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IDE DISCUSSION PAPER No. 611

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July 2016

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Preferential trade agreements and antidumping actions against members and nonmembers[*]

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March 8, 2016

Abstract

In a three-country oligopoly model, this paper analyzes a country's decisions concerning antidumping (AD) action against two foreign countries and the relationship between those decisions and regional trade agreements (RTAs). An RTA intensifies product-market competition in the markets of member countries and lowers product prices, while it raises export prices of goods subject to tariff reductions. This effect widens the dumping margin of the non-member firm and narrows the dumping margin of the member firm. If the government is more concerned with domestic firm profit in its AD decision, the RTA may invoke the member's AD action against the nonmember. If the governments attach a sufficiently high value on social welfare, however, the RTA may promote the AD action against the member. If the governments' weight on the domestic firm's profit is neither high nor low, an RTA may block the AD actions against both countries.

Key words: preferential trade liberalization, antidumping, international oligopoly

JEL classification numbers: F12, F13, F15, L13

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1 Introduction

Recently, the world economy has witnessed a rapid growth in regional trade agreements (RTAs). RTAs include trade agreements for goods such as free trade agreements, customs unions, and partial scope agreements. RTAs also include service trade agreements called economic integration agreements. RTAs preferentially liberalize trade among member countries. As of March 7, 2016, 424 RTAs were in force, counting trade agreements in goods, services and accession separately.[1] The number of RTAs was 28 in 1990.

Many theoretical and empirical studies address RTAs, and one strand examines the effect of RTAs on trade polices between member and nonmember countries. With respect to import tariffs, many theoretical papers found that member countries that eliminate tariffs imposed on other member countries, are willing to *reduce* tariffs against outside countries.[2] This result is supported by some empirical studies[3] and is valid even if governments are politically motivated and concerns more with domestic producers. These studies indicate that a proliferation of RTAs prevents protectionist trade policies and contributes to multilateral trade liberalization. However, governments use other protectionist trade policies other than simple import tariffs.

A typical example of trade-restricting policies other than tariffs is antidumping (AD) policy. Under the rule of the World Trade Organization (WTO), countries are allowed to impose an AD duty on an imported good by adopting an AD law. Under AD law, if the government receives a request of AD policy from a domestic industry, it initiates an AD investigation. Then, if the importing country's administrator concludes that the foreign producer is "dumping" its exported product and the dumping causes a "material injury" to a domestic industry, the government can impose an AD duty at a level lower than the dumping margin. In the context of international trade, dumping is identified if the free on board (f.o.b) price of a product in the importing country is less than the "normal value."[4] Typically, the "normal value" is the price in the exporting country market. The dumping margin is defined as the price in the exporting country minus the f.o.b price of

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[1]If different agreements and accessions among the same countries are counted together, 270 RTAs were in force.

[2]See Bagwell and Staiger (1999) and Ornelas, (2005a,b), for instance.

[3]See Estevadeordal, et al. (2008), Calvo-Pardo, et al. (2011), for instance.

[4]The free on board price is the price excluding transportation costs and tariffs. It is the producer price of a good that the producer recieves when exporting.

the importing country.

Countries are frequently using AD actions to protect domestic industries. From 1995 to 2014, there were a total of 4,757 AD investigations. Among them, 2,901 actions were actually implemented. The large number of AD actions in the world would be associated with the recent waves of adopting AD laws. The number of countries with AD laws was about 50 in 1990, and it exceeds 120 in 2014 (Blonigen and Prusa, 2015). Some countries strengthen the implementation of their existing AD laws. For instance, Japan amended its guideline for applying its AD law in 2011 to boost the domestic industries' use of AD.[5]

An intriguing question is whether and how the growing number of RTAs is associated with the frequent use of AD rules. If the formation of an RTA prevents AD actions, the trade promoting effect of RTAs will be more pronounced. If RTA formation promotes AD actions, the trade-creating effect of RTAs should be diminished or even reversed by the increased use of AD rules.

Particularly, if RTAs induce countries to apply AD rules more frequently against nonmember countries, RTAs can hurt nonmember countries even if (normal) tariffs are reduced. For instance, Bhagwati (1993) suggests that '....trade creation can degenerate rapidly into trade diversion, when AD actions ... are freely used.' Hindley and Messerlin (1993) also show the evidence that internal liberalization in the European Community was accompanied by more vigorous anti-dumping action towards nonmember countries. Prusa and Teh (2010) have estimated that RTAs cause a ten to 30 percent increase in the number of AD filings against non-RTA members.

Despite these concerns, there are few theoretical analyses on this subject.[6] This paper examines the relationship between preferential trade liberalization in the form of an RTA and AD policies. We extend the reciprocal dumping model of Brander and Krugman to a three-country model. Specifically, three firms (firms 1, 2, and 3) located in each country (countries 1, 2, and 3) supply imperfectly substitutable products to the markets in those countries. Without AD actions and RTAs, each country imposes the same tariff on imports from all countries. In this situation, the existence of tariffs (trade costs)

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[5]See Japan's Trade Remedy Laws, Regulations and Rules (http://enforcement.trade.gov/trcs/downloads/documents/japan/index.html), accessed on October 26, 2015.

[6]There have been some theoretical analyses that examine the effects of AD protection in an international oligopoly model, such as Reitzes (1993), Anderson et al. (1995), Gao and Miyagiwa (2005), Miyagiwa and Ohno (2007), and Moraga-González and Viaene (2015).

induces firms to set export prices lower than their respective domestic prices, and we observe a reciprocal dumping between countries.

To make clear the effect of an RTA, this paper focuses on country 1's AD actions. Country 1 may block foreign firms' dumpings by implementing AD actions. Specifically, if firm 1 files an AD petition against a particular foreign firm, the government of country 1 initiates an AD investigation and decides whether to accept the firm 1's request and impose the AD duty on the targeted firm, whose level is equal to the dumping margin. Note that even if the targeted firm faces an AD duty, it has an option to avoid the AD duty by setting the uniform price across the markets, and we will see that she actually does such a "price undertaking" in equilibrium.

If a pair of countries forms an RTA, the tariff between them is reduced while the tariff against the nonmember country remains constant. The formation of an RTA intensifies the product-market competition in the markets of member countries and changes the dumping margins and the effect of countries' AD actions. This may in turn change the government's incentives to implement an AD action, or it affects whether the domestic firm files an AD petition.

The result shows that the formation of an RTA that includes country 1 may either promote or prevent country 1's AD use against the other member and the nonmember country, depending on the extent of the government's political motivation to protect the domestic firm and the administrative cost of AD investigations. Specifically, if the government places sufficient weight on the domestic firm's profit, and the administrative cost is neither low nor high, the RTA may trigger a member's AD action against the nonmember. If the government is less concerned with the domestic firm and more concerned with social welfare, the RTA may block the member's AD action that would have applied had the RTA been absent.

Conversely, the RTA may block the member's use of AD against the other member if the government weight on the domestic profit is high, whereas the RTA may promote the member's use of AD action if the government sufficiently values social welfare. If country 1 becomes the nonmember of an RTA, it will discourage its AD actions if the government's weight on the producer's profit is high while the RTA may promote AD actions if it is low.

These results indicate that there is no clear-cut relationship between preferential trade liberalization and AD. If the government cares more about the producer's profit, an RTA will promote ADs against nonmembers and discourage ADs against members. If the government care less about social welfare but it is still not a social-welfare maximizer, an RTA may prevent ADs against nonmembers and instead promote ADs against members. There is also a case where an RTA blocks ADs against all firms.

The remainder of the paper is organized as follows. Section 2 sets up the basic model. Section 3 derives the equilibrium of the product-market competition given the country 1's AD decisions. Section 4 analyzes the determination of countries' AD actions and explores the effect of preferential trade liberalization. Section 5 summarizes the paper and presents concluding remarks.

