:

$\Delta CS_1 = CS_1^{AD} - CS_1^{FT} = \frac{(3a+2)(4a+12\gamma_1+6a\lambda+9a\gamma_1)}{54\gamma_1} - \frac{(3a+2)(4a+12\gamma_1+4a\lambda+9a\gamma_1)}{54\gamma_1} = \frac{a\lambda(3a+2)}{27\gamma_1}$which implies that $CS_1^{AD} > CS_1^{FT}$ and

$$\Delta CS_2 = CS_2^{AD} - CS_2^{FT} = \frac{(3a-1)(12\lambda - 9\gamma_1 - 27a\gamma_1 + 8)}{162\gamma_1} - \frac{(3a-1)(8\lambda - 9\gamma_1 - 27a\gamma_1 + 8)}{162\gamma_1} = \frac{2\lambda(3a-1)}{81\gamma_1}$$

which suggests that $CS_2^{AD} > CS_2^{FT}$. These results indicate that, under an AD regime, gains in surplus (ΔCS_1) to LDC consumers from enjoying the higher-quality product with enhanced quality (due to DC firm's R&D investment) exceed the losses in consumer surplus(ΔCS_2) that LDC consumers encounter when consuming the lower-quality product at an increased price. Thus, compared to the result under free trade, LDC's consumer surplus is higher under an AD policy than under free trade.

(i) The ranking of LDC's social welfare

Given the optimal levels of LDC welfare under the three regimes in (15d), (20c), and (25d), we have:

$$SW_{LDC}^{FT} - SW_{LDC}^{AD} = \frac{\lambda(4\lambda+4)}{81\gamma_1} - \frac{a\lambda(9a+12)}{81\gamma_1};$$

$$SW_{LDC}^{PU} - SW_{LDC}^{FT} = \frac{(1-\lambda)\left(128\lambda^4 + 559\lambda^3 + 787\lambda^2 + 293\lambda + 81\right)}{2592\gamma_1(\lambda+1)^3}$$
$$+ \frac{a(1-\lambda)\left(252a\lambda^3 + 252a\lambda^2 - 252a\lambda - 252a + 228\lambda^3 - 324\lambda^2 - 996\lambda - 444\right)}{2592\gamma_1(\lambda+1)^3}.$$

Evaluating the above expressions for $a > (6\lambda+4)/9\gamma_1$, we find that $SW_{LDC}^{FT} - SW_{LDC}^{PU} > 0$ and $SW_{LDC}^{PU} - SW_{LDC}^{FT} > 0$. It follows that $SW_{LDC}^{PU} > SW_{LDC}^{FT} > SW_{LDC}^{AD}$.

A4. The ranking of global welfare

The optimal levels of global welfare under the three different regimes are calculated as follows:

$$GW^{FT} = \frac{(1+\lambda)[(16\lambda + 81\gamma_1 + 16) + a(48 + 48\lambda + 162\gamma_1 + 36a + 36a\lambda)]}{162\gamma_1}.$$

$$GW^{AD} = \frac{36\lambda + 81\gamma_1 + 18\lambda^2 + 81\lambda\gamma_1 + 16}{162\gamma_1} + \frac{a\left(48 + 162a\lambda^2 + 168\lambda + 162\gamma_1 + 144\lambda^2 + 162a\lambda + 36a + 162\lambda\gamma_1\right)}{162\gamma_1}.$$

$$GW^{PU} = \frac{540\lambda + 648\gamma_1 + 806\lambda^2 + 540\lambda^3 + 81\lambda^4 + 1944\lambda\gamma_1 + 1944\lambda^2\gamma_1 + 648\lambda^3\gamma_1 + 81}{1296\gamma_1(1+\lambda)^2}$$
$$+ \frac{a\left(162 + 162a + 1296\gamma_1 + 3888\lambda\gamma_1 + 3888\lambda^2\gamma_1 + 1296\lambda^3\gamma_1\right)}{1296\gamma_1(1+\lambda)^2}$$
$$+ \frac{a\lambda\left(1152a + 1980a\lambda + 1152a\lambda^2 + 162a\lambda^3 + 1368 + 3084\lambda + 1368\lambda^2 + 162\lambda^3\right)}{1296\gamma_1(1+\lambda)^2}.$$

It follows that

$$GW^{AD} - GW^{FT} = \frac{\lambda(36a + \lambda + 48a\lambda + 63a^2\lambda + 45a^2 + 2)}{81\gamma_1} > 0;$$

$$GW^{FT} - GW^{PU} = \frac{(1-\lambda)^2\left(47\lambda^2 + 66\lambda + 47\right)}{1296\gamma_1(1+\lambda)^2} + \frac{a(1-\lambda)^2\left(126a\lambda^2 + 252a\lambda + 126a + 222\lambda^2 + 612\lambda + 222\right)}{1296\gamma_1(1+\lambda)^2} > 0.$$

We thus have $GW^{AD} > GW^{FT} > GW^{PU}$.

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