Cross-country Productivity Heterogeneity, Trade Agreement, and the Quest to Free Trade

by

Yaohan Duan

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Dissertation Committee:

Dr. Wisarut Suwanprasert, Chair

Dr. Bichaka Fayissa

Dr. Adam D. Rennhoff

DEDICATION

To

Guoyou Duan

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SUMMARY

In this dissertation, I study the role played by the slope of the endogenous supply curve which represents the heterogeneity of producing powers in affecting the formation of trading regimes. My major contributions lie at the investigation of the connection between the productivity asymmetry (i.e. productivity difference between countries) and the welfare response to tariffs under different trading regimes.

I firstly corroborate the significance of a larger productivity asymmetry to abridge the appeal of global FTA. Under all trading environments that I study in this paper, the global FTA will fail to form when the productivity asymmetry level is too large.

Secondly I study how productivity asymmetry affects the role played by bilateralism in affecting the formation of global free trade. I find that: in the case of asymmetric productivity, the consent of bilateralism can either help or hinder the formation of global free trade. I study two special trading environments: (i) there are one highly-productive country and two low-productive countries and (ii) there are two highly-productive countries and one low-productive country. I find that in the case of two highly-productive countries and one low-productive country, the consent of bilateralism can help the formation of global free trade; but in the case of one highly-productive country and two low-productive countries, the consent of bilateralism can prevent the formation of global free trade.

Lastly, I study how productivity asymmetry affects the role played by a popular preferential trade agreement (PTA) which is customs unions in affecting the formation of global free trade. My main findings show that the consent of CUs can nudge the formation of global free trade no matter if there is only one highly-productive country, or there are two highly-productive countries. I also study the case when both CUs and bilateral FTA are approved meantime under the condition of asymmetric productivity. I find that the global free trade will be less likely to form because bilateral FTA will be always preferred to CUs.

ABSTRACT

In the first essay, I study the role played by cross-country productivity heterogeneity in affecting the formation of global free trade. My model extends the three-country endowment model of Bagwell and Staiger (1999) by introducing production and productivity heterogeneity across countries. There are two main findings: (i) global free trade is the only equilibrium in the case of symmetric productivity; (ii) the bilateral free trade between two similarly-productive countries can be in equilibrium in the case of asymmetric productivity. I study two special trading cases of productivity asymmetry: (i) one highly-productive country and two low-productive countries and (ii) two highly-productive countries and one low-productive country. I find that in both cases when the degree of productivity asymmetry is too large, in equilibrium, only the two similarly-productive countries will form a bilateral free trade agreement.

In the second essay, I study the role played by bilateralism (i.e. discriminatory tariff policy) under a condition of asymmetric productivity across countries in affecting the formation of global free trade. I show that global free trade is the only equilibrium in the case of symmetric productivity no matter if bilateralism is prohibited, or not. However, in the case of asymmetric productivity, the consent of bilateralism will either help or hinder the formation of global free trade. I study two special cases: (i) one highly-productive country and two low-productive countries

and (ii) two highly-productive countries and one low-productive country. I find that in the case of two highly-productive countries and one low-productive country, the consent of bilateralism can help the formation of global free trade; but in the case of one highly-productive country and two low-productive countries, the consent of bilateralism can prevent the formation of global free trade.

In the third essay, I study the role played by custom unions under a condition of asymmetric productivity across countries in affecting the formation of global free trade. I find that the consent of custom unions can always help achieve the global free trade. I also study the case of that custom unions and bilateral free trade agreement are both available. Bilateral free trade are always preferred to custom unions. The role of productivity asymmetry in the case of custom unions is same with that in the case of bilateral free trade: as the productivity asymmetry level is too large, only the custom union formed between two similarly-productive countries is the stable equilibrium.