2   The model

The model includes three countries, and $\Omega = \{1, 2, 3\}$ is a set of countries. Country i has a single firm, firm i, that produces a differentiated product and sells that product in all three countries. Let t_{ij} (≥ 0) denote the import tariff imposed by country i $(i \in \Omega)$ on imports from country j $(j \in \Omega)$. For expositional convenience, we set $t_{ij} = 0$ if $i = j$.

We focus on AD actions of country 1, which may implement AD action against either country 2 or country 3, or both. If firm 1 requests an AD action towards country k $(k = 2, 3)$, it incurs a fixed application cost per request, which is denoted by F. If firm 1 requests AD actions against both foreign countries, it must incur $2F$. The fixed cost includes the cost of documenting and reporting the damages caused by the targeted firm's dumping.

The direct utility function of the representative consumer in country i is given by

$$U_i = \sum_{j \in \Omega} \left(a x_{ij} - \frac{(x_{ij})^2}{2} - b x_{ij} \sum_{h \neq j} x_{ih} \right) + Y_i \tag{1}$$

where x_{ij} is the consumption of product j $(j \in \Omega)$ and Y_i is the consumption of the numeraire good in country i. By maximizing U_i with respect to x_{ij}, subject to $\sum_{j \in \Omega} p_{ij} x_{ij} + Y_i \leq M_i$ where M_i is the income in country i, the inverse demand function of the product

j in country i becomes

$$p_{ij} = a - x_{ij} - b\sum_{k\neq i} x_{kj}, \tag{2}$$

where $b \in (0,1)$ represents the substitutability of products. If $b = 0$, the products are non-substitutable and as b approaches one, the products become more substitutable. Then, the demand function of good j in country i becomes

$$x_{ij}(\boldsymbol{p}_i) = \frac{1}{(1-b)(1+2b)}\left[(1-b)a - (1+b)p_{ij} + b\sum_{k\neq j} p_{ik}\right] \tag{3}$$

where $\boldsymbol{p}_i' = (p_{i1}, p_{i2}, p_{i3})$ is the price vector in country i. By substituting (3) into (1), we have the representative consumer's indirect utility function in country i as $V_i(\boldsymbol{p}_i, M_i)$.

Each firm's unit cost of production is constant and normalized to zero. Let $r_{ij} = p_{ij} - t_{ij}$ denote the producer price of the good j in country i. Then, firm j's total profits (gross of the fixed cost of an AD application) becomes:

$$\Pi_j = \sum_i r_{ij} x_{ij}(\boldsymbol{p}_i) = \sum_i (p_{ij} - t_{ij}) x_{ij}(\boldsymbol{p}_i). \tag{4}$$

Country i's social welfare (gross of the fixed cost) is given by

$$W_i = V_i(\boldsymbol{p}_i, M_i) - M_i + \sum_j t_{ij} x_{ij}(\boldsymbol{p}_i) + \Pi_i. \tag{5}$$

We assume each pair of countries levies the same tariff on each other's imports. Therefore, we have $t_{21} = t_{12}$, $t_{31} = t_{13}$, and $t_{32} = t_{23}$.

If firm 1 request an AD action, the governments of country 1 chooses whether to undertake an AD investigation. Government 1's AD actions towards country 2 and country 3 are respectively given by $s_2 \in \{N, AD\}$ and $s_3 \in \{N, AD\}$ where N represents the government decision not to make an AD investigation, and AD represents the government decision to undertake an AD investigation. Government 1's payoff, gross of the fixed cost of AD application, is given by

$$G_1(s_2, s_3) = \gamma W_1(s_2, s_3) + (1-\gamma)\Pi_1(s_2, s_3), \tag{6}$$

where γ is the government's weight on social welfare relative to domestic firm's profit. If $\gamma = 1$, the government maximizes social welfare and, if $\gamma = 0$, the government only concerns with the domestic firm's profit. This government's payoff function reflects the fact that countries sometimes consider public interests concerns before making a decision on the imposition of AD duty. The public interests include the interests of consumers and industrial users of the products, who will be negatively affected by the AD measures.[7] In our model, we regard γ as the degree of the government's consideration of public interests in implementing AD actions.

With regard to governments' tariffs other than AD duty, we treat them as exogenous variables and consider three possible situations: (i) no RTA where all countries impose MFN tariffs ($t_{12} = t_{23} = t_{13} = \tau$), (ii) countries 1 and 2 form an RTA, $t_{12} = t < t_{23} = t_{13} = \tau$, where country 1 becomes a member of the RTA, (iii) countries 2 and 3 form an RTA, $t_{23} = t < t_{12} = t_{13} = \tau$, where country 1 becomes the non-member of the RTA

The timing of the game is as follows. In Stage 1, firms 1 decides whether to request an AD investigation against each foreign firm to its domestic governments. In Stage 2, if firm 1 requests in Stage 1, the government of country 1 decides whether to implement requested AD actions. The government of country 1 may place substantial weight on the domestic firm's profits in AD decisions, which we will address later. In Stage 3, the three firms engage in Bertrand-type competition in the markets of three countries. Under AD action, AD duty is actually levied only if the targeted firm's dumping is detected.

3 Product market competition and firms' dumpings

This section derives the subgame equilibrium in Stage 3. The AD action of country 1 is effective if and only if firm 1 requests an AD action in Stage 1 and government 1 accepts the request and implement the AD action in Stage 2. Depending on firm 1's decision and the government's decision on AD action in Stage 1 and Stage 2, there are four possible equilibrium outcomes.

1. **N**: No AD actions, $(s_2, s_3) = (N, N)$.

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[7]See Kotsiubska (2011) for details.

2. **AD₂**: AD action against only country 2, $(s_2, s_3) = (AD, N)$.

3. **AD₃**: AD action against only country 3, $(s_2, s_3) = (N, AD)$.

4. **AD₂₃**: AD actions against both countries, $(s_2, s_3) = (AD, AD)$.

We derive the product-market equilibrium for each case.

3.1 No AD action

Let us first derive the subgame equilibrium without AD actions (**N**). In this case, firms can freely set different prices in different markets. Firm j maximizes (4) with respect to each price. The equilibrium consumer prices of products in country i are given by

$$p_{ii}(N, \boldsymbol{t}) = \frac{a(1-b)}{2} + \frac{b(1+b)(t_{ij} + t_{ik})}{4 + 6b}, \tag{7}$$

$$p_{ij}(N, \boldsymbol{t}) = \frac{a(1-b)}{2} + \frac{(1+b)\{(2+b)t_{ij} + bt_{ik}\}}{4 + 6b}, \text{ and} \tag{8}$$

$$p_{ik}(N, \boldsymbol{t}) = \frac{a(1-b)}{2} + \frac{(1+b)\{(2+b)t_{ik} + bt_{ij}\}}{4 + 6b}, \tag{9}$$

where $i \neq j \neq k$ $(i, j, k \in \Omega)$ and $\boldsymbol{t} = (t_1, t_2, t_3)$ is the tariff vector.

Accordingly, the producer prices are calculated as $r_{ii}(N, \boldsymbol{t}) = p_{ii}(N, \boldsymbol{t})$, $r_{ij}(N, \boldsymbol{t}) = p_{ij}(N, \boldsymbol{t}) - t_{ij}$, and $r_{ik}^N(N, \boldsymbol{t}) = p_{ik}(N, \boldsymbol{t}) - t_{ik}$. An important property is that the consumer price of each good in country i is increasing while the producer price is decreasing in i's tariff on the good. Then, the equilibrium dumping margins of goods 2 and 3 in country 1 become

$$d_2(N, \boldsymbol{t}) = r_{22}(N, \boldsymbol{t}) - r_{12}(N, \boldsymbol{t}) = \frac{2(1 + 2b)t_{12} + b(1 + b)(t_{23} - t_{13})}{2(2 + 3b)}, \tag{10}$$

$$d_3(N, \boldsymbol{t}) = r_{33}(N, \boldsymbol{t}) - r_{13}(N, \boldsymbol{t}) = \frac{2(1 + 2b)t_{13} + b(1 + b)(t_{23} - t_{12})}{2(2 + 3b)}. \tag{11}$$

Without any RTA, countries must follow the most-favored-nations (MFN) principle of WTO and levy the same tariff (i.e., the MFN tariff) on the imports from all countries. Since countries and firms are symmetric, it is plausible to suppose three countries impose the identical MFN tariff and $t_{12} = t_{23} = t_{13} = \tau$ holds. Let $\boldsymbol{t}_N = (\tau, \tau, \tau)$ denote the tariff

vector under No RTA. In this case, $d_2(N, \boldsymbol{t}_N) = d_3(N, \boldsymbol{t}_N) > 0$ holds and the dumping margins of goods 2 and 3 are positive in country 1.

Without loss of generality, we suppose country 2 is chosen as the partner country if when country 1 forms an RTA. If countries 1 and 2 form an RTA, $t_{12} = t < t_{23} = t_{13} = \tau$ holds. Let $\boldsymbol{t}_{12} = (t, \tau, \tau)$ denote the tariff vector under 1-2 RTA. Preferential trade liberalization realized by an RTA increases the product market competition and thereby decreases the equilibrium prices of the goods in countries 1 and 2. First, a decrease in $p_{13}(N)$ widens the dumping margin of good 3. Second, $p_{22}(N)$ and $p_{12}(N)$ decrease but the producer price of good 2 in country 1, $p_{12}(N) - t_{12}$, increases with a reduction of t_{12}. This narrows the dumping margin of good 2. Therefore, the dumping margin under no AD action is smaller for good 2 and greater for good 3, $d_2(N, \boldsymbol{t}_{12}) < d_2(N, \boldsymbol{t}_N) = d_3(N, \boldsymbol{t}_N) < d_3(N, \boldsymbol{t}_{12})$.

If countries 2 and 3 form an RTA, $t_{23} = t < t_{12} = t_{13} = \tau$, where country 1 becomes an non-member of the RTA, then the dumping margins of both imported goods decrease in country 1 and $d_2(N, \boldsymbol{t}_{23}) = d_3(N, \boldsymbol{t}_{23}) < d_2(N, \boldsymbol{t}_N) = d_3(N, \boldsymbol{t}_N)$ holds where $\boldsymbol{t}_{23} = (\tau, \tau, t)$.

Proposition 1 *Given that countries levy the same MFN tariff without RTAs, the dumping margins of goods 2 and 3 in country 1 are positive. Country 1's RTA with country 2 decreases the dumping margin of good 2 and increases the dumping margin of good 3. The dumping margin of good 2 is positive as long as $t > 0$. RTA between countries 2 and 3 decreases the dumping margin of both good 2 and good 3.*

The equilibrium profit of firm j $(j \in \Omega)$ is given by

$$\Pi_j(N, \boldsymbol{t}) = \frac{1 + b}{(1 - b)(1 + 2b)} \sum_i \{r_{ij}(N, \boldsymbol{t})\}^2. \tag{12}$$

3.2   AD action against one foreign country

Next, we investigate the case in which country 1 only files an AD investigation against either firm 2 or firm 3 ($\mathbf{AD_2}$ or $\mathbf{AD_3}$).

Suppose firm 2 is a target of the AD investigation. Firm 2 anticipates that if its dumping margin is positive ($d_2 = r_{22} - r_{12} = p_{22} - (p_{12} - t_{12}) > 0$), the government of country 1 will charge the antidumping duty equal to d_2. Then, firm 2 's optimal

reaction is to offer a "price-undertaking" to the government of country 1, by which the firm eliminates the dumping margin and sets a uniform price across countries 1 and 2. This paper focuses on the case where the importing countries accept any offer of price undertaking.

Firm 2 maximizes (4) with respect to p_{12} subject to $p_{22} = p_{12} - t_{12}$, while the other two firms continue to discriminate prices between in countries 1 and in its own country. The equilibrium consumer price of good j in country i is given by $p_{ij}(AD_2, \boldsymbol{t})$. The equilibrium consumer prices of good 2 becomes

$$p_{12}(AD_2, \boldsymbol{t}) = p_{12}(N, \boldsymbol{t}) + \frac{1}{2} d_2(N, \boldsymbol{t}), \tag{13}$$

$$p_{22}(AD_2, \boldsymbol{t}) = p_{22}(N, \boldsymbol{t}) - \frac{1}{2} d_2(N, \boldsymbol{t}), \tag{14}$$

$$p_{32}(AD_2, \boldsymbol{t}) = p_{32}(N, \boldsymbol{t}). \tag{15}$$

Hence, the producer prices of good 2 are adjusted to a uniform price by increasing the consumer price in the foreign market and decreasing the consumer price in the domestic market. The degree of the price changes are equal to 50 percent of the dumping margin under no AD actions.

The firm 2's price adjustment affects other firms pricing. By comparing the equilibrium consumer prices of good 1 and good 3 in countries 1 and 2, we have $p_{11}(AD_2, \boldsymbol{t}) - p_{11}(N, \boldsymbol{t}) = bd_2(N, \boldsymbol{t})/\{2(2 + b)\} > 0$, $p_{13}(AD_2, \boldsymbol{t}) - p_{31}(N, \boldsymbol{t}) = bd_2(N, \boldsymbol{t})/\{2(2 + b)\} > 0$, $p_{21}(AD_k, \boldsymbol{t}) - p_{21}(N, \boldsymbol{t}) = -bd_2(N, \boldsymbol{t})\backslash\{2(2 + b)\} < 0$, and $p_{23}(AD_k, \boldsymbol{t}) - p_{23}(N, \boldsymbol{t}) = -bd_2(N, \boldsymbol{t})/\{2(2 + b)\} < 0$. Compared to the No AD action case, firm 2 increases the price in country 1 and decreases the price in country 2. Because a firms' pricing is strategic complement, this increases the other firms' equilibrium prices in country 1 and decreases the equilibrium prices in country 2.

Under country 1's AD action against firm 2, the dumping margin of good 3 becomes

$$d_3(AD_2, \boldsymbol{t}) = d_3(N, \boldsymbol{t}) - \frac{b}{2(2 + b)} d_2(N, \boldsymbol{t}) > 0. \tag{16}$$

Country 1's AD against firm 2 decreases firm 3's dumping margin in country 1.

Similarly, if firm 3 is the target of country 1's AD action, firm 3 increases the price of

good 3 in country 1 and decreases it in country 3. These price changes subsequently increase the prices of goods 1 and 2 in country 1 and decrease them in country 3, decreasing firm 2's dumping margin. We have the following proposition.

Proposition 2 *Starting from no AD action, country 1's AD action towards one country increases the consumer prices in all goods in country 1 and decreases those in the targeted country. The prices in the country that is not a target of AD remain unchanged.*

The equilibrium profit of each firm when only firm k ($k \in \{2.3\}$) is the target of AD action is given by

$$\Pi_j(AD_k, \boldsymbol{t}) = \frac{1+b}{(1-b)(1+2b)} \sum_i \{r_{ij}(AD_k, \boldsymbol{t})\}^2 \tag{17}$$

where $r_{ij}(AD_k, \boldsymbol{t}) = p_{ij}(AD_k, \boldsymbol{t}) - t_{ij}$.