Chapter 1

Cross-Country Productivity Asymmetry and the Quest to Free Trade

1.1 Introduction

The World Trade Organization (WTO) which has always been advocating free trade has investigated what factors are crucial for influencing the world trade system toward the global free trade. A number of studies have investigated the roles played by endowment asymmetry across countries in determining incentives for trade liberalization (Krugman, 1991; Grossman and Helpman, 1995; Bagwell and Staiger, 1999; Kose and Riezman, 2000; Kowalczyk and Riezman, 2009; Saggi and Yildiz, 2010; Saggi, Woodland, and Yildiz, 2013; Saggi, Wong, and Yildiz, 2019; Cole, Zissimos and Lake, 2021). However, existing literature has tended to pay little attention to study the role played by productivity heterogeneity.

In this paper, we propose that productivity heterogeneity across countries can affect the formation of global free trade. We start with a two-country model to better understand the underlying intuitions and then extend to a three-country model to study how the productivity asymmetry affects the formation of global free trade under different trading environments.

In the two-country model, there are two countries and two goods. Each country consumes both two goods, but can supply only one good. Therefore, each country is a natural exporter of one good and a natural importer of the other good. Each country may impose positive tariffs on its imports from its trading partner. Alternatively, the two countries can form a free trade agreement (FTA) which completely eliminates tariff barriers for each other. Each country has a country-specific productivity. We define the productivity asymmetry as the difference between two countries' productivity. We find that FTA can arise as the stable equilibrium when the productivity asymmetry level is sufficiently small. However, when the productivity asymmetry level is too large, the highly-productive country prefers no agreement to FTA. The intuition is that: when a country has a higher productivity level, both its benefits and the costs from a lower tariff will decrease but the benefits decrease faster than the costs. Therefore, when productivity asymmetry degree reaches above a threshold, the highly-productive country will opt out from FTA to raise the tariff level.

We extend the model to a three-country model, in which there are three countries and three goods. Each country consumes all three goods, but can supply only two goods. Therefore, each country is a natural exporter of two goods and a natural importer of the other good. We then consider four trade regimes: (i) bilateral free trade agreement (i.e. two countries sign a bilateral FTA and impose a discriminatory tariff on the other non-member country); (ii) global free trade agreement (i.e. all three countries sign FTA with each other); (iii) hub-spoke agreement (i.e. one country, serving as a hub, signs bilateral FTAs with the other two countries which, serving as two spokes, do not sign FTA with each other); (iv) status quo (i.e. no country communicates with others). Our equilibrium analysis follows from the concept of coalition proof Nash equilibrium.

In the three-country model, we show that in the case of symmetric productivity levels, global free trade is the only equilibrium. We then investigate how asymmetric productivity can affect the change of equilibrium. We consider two special cases for productivity asymmetry: (i) two identically highly-productive countries and one unique low-productive country and (ii) one unique highly-productive country and two identically low-productive countries. We find that when the degree of productivity asymmetry is too large, in equilibrium only the two similarly productive countries will form a bilateral free trade agreement. When the degree of productivity asymmetry is sufficiently small, global free trade will form as the only equilibrium.

The intuitions in the three-country model follow the same mechanism in the two-country model. As in the case of two highly-productive countries and one unique low-productive country, a larger productivity asymmetry level will increase both the benefits and costs from being a non-member of global FTA by the unique low-productive country. A larger productivity asymmetry degree grows the benefits of the unique low-productive country from being a non-member faster than the costs of the unique low-productive country from being a non-member. Therefore the unique low-productive country will opt out from FTA when the productivity asymmetry level is too large.

As in the case of one unique highly-productive country and two low-productive countries, a larger productivity asymmetry level will decrease both the benefits and costs from being a non-member of FTA by the unique highly-productive country. A larger productivity asymmetry degree reduces the costs faster than the benefits. Therefore the unique highly-productive country will opt out from FTA when the productivity asymmetry level is too large.

The chapter proceeds as follows. Section 1.2 presents the literature review. Section 1.3 presents the two-country model. Section 1.4 extends to a three-country model and presents the generalized results of comparative static. Section 1.5 presents the equilibrium analysis under the three-country model. Section 1.6 concludes.