3.3 AD actions against two foreign countries

Finally, if country 1 implements AD actions against both and countries 2 and 3 ($\mathbf{AD}_{23}$), then both firm 2 and firm 3 set uniform prices across the two markets. Let $p_{ij}(AD_{23}, \boldsymbol{t})$ denote the equilibrium consumer price of good j in country i in this case. Compared with the case where country 1 only implement AD action against firm 2, the equilibrium consumer prices of newly targeted firm, firm 3, are given by

$$p_{13}(AD_{23}, \boldsymbol{t}) = p_{13}(AD_2, \boldsymbol{t}) + \frac{8 + 8b + b^2}{(4 + 3b)(4 + b)} d_3(AD_2, \boldsymbol{t}), \tag{18}$$

$$p_{23}(AD_{23}, \boldsymbol{t}) = p_{23}(AD_2, \boldsymbol{t}) + \frac{b^2}{(4 + 3b)(4 + b)} d_3(AD_2, \boldsymbol{t}), \tag{19}$$

$$p_{33}(AD_{23}, \boldsymbol{t}) = p_{33}(AD_2, \boldsymbol{t}) - \frac{2(2 + b)^2}{(4 + 3b)(4 + b)} d_3(AD_2, \boldsymbol{t}). \tag{20}$$

Firm 3 increases the price in country 1 and reduces the price in country 3. Because firm 2 has already set uniform prices between countries 1 and 2, an increase in the price of good 3 in country 1 increases both prices of good 2 in both countries 1 and 2. This in turn induces firm 3 to set higher price of good 3 in country 2.

Similarly, if we compare these prices with the prices when only country 3 is the target

of country 1's AD, all prices in countries 1 and 3 increase while those prices in country 2 decrease. We have the following proposition.

Proposition 3 *Starting from the country 1's AD action against one country, country 1's AD action towards another country decreases the consumer prices of all goods in newly targeted country and increases the consumer prices of all goods in the other two countries.*

The equilibrium profit of each firm is given by

$$\Pi_j(AD_{23}, \boldsymbol{t}) = \frac{1+b}{(1-b)(1+2b)} \sum_i \{r_{ij}(AD_{23}, \boldsymbol{t})\}^2 \tag{21}$$

where $r_{ij}(AD_{23}, \boldsymbol{t}) = p_{ij}(AD_{23}, \boldsymbol{t}) - t_{ij}$.

3.4 The effect of AD action on firms' profits

Given no AD action is implemented, the effect of country 1's AD action against one foreign firm, firm k, on firm j's operating profit (i.e., the profit gross of the fixed cost of an AD application) is given by $\Delta\Pi_j(AD_k^N, \boldsymbol{t}) = \Pi_j(AD_k, \boldsymbol{t}) - \Pi_j(N, \boldsymbol{t})$. If country 1 implements AD actions against both foreign firms, the changes in firm j's operating profit is given by $\Delta\Pi_j(AD_{23}^N, \boldsymbol{t}) = \Pi_j(AD_{23}, \boldsymbol{t}) - \Pi_j(N, \boldsymbol{t})$. If $\Delta\Pi_1(AD_k^N, \boldsymbol{t}) > F$ holds, firm 1 benefits from the AD action against firm k. If $\Delta\Pi_j(AD_{23}^N, \boldsymbol{t}) > 2F$ holds, firm 1 benefits from the AD actions against both foreign firms. Firm 1 prefers implementing two ADs to one AD if $\{\Delta\Pi_1(AD_{23}^N, \boldsymbol{t}) - 2F\} - \{\Delta\Pi_1(AD_k^N, \boldsymbol{t}) - F\} = \Delta\Pi_1(AD_{23}^k, \boldsymbol{t}) - F > 0$ is satisfied, where $\Delta\Pi_j(AD_{23}^k, \boldsymbol{t}) = \Pi_j(AD_{23}^N, \boldsymbol{t}) - \Delta\Pi_1(AD_k^N, \boldsymbol{t})$ is the profit change of firm j from one AD against firm k to two ADs against both firms.

Lemma 1 *When $max[\Delta\Pi_1(AD_2^N, \boldsymbol{t}), \Delta\Pi_1(AD_3^N, \boldsymbol{t})] = \Delta\Pi_1(AD_k^N, \boldsymbol{t}) > F$ holds, firm 1 prefers the AD actions against both countries if $\Delta\Pi_1(AD_{23}^k, \boldsymbol{t}) > F$ holds and prefers the AD action only against firm k otherwise. When $max[\Delta\Pi_1(AD_2^N, \boldsymbol{t}), \Delta\Pi_1(AD_3^N, \boldsymbol{t})] < F$ holds, firm 1 prefers no AD actions.*

We can confirm that, as long as the dumping margin of the targeted foreign firm is positive, both $\Delta\Pi_1(AD_k^N, \boldsymbol{t}) > 0$ and $\Delta\Pi_1(AD_{23}^k, \boldsymbol{t}) > 0$ hold, implying that country 1's AD action always increases the operating profit of firm 1. However, the AD action hurts

the targeted foreign firm's profit because $\Delta\Pi_k(AD_k^N, \boldsymbol{t}) < 0$ and $\Delta\Pi_l(AD_{23}^k, \boldsymbol{t}) < 0$ $(k, l \in \{2, 3\}, l \neq k)$ hold. Meanwhile, the profit of the non-targeted foreign firm, $\Delta\Pi_l(AD_k, \boldsymbol{t})$, may decrease if country 1 is the non-member of an RTA. Otherwise, $\Delta\Pi_l(AD_k, \boldsymbol{t}) > 0$ holds.

Note that the equilibrium profit of each firm in each country is quadratic in the producer price in that country and the total profit is additive sum of them. Therefore, if the mean price is kept constant, each firm's profit increases as the price difference among countries increases. From the perspective of firm 2, if countries 2 and 3 form an RTA and tariffs satisfy $t_{23} = t < t_{12} = t_{13} = \tau$, the producer price of good 2 is initially higher in country 3 because the RTA between countries 2 and 3 makes the effective market size of good 2 in country 3 is greater than the effective market size in country 1. Because the country 1's AD action against country 3 increases the prices in country 1 and reduces the prices in country 3, it may decrease the price difference of good 2 between countries 1 and 3 and hurts firm 2. If countries 2 and 3 do not form an RTA and t_{23} is equal to or higher than t_{12} and t_{13}, the AD action always widens the price difference and benefits firm 2. The same effect applied for firm 3 if country 1's AD action targets firm 2.

Proposition 4 *Country 1's AD action increases the operating profit of firm 1, while it decreases the profit of the targeted firm. It may decrease the profit of the non-targeted firm if countries 2 and 3 form an RTA. It increases the profit of the non-targeted firm otherwise.*

4 Decisions on antidumping

Here, we investigate the decisions of the government of country 1 in Stage 2. The change in government 1's payoff from its AD action against one foreign country (country k) is given by

$$\begin{aligned}
\Delta G_1(AD_k^N, \boldsymbol{t}) &= G_1(AD_k, \boldsymbol{t}) - G_1(N, \boldsymbol{t}) \\
&= \gamma\Delta W_1(AD_k^N, \boldsymbol{t}) + (1-\gamma)\Delta\Pi_1(AD_k^N, \boldsymbol{t})
\end{aligned} \tag{22}$$

where $\Delta W_j(AD_k^N, \boldsymbol{t}) = W_1(AD_k^N, \boldsymbol{t}) - W_1(N, \boldsymbol{t})$ represents the changes in welfare of country j, gross of the fixed costs of AD actions if $J = 1$, from the country 1's AD action only against country k. Similarly, the change in the government payoff in country 1 from its AD actions against both foreign firms becomes $\Delta G_1(AD_{23}^N, \boldsymbol{t}) = \gamma \Delta W_1(AD_{23}^N, \boldsymbol{t}) + (1 - \gamma)\Delta \Pi_1(AD_{23}^N, \boldsymbol{t})$. We can confirm that $\Delta W_1(AD_k^N, \boldsymbol{t}) < 0$ and $\Delta W_1(AD_{23}^k, \boldsymbol{t}) < 0$ always hold, as long as the dumping margin of the targeted firm is positive. An AD action increases consumer prices in the domestic market and the resulting reductions in imports volume reduces consumer surplus and tariff revenues. Therefore, an AD action always decreases the welfare of country 1. Because $\Delta \Pi_1(AD_k^N, \boldsymbol{t}) > 0$ and $\Delta \Pi_1(AD_{23}^k, \boldsymbol{t}) > 0$ hold, we have the following lemma.

Lemma 2 $\partial\{\Delta G_1(\sigma, \boldsymbol{t})\}/(\partial \gamma) < 0$ holds ($\sigma \in \{AD_k^N, AD_{23}^k\}$), where $\Delta G_1(\sigma, \boldsymbol{t}) > 0$ at $\gamma = 0$ and $\Delta G_1(\sigma, \boldsymbol{t}) < 0$ at $\gamma = 1$.

As γ increases, the gains from AD action decrease because the government is more concerned with the negative effect of AD action on consumer surplus and tariff revenues than the positive effect on the domestic firm's profit. This lemma indicates that there exists the level of γ at which $\Delta G_1(AD_k^N, \boldsymbol{t}) = 0$ holds, $\gamma_k^N(\boldsymbol{t})$ (< 1). Similarly, let $\gamma_{23}^k(\boldsymbol{t})$ (< 1) be the level of γ at which $\Delta G_1(AD_{23}^k, \boldsymbol{t}) = 0$ holds.

Suppose firm 1 only requests AD action against firm k. Then, the government of country 1 accepts it if $\Delta G_1(AD_k^N, \boldsymbol{t}) > F$ holds and rejects it otherwise. Suppose firm 1 requests AD action against both firms. The government in country 1 accepts them if $\Delta G_1(AD_k^N, \boldsymbol{t}) \geq \Delta G_1(AD_l^N, \boldsymbol{t})$ ($k \neq l$) and $\min[\Delta G_1(AD_k^N, \boldsymbol{t}), \Delta G_1(AD_{23}^k, \boldsymbol{t})] > F$ hold where $\Delta G_1(AD_{23}^k, \boldsymbol{t}) = \Delta G_1(AD_{23}^N, \boldsymbol{t}) - \Delta G_1(AD_k^N, \boldsymbol{t})$. The government only accepts AD action against firm k and rejects AD action against another foreign firm if $\Delta G_1(AD_k^N, \boldsymbol{t}) > F \geq \Delta G_1(AD_{23}^k, \boldsymbol{t})$ holds. If $\Delta G_1(AD_k^N, \boldsymbol{t}) < F$ holds for any k, the government rejects any AD requests.

Firm 1 correctly anticipates which request will be accepted by the government, and chooses and requests the AD action(s) from acceptable options that maximizes its profit.

Lemma 3 $\Delta \Pi_1(\sigma, \boldsymbol{t}) > F$ always hold whenever $\Delta G_1(\sigma, \boldsymbol{t}) > F$ holds ($\sigma \in \{AD_k^N, AD_{23}^k\}$).

This lemma suggests that firm 1 always request an AD action if it anticipates it will be accepted by the government. In the following subsections, we discuss how the government 1's AD actions are related to the formation of an RTA.

4.1 No RTA

We start with the case where there are no RTA and, therefore, $t_{12} = t_{13} = t_{23} = \tau$ holds and the tariff vector is $\boldsymbol{t}_N = (\tau, \tau, \tau)$. In this case, because foreign countries are symmetric in all aspects, we have $\Delta G_1(AD_2^N, \boldsymbol{t}_N) = \Delta G_1(AD_3^N, \boldsymbol{t}_N)$ and $\Delta G_1(AD_{23}^2, \boldsymbol{t}_N) = \Delta G_1(AD_{23}^3, \boldsymbol{t}_N)$. We can confirm that $\Delta \Pi_1(AD_k^N, \boldsymbol{t}_N) > \Delta \Pi_1(AD_{23}^k, \boldsymbol{t}_N) > 0$ is satisfied, implying that an AD action against one foreign country reduces the firm 1's gains from an AD action against another foreign country.

Suppose country 1 implements AD action against country 2. The AD action raises the prices in country 1 and reduces the pries in country 2, while the prices in country 3 remain unchanged. This reduces the dumping margin of good 3, decreasing firm 1's gains from AD action against country 3. The decreased dumping margin of good 3 also reduces the welfare loss of AD action, $\Delta W_1(AD_k^N, \boldsymbol{t}_N) < \Delta W_1(AD_{23}^k, \boldsymbol{t}_N) < 0$. Therefore, by (22), $\partial\{\Delta G_1(AD_k^N, \boldsymbol{t}_N)\}/(\partial\gamma) < \partial\{\Delta G_1(AD_{23}^k, \boldsymbol{t}_N)\}/(\partial\gamma) < 0$ holds and an increase in γ decreases the gains from an AD action against a particular firm less if country 1 implements an AD action against another firm. We have the following proposition.

Proposition 5 *If there are no RTAs, the equilibrium outcome becomes (i)* **AD$_{23}$** *if $F < \min[\Delta G_1(AD_k^N, \boldsymbol{t}_N), \Delta G_1(AD_{23}^k, \boldsymbol{t}_N)]$ holds, (ii) either* **AD$_2$** *or* **AD$_3$** *if $\Delta G_1(AD_{23}^k, \boldsymbol{t}_N) \leq F < \Delta G_1(AD_k^N, \boldsymbol{t}_N)$ holds. Otherwise, the equilibrium outcome becomes* **N**.

Figure 1 shows the possible equilibrium outcome in the (γ, F) space. In depicting Figure 1, parameters are set at $a = 10$, $b = 0.75$, $\tau = 6$.

[**Figure 1 around here**]

If the government in country 1 places a sufficiently large weight on firm 1's profit in its AD decision, firm 1 requests and the government accepts AD actions against both foreign firms. If the fixed cost of AD is in the middle range, firm 1 requests an AD only against

14

one foreign firm, which is implemented in equilibrium. Since countries are symmetric, it is undetermined which foreign firm becomes the target. If the fixed cost of AD is sufficiently high or the government places sufficiently large weight on social surplus, firm 1 does not request any AD action.

4.2 RTA between countries 1 and 2

Here, we elaborate on the effect of an RTA on AD actions against the member and the non-member countries. Suppose country 1 and 2 forms an RTA and the tariffs between them is reduced to $t_{12} = t$ that is smaller than τ, and the tariff vector becomes $\boldsymbol{t}_{12} = (t, \tau, \tau)$.

By Proposition 1, the dumping margin under no AD action is smaller for good 2 and greater for good 3, $d_2(N, \boldsymbol{t}_{12}) < d_2(N, \boldsymbol{t}_N) = d_3(N, \boldsymbol{t}_N) < d_3(N, \boldsymbol{t}_{12})$. This implies that the price changes from AD action are greater if country 1 implements AD measure against country 2. From the perspective of firm 1's profit, a smaller dumping margin of the rival firm decreases while a larger dumping margin increases its gains from an AD action. Hence, $\Delta G_1(AD_2^N, \boldsymbol{t}_{12}) < \Delta G_1(AD_2^N, \boldsymbol{t}_N) = \Delta G_1(AD_3^N, \boldsymbol{t}_N) < \Delta G_1(AD_3^N, \boldsymbol{t}_{12})$ holds at $\gamma = 0$. This implies that the formation of an RTA increases the domestic firm's incentive to request an AD measure against the non-member and it decreases its incentive to request an AD measure against the member.