1.2 Literature Review

Our study adds contributions to a strand of literature following Bagwell and Staiger (1999), which studies the role of reciprocal trade liberalization in helping improve welfare gains. Recent papers address the topic mainly about lateralism and regime designs. Thompson and Verdier (2014), based on the fact that bilateralism gives more tailored FTAs but can raise the transaction costs, offer illustrations for some well-designed trading regimes. Altemoller (2018) answers the questions: what are the structural incentives that bilateral strategies open up, and concludes with a look at what the future holds for the changing shape and reorganization of trade policies. Krotz and Schild (2018) ponder the consequences of Brexit on the "embedded bilateralism" between France and Germany. Saggi, Wong and Yildiz (2019) study the effects of the eradication of internal tariffs, and find results that argue against the findings in Saggi and Yildiz (2010): removing the internal tariffs may nudge the outside country to deviate from global free trade. Matala (2020), poring over the history of the clearing trade and payment system between Finland and the Soviet Union, examines the reasons and consequences of negotiating bilateralism. Suwanprasert (2020) suggests that the MFN principle may prevent bilateral trade agreements in the future when tariffs are already low. Shang and Shen (2021) study how the bilateral interaction after trade war between China and USA affects China's legal changes, and conclude that stricter rules on US intellectual property rights may serve as a bridge for US-China trade talks in the future. Emanuel and Tovar (2022) indicates that countries should set systematically lower preferential margins when the bloc takes the form of a free trade area, relative to a customs union. In contrast to these works, our study will add values in better mimicking the real-world trading system, in which different suppliers have different producing powers.

Our study is also in line with several papers that are inspired by Bagwell and Staiger (1997)'s contribution to tariff complementarity effect. Saggi and Yildiz (2010) theoretically confirm the tariff complementarity effect in their endowment model. Maggi (2014) provides a solid intuition that signing a PTA induces member countries to import less from non-member countries, therefore member countries are inclined to loose their trade compression among non-member countries. Mai and Stoyanov (2015) studies the consequences of CUSFTA and find that this FTA indeed reduces the external tariffs of Canada. Crivelli (2016) empirically confirms the complementarity effect and adds a new finding that the initial tariff levels affect the magnitude of this complementarity effect.

There is a branch of literature that uses the political economy to explain why countries sign free trade agreements. The idea comes from the protection-for-sale motivation in Grossman and Helpman (1994) that domestic producers may form lobby groups to negotiate with the government for trade protection. Maggi and Rodriguez-Clare (1998) show that a country may commit to free trade to avoid future negotiations. Subsequent works include Suwanprasert (2017), Suwanprasert (2018), Suwanprasert (2020), Potipiti and Suwanprasert (2022). Empirical works such as Goldberg and Maggi (1999), Gawande and Bandyopadhyay (2000), Eicher and Osang (2002), Mitra, Thomakos, and Ulubasoglu (2002), McCalman (2004), Facchini, Van Biesebroeck, and Willmann (2006), Jonelis and Suwanprasert (2022) provide evidence supporting the protection for sale theory. My dissertation is different from this line of work in that the governments in my model maximize social welfare.

This paper is mostly related to two papers: Saggi and Yildiz (2010) and Saggi, Woodland, and Yildiz (2013). To isolate the effect of bilateralism, Saggi and Yildiz (2010) allow asymmetric endowment levels, and thus their main contribution affirms the necessity of bilateralism that can nudge small countries (i.e. countries with lower endowments) to sign FTA with large countries. Under our model that adds the heterogeneity in supply curve and allows asymmetry in productivity, our findings generalize Saggi and Yildiz (2010)'s result. We mainly differ with them on the track that we allow endogenous supply curves, and also we execute the equilibrium analysis under different trading patterns. Saggi, Woodland, and Yildiz (2013) also studies the effects from asymmetric endowment, but they study the effects on another type of preferential trade agreement (custom union). We differ with them on the same track that we allow endogenous supply curves.

1.3 Model

In this section, we focus on a two-country model to highlight the role played by the asymmetry degree in productivity. We will describe the three-country extension in the next section.

1.3.1 Two-Country Model Set-up

There are two differentiated goods, which are denoted as A and B. There are two countries, which are denoted as a and b. Each country consumes both two differentiated goods, but produces only one differentiated good. Therefore, each country imports one differentiated good that it is not able to produce domestically. We denote this good as the upper case letter of the corresponding country. For example, country a neither produces good A nor has any endowments of good A. Country a thus imports good A from country b and exports good B to country b.