Lemma 4 *The RTA of country 1 and country 2 increases firm 1's gains from country 1's AD action against firm 3 and decreases them from country 1's AD action against firm 2.*

From the perspective of consumer surplus and tariff revenues, a greater dumping margin increases the efficiency loss from implementing an AD measure. Hence,

$$\frac{\partial \{\Delta G_1(AD_3^N, \boldsymbol{t}_{12})\}}{\partial \gamma} < \frac{\partial \{\Delta G_1(AD_3^N, \boldsymbol{t}_N)\}}{\partial \gamma} = \frac{\partial \{\Delta G_1(AD_2^N, \boldsymbol{t}_N)\}}{\partial \gamma} < \frac{\partial \{\Delta G_1(AD_2^N, \boldsymbol{t}_{12})\}}{\partial \gamma} < 0 \tag{23}$$

holds. Similarly, $\Delta G_1(AD_{23}^3, \boldsymbol{t}_{12}) < \Delta G_1(AD_{23}^3, \boldsymbol{t}_N) = \Delta G_1(AD_{23}^2, \boldsymbol{t}_N) < \Delta G_1(AD_{23}^2, \boldsymbol{t}_{12})$ hold at $\gamma = 0$ and $\partial \{\Delta G_1(AD_{23}^2, \boldsymbol{t}_{12})\}/(\partial \gamma) < \partial \{\Delta G_1(AD_{23}^3, \boldsymbol{t}_{12})\}/(\partial \gamma) < 0$ hold. As the government cares more about social surplus, the government becomes less eager to

accept AD requests, and the degree of decrease in the government payoff is larger if AD targets the non-member firm and smaller if the target is the member firm.

This implies that, in the presence of an RTA between countries 1 and 2, the government of country 1 gains more from its AD action against the non-member country (country 3) when the government's weight on social welfare is sufficiently small, and it gains more from its AD action against the member country (country 2) when it is sufficiently large. The same result applies if country 1 chooses country 3 rather than country 2 as a partner of an RTA. Let $\overline{\gamma}$ denote the cut-off level of γ at which $\Delta G_1(AD_2^N, \boldsymbol{t}_{12}) = \Delta G_1(AD_3^N, \boldsymbol{t}_{12})$ holds. We have $\Delta G_1(AD_2^N, \boldsymbol{t}_{12}) < \Delta G_1(AD_3^N, \boldsymbol{t}_{12})$ for $\gamma \in [0, \overline{\gamma})$ and $\Delta G_1(AD_2^N, \boldsymbol{t}_{12}) > \Delta G_1(AD_3^N, \boldsymbol{t}_{12})$ for $\gamma \in (\overline{\gamma}, 1]$. Given that implementing multiple AD actions is unprofitable of the government of country 1 (i.e., $\Delta G_1(AD_{23}^k, \boldsymbol{t}_{12}) \leq F$ is satisfied), even if $\gamma > \overline{\gamma}$ and $\Delta G_1(AD_2^N, \boldsymbol{t}_{12}) > \Delta G_1(AD_3^N, \boldsymbol{t}_{12}) > F$ holds, the AD action against country 3 will be chosen. This is because the AD action against the non-member country generate larger gains to firm 1, and firm 1 requests an AD action only against country 3. Because any AD action must be backed up by the domestic firm's AD requests, the government of country 1 cannot choose an AD action against country 2 even though it generates a larger payoff for the government.

As in the non-RTA case, it is ambiguous whether the gains from an AD against country k, $\Delta G_1(AD_k^N, \boldsymbol{t}_{12})$, is larger or smaller than the gains from additional AD against another country, $\Delta G_1(AD_{23}^k, \boldsymbol{t}_{12})$.

Proposition 6 *If country 1 has an RTA with country 2, the equilibrium outcome becomes:*
(i) **AD₂₃** *if $\gamma < \overline{\gamma}$ and $F < \min[\Delta G_1(AD_3^N, \boldsymbol{t}_{12}), G_1(AD_{23}^3, \boldsymbol{t}_{12})]$ hold or if $\gamma \geq \overline{\gamma}$ and $F < \min[\Delta G_1(AD_3^N, \boldsymbol{t}_{12}), G_1(AD_{23}^3, \boldsymbol{t}_{12})]$ hold, (ii)* **AD₃** *if $\Delta G_1(AD_{23}^3, \boldsymbol{t}_{12}) \leq F < \Delta G_1(AD_3^N, \boldsymbol{t}_{12})$ holds, (iii)* **AD₂** *if $\overline{\gamma} \leq \gamma$ and $max[\Delta G_1(AD_3^N, \boldsymbol{t}_{12}), \Delta G_1(AD_{23}^2, \boldsymbol{t}_{12})] \leq F < \Delta G_1(AD_3^N, \boldsymbol{t}_{12})$ hold, (iv)* **N** *otherwise.*

Figure 2 shows the possible equilibrium outcomes in the (γ, F) space. The parameter values are set at the same level as in Figure 1 and we set $t = 4$.

[**Figure 2 around here**]

With the RTA between countries 1 and 2, a single AD action against the non-member country, $\mathbf{AD_3}$, can be the unique equilibrium outcome when the government 1's weight on firm 1's profit is large and the fixed cost of AD firm 1 must incur, F, is neither so large nor so small. If γ exceeds $\overline{\gamma}$, however, a single AD action against the member country, $\mathbf{AD_2}$, can also be the unique equilibrium outcome.

Figure 3 combines Figures 1 and 2 and shows that how an RTA between countries 1 and 2 changes the equilibrium outcomes in the (γ, F) space.

[**Figure 3 around here**]

If γ is small while F is less small, an RTA increases the likelihood of the member's AD action against a nonmember, because the equilibrium outcome changes from no AD action to a single AD action against the non-member (i.e., from $\mathbf{N}$ to $\mathbf{AD_3}$), or the outcome changes from a single AD action against either the member or the nonmember country, or multiple AD actions against both countries, to a single AD action against the non-member country (i.e., from $\mathbf{AD_2}$ or $\mathbf{AD_3}$ to $\mathbf{AD_3}$, or $\mathbf{AD_{23}}$ to $\mathbf{AD_3}$).

Country 1's RTA increases the dumping margin of the non-member firm's product and increases firm 1's gains from its AD action against the non-member firm. Therefore, if the government of country 1 places higher weight on the firm 1's profit, the RTA enhances the AD action against the non-member firm. Meanwhile, the RTA decreases the dumping margin of the member firm, diminishing the government 1's incentive to implement AD action against the member firm.

However, the opposite case is also possible. If γ is large, an RTA increases the likelihood of country 1's AD action against the member country, because the equilibrium outcome changes from multiple AD actions to unilateral AD action by the nonmember country (i.e., from $\mathbf{AD_{23}}$ to $\mathbf{AD_2}$). The increased dumping margin of the non-member firm increases the welfare loss from the AD action against it, while decreased dumping margin decreases the welfare loss. Therefore, when the government of country 1 sufficiently cares about social welfare, the RTA promotes the AD against the member and undermines the AD against the non-member

Interestingly, if γ is in the middle range, an RTA may block the AD actions because the equilibrium outcome changes from $\mathbf{AD_2}$ or $\mathbf{AD_3}$ to $\mathbf{N}$. In the middle level for γ,

17

the gains from AD actions against both the member and the non-member firm decrease, although the reason for the decline is the increased efficiency loss for the AD against the non-member and the decreased profit gains for the AD against the member. We have the following proposition.

Proposition 7 *If the country becomes the member of an RTA, it increases its incentive to implement AD action against the non-member firm while it decreases its incentive to implement AD action against the member firm. The RTA may promote the member's AD against the member, or it may block any AD action if the government's weight on social welfare is large enough.*

4.3   RTA between countries 2 and 3

If countries 2 and 3 form an RTA and country 1 becomes the non-member, the prices in the markets of countries 2 and 3 decrease. Let $\boldsymbol{t}_{23} = (\tau, \tau, t)$ denote the tariff vector of this case. Because the domestic prices of goods 2 and 3 decrease and the dumping margins of both goods decline, $d_2(N, \boldsymbol{t}_{23}) = d_3(N, \boldsymbol{t}_{23}) < d_2(N, \boldsymbol{t}_N) = d_3(N, \boldsymbol{t}_N)$. These changes in dumping margins decrease firm 1's gains from AD actions while it decreases the efficiency loss.

Therefore, for $\sigma \in \{AD_k^N, AD_{23}^k\}$, $\Delta G_1(\sigma, \boldsymbol{t}_{23}) < \Delta G_1(\sigma, \boldsymbol{t}_N)$ holds at $\gamma = 0$ and

$$\frac{\partial\{\Delta G_1(\sigma, \boldsymbol{t}_N)\}}{\partial \gamma} < \frac{\partial\{\Delta G_1(\sigma, \boldsymbol{t}_{23})\}}{\partial \gamma} < 0 \tag{24}$$

hold. An RTA between targeted countries discourages AD actions when government places a large weight on the firm 1's profit, and promote it when government places a large weight on social welfare. Figure 4 shows changes in the equilibrium outcomes by the formation of the RTA between countries 2 and 3 in the (γ, F) space.

[Figure 4 around here]

If a country becomes the non-member of an RTA, the RTA reduces the likelihood of its AD action against those countries when γ is small because the equilibrium outcome changes from $\mathbf{AD_2}$ or $\mathbf{AD_3}$ to $\mathbf{N}$, or from $\mathbf{AD_{23}}$ to $\mathbf{AD_2}$ or $\mathbf{AD_3}$. However, the RTA

increases the likelihood of country 1's AD actions when γ is large, because the equilibrium outcome changes from **N** to $\mathbf{AD_2}$ or $\mathbf{AD_3}$, or from $\mathbf{AD_2}$ or $\mathbf{AD_3}$ to $\mathbf{AD_{23}}$.

Proposition 8 *If the country becomes the non-member of an RTA, it reduces its incentives to implement AD action when the government's weight on the firm's profit is large, while it raises its incentives when the government weight on social welfare is large enough.*

5   Conclusion

In a three-country oligopoly model, this paper analyzed a country's decisions concerning AD actions against two foreign countries and the relationship between those decisions and the countries' RTAs. An RTA intensifies product-market competition and lowers product prices in the member countries. This effect widens the dumping margin of the nonmember firm and narrows the dumping margin of the member firm. If the government is more concerned with domestic firm profit in its AD decision, the RTA may invoke the member's AD action against the nonmember. If the governments attach a sufficiently high value on social welfare, however, the RTA may promote the AD action against the member. If the governments' weight on the domestic firm's profit is neither high nor low, an RTA may block the AD actions toward both countries.

These results suggest that RTAs can either promote or prevent AD actions against the nonmember, and sometimes RTAs promotes AD actions against member countries. If the RTA promotes AD actions toward nonmembers, it hurts nonmembers more than when AD actions are absent. If the RTA promotes AD actions toward members, RTA may not benefit member countries even though trade between member countries are preferentially liberalized. In any case, policy makers should take into account the effect of RTA on the imposition of AD measures.

My analysis can be extended in several directions. It will be interesting to analyze the effects of nondiscriminatory, multilateral trade liberalization and compare them with the effects of preferential trade liberalization. I have assumed that only a single country implements AD actions. The assumption helps explore how RTAs affects the domestic firm's and the government's incentives to implement AD actions. Incorporating AD

actions of other two countries and considering strategic interaction between governments in AD decisions will provide further insights on this issue.[8]

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Figure 1: Possible equilibrium outcomes without RTAs

F

AD_2 or AD_3

N

$\Delta G_1(AD_{23}^k, t_N)$

AD_{23}

$\Delta G_1(AD_k^N, t_N)$

0

γ

1

Figure 2: Possible equilibrium outcomes without 1-2RTA

F

N

AD_3

AD_2

AD_{23}

0

γ

$\Delta G_1(AD_{23}^2, t_{12})$

$\Delta G_1(AD_{23}^3, t_{12})$

$\Delta G_1(AD_3^N, t_{12})$

$\Delta G_1(AD_2^N, t_{12})$

1
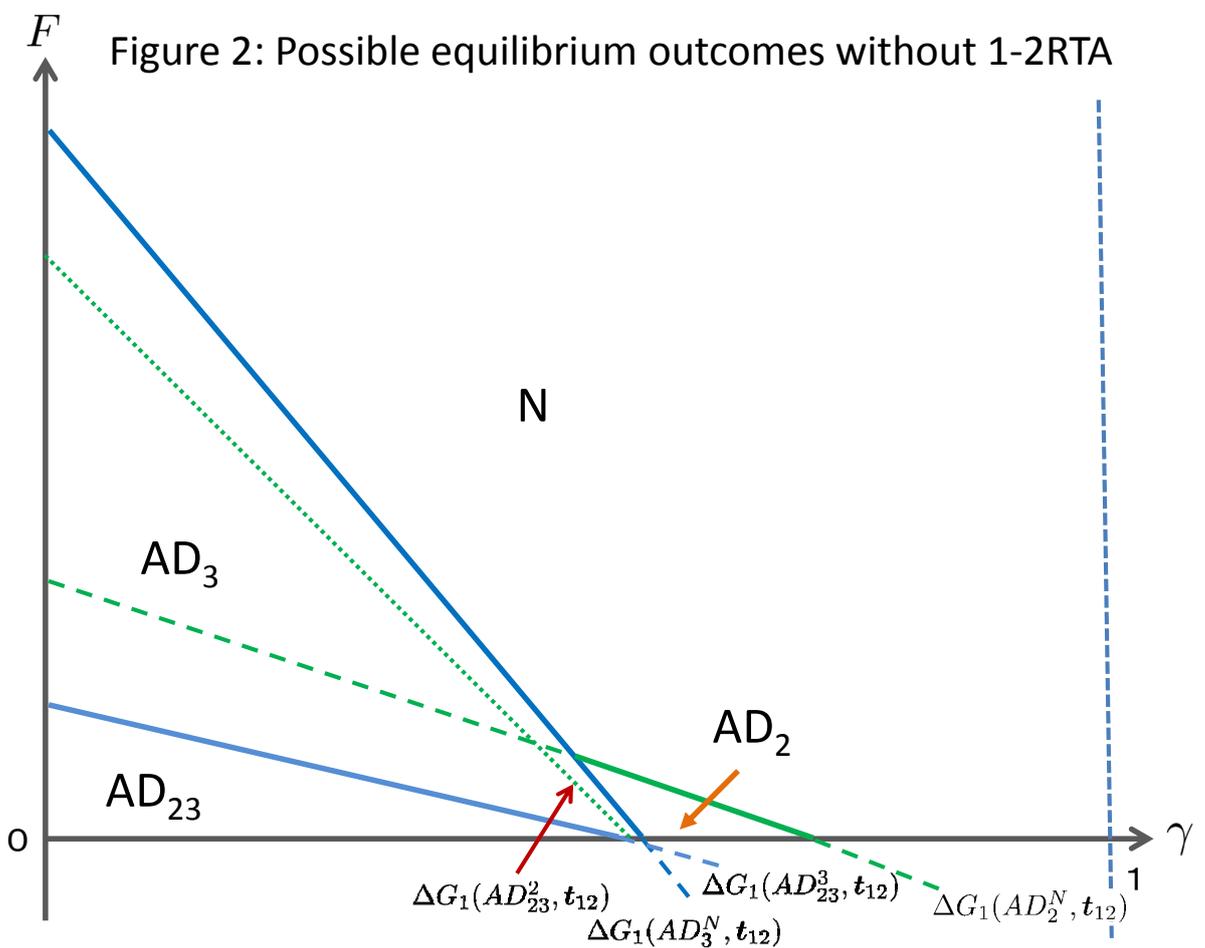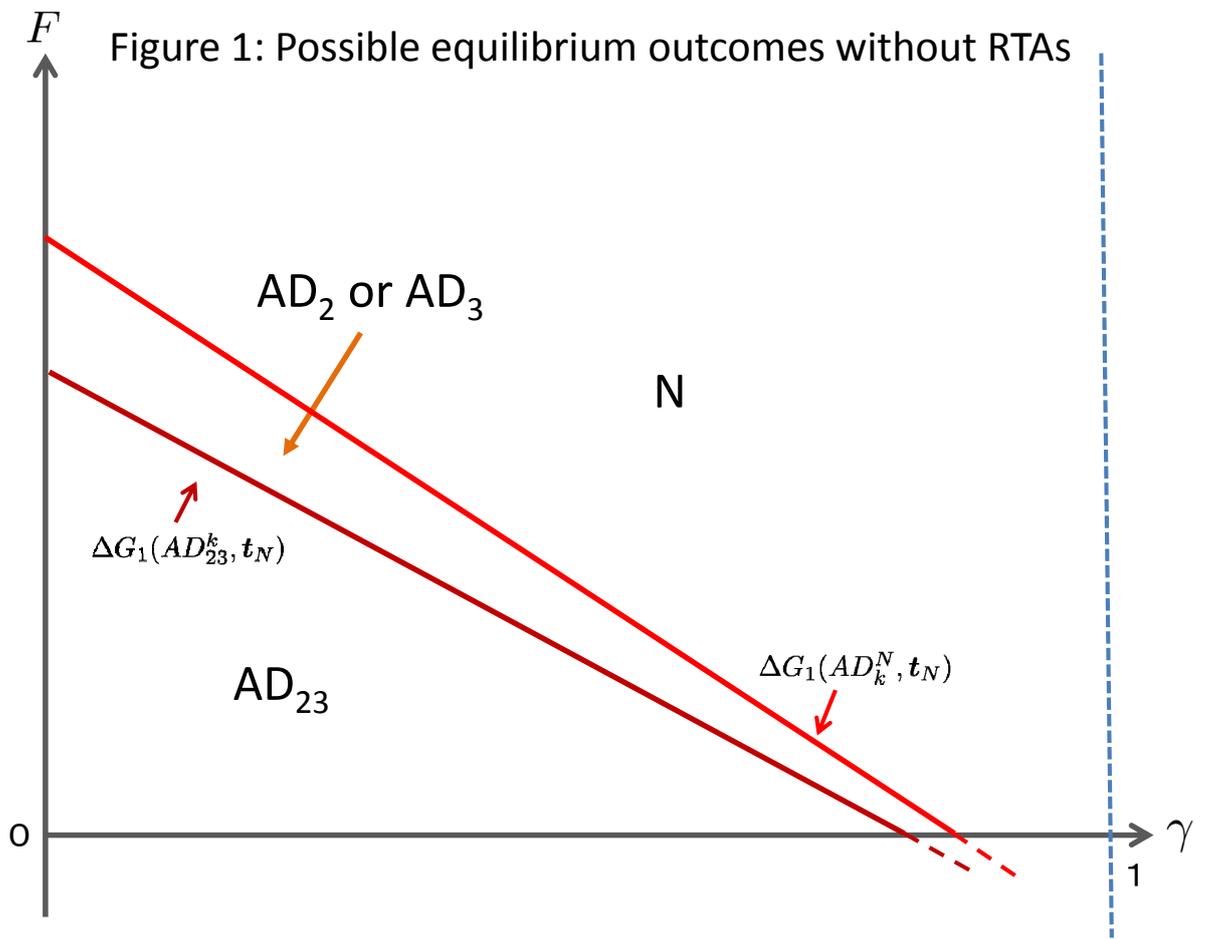
Figure 3: The effect of 1-2 RTA