The utility function follows a conventional quadratic and additively separable form. Country i's preference is thus:

$$U_i(d_{iA}, d_{iB}, \omega_i) = \left(d_{iA} - \frac{(d_{iA})^2}{2}\right) + \left(d_{iB} - \frac{(d_{iB})^2}{2}\right) + \omega_i \text{ for } i \in \{a, b\},$$

where d_{iA} is country i's demand (i.e. consumption) of good A and d_{iB} is country i's demand of good B.

ω_i is the numeraire good endowed in country i. In order to balance trade, in addition to exporting the differentiated good, country i exports the numeraire good to its trading partner. Each country has large enough endowments of the numeraire good to ensure trade balance.

The demand functions are: $d_{iA} = 1 - p_{iA}$[1] in which p_{iA} is the price of good A at country i; $d_{iB} = 1 - p_{iB}$ in which p_{iB} is the price of good B at country i. Then we have the consumer surplus of country i as:

$$CS_i = \frac{(1-p_{iA})^2}{2} + \frac{(1-p_{iB})^2}{2} \text{ for } i \in \{a, b\}.$$

The production function is:

$$cost_{iJ} = \frac{\frac{(q_{iJ})^2}{2} - e_i q_{iJ}}{\beta_i},$$

where $q_{iJ} = e_i + \beta_i p_{iJ}$ for $J \in \{A, B\}$ and $J \neq I$ is the supply of good J by country i (note that $q_{iI} = 0$), e_i is country i's endowments of good J (note that country i's endowment of good I is also zero), and β_i is country i's productivity, which we will allow to be asymmetric later.

Country i's producer surplus is based on country i's supply of good J (again, note that country i does not supply good I). We denote country i's producer surplus as PS_i:

$$PS_i = p_{iJ} q_{iJ} - \frac{\frac{(q_{iJ})^2}{2} - e_i q_{iJ}}{\beta_i} \text{ for } i \in \{a, b\}, J \in \{A, B\}, I \in \{A, B\}, \text{and } J \neq I.$$

We denote country i's tariff revenues as TR_i. The tariff revenues are from imposing tariffs on its trading partner, which is country j. We denote t_{ij} as the tariff imposed by country i on its partner country j for $j \in \{a, b\}$ and $i \neq j$. Since we only have

[1] We scale the market size. Therefore, this paper is more general than it seems.

two countries, we can simply denote $t_{ij} = t_i$ and $t_{ji} = t_j$.[2]

We next denote x_{jI} as the exports of good I by country j for $j \neq i$. Therefore, the tariff revenue TR_i is:

$$TR_i = t_{ij} x_{jI} \text{ for } i \in \{a, b\}, j \in \{a, b\}, i \neq j.$$

The welfare of country i is:

$$W_i = CS_i + PS_i + TR_i \text{ for } i \in \{a, b\}.$$

The market clearing condition comes from that the consumption of good I by country i is equal to the export of good I by country j because each country consumes both two differentiated goods but only supplies one of the two goods:

$$d_{iI} = x_{jI} = q_{jI} - d_{jI} \text{ for } i \in \{a, b\}, j \in \{a, b\}, i \neq j, I \in \{A, B\}, I \neq J.$$

Since arbitrage does not exist in such trading markets, we have the baseline price equation as:

$$p_{iI} = p_{jI} + t_{ij},$$

where p_{iI} is the price of good I at country i, t_{ij} is the tariff imposed by country i on its imports of good I that is exported by country j. Then we can derive the following equations that represent the price levels:

$$p_{iI} = \frac{2 - e_j + (\beta_j + 1)\, t_{ij}}{(\beta_j + 2)}$$

$$p_{jI} = \frac{2 - e_j - t_{ij}}{(\beta_j + 2)}$$

[2]However, in the three-country setting, we cannot simply denote $t_{ji} = t_j$.

Based on these prices, we will then solve for the optimal MFN tariffs under each trading regime and find out what trading regimes will be stable.

1.3.2 Equilibrium for the two-country model

There are two regimes in this two-country framework. First, if one country (or both two countries) announces no trade agreements, then a status quo, denoted as $\{\Phi\}$, forms. Second, if two countries both agree to sign a free trade agreement, a global FTA forms and this equilibrium is denoted by $\{F\}$. To derive the Nash equilibrium, each country plays its strategy simultaneously. They judge a trade regime based on the welfare maximizing rule, and announce that which trade regime they will participate.

We can obtain the optimal tariffs under each regime. We denote $t_i^{\{F\}}$ as the tariff imposed by country i on its trading partner under the regime $\{F\}$, and $t_i^{\{\Phi\}}$ as the tariff imposed by country i on its trading partner under the regime $\{\Phi\}$.

Definition 1. In the global free trade regime, denoted by $\{F\}$, the tariffs are such that

$$t_a^{\{F\}} = t_b^{\{F\}} = 0.$$

In the status quo regime, denoted by $\{\Phi\}$, the tariffs are such that

$$t_i^{\{\Phi\}} = \underset{t_i}{Argmax} \left\{ W_i^{\{\Phi\}} \right\} = \underset{t_i}{Argmax} \left\{ CS_i^{\{\Phi\}} + PS_i^{\{\Phi\}} + TR_i^{\{\Phi\}} \right\}.$$

The optimal tariff under the status quo regime is thus:

$$t_i^{\{\Phi\}} = \frac{\beta_j + e_j}{(3+\beta_j)(1+\beta_j)}.$$

We denote $W_i^{\{r\}}$ as the welfare of country i under the regime $\{r\}$, and $\triangle W_i^{\{r\}-\{s\}} =$

$W_i^{\{r\}} - W_i^{\{s\}}$ as the welfare difference between regime $\{r\}$ and $\{s\}$. If $W_i^{\{r\}-\{s\}} = 0$, we conclude that country i is indifferent between $\{r\}$ and $\{s\}$; if $\triangle W_i^{\{r\}-\{s\}} > 0$, we conclude that country i prefers $\{r\}$ to $\{s\}$. We denote $\beta_i^{\{r\}-\{s\}}$ as the value of β that makes country i be indifferent between $\{r\}$ and $\{s\}$.

In our two-country model, if and only if country a and country b simultaneously prefer $\{F\}$, then $\{F\}$ will be the only stable equilibrium. Otherwise, $\{\Phi\}$ is the only stable equilibrium.

Proposition 1 concludes our first result based on the condition of symmetry in the two-country model:

Proposition 1. *If $\beta_a = \beta_b$ and $e_a = e_b$, $\{F\}$ is the only stable equilibrium.*

Proposition 1 is in line with the conventional intuition: under the condition of symmetry (i.e. $\beta_a = \beta_b$ and $e_a = e_b$) the world welfare gains will be spread equally into each country. As countries are announcing their strategies simultaneously, no one has an incentive to deviate for the FTA that brings considerably more consumer and producer surplus than opting out. As a result, the final regime will be global FTA that will reach a Pareto optimal outcome.

Proposition 1 motivates a question: is global FTA still uniquely stable under a condition of asymmetry? We then will solve for the equilibrium regimes under the condition of asymmetry from the perspective of productivity. It is noteworthy that we want to isolate the effects solely from the productivity heterogeneity. Therefore, henceforth we will assume that countries have identical endowment by assuming $e_i = 1$ for all i.[3]

Proposition 2 concludes our second result based on the condition of productivity asymmetry in the two-country model:

[3]Productivity can be correlated with endowments. Therefore, we assume that endowments are identically equal to one.

Proposition 2. *If $\beta_a > 0$ and $\beta_b = 0$, there exists a threshold $\beta_a^{\{F\}-\{\Phi\}} > 0$ such that country a prefers regime $\{F\}$ to regime $\{\Phi\}$ if and only if $\beta_a < \beta_a^{\{F\}-\{\Phi\}}$. Country b prefers $\{F\}$ for