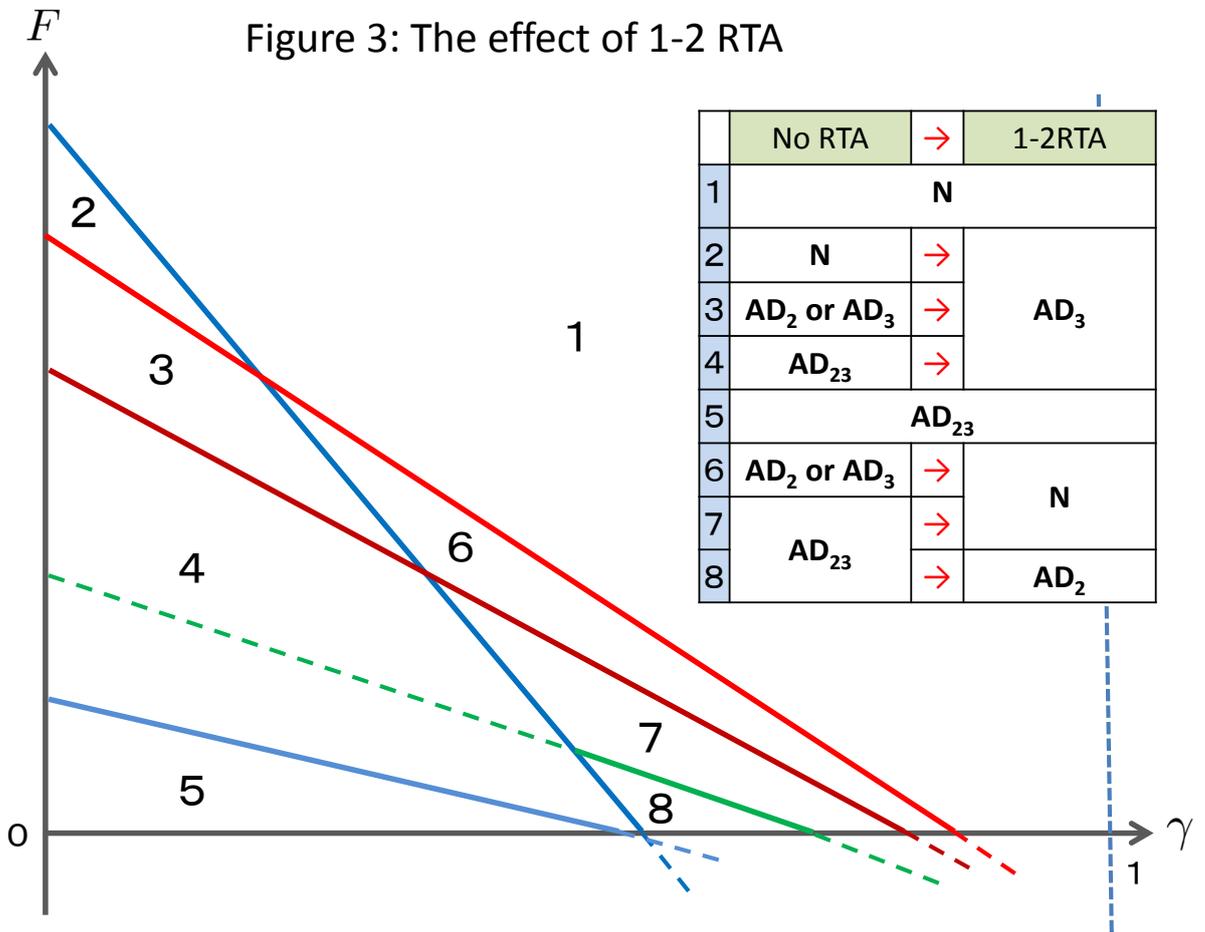|	No RTA	→	1-2RTA
1		N	
2	N	→	
3	AD_2 or AD_3	→	AD_3
4	AD_{23}	→	
5		AD_{23}	
6	AD_2 or AD_3	→	N
7	AD_{23}	→	
8		→	AD_2

Figure 4: The effect of 2-3 RTA

$\Delta G_1(AD_k^N, t_N)$

$\Delta G_1(AD_{23}^k, t_N)$

$\Delta G_1(AD_{23}^k, t_{23})$

$\Delta G_1(AD_k^N, t_{23})$

	No RTA	→	2-3 RTA
1		N	
2	AD_2 or AD_3	→	N
3		AD_2 or AD_3	
4	AD_{23}	→	AD_2 or AD_3
5		AD_{23}	
6	AD_2 or AD_3	→	N
7		→	AD_{23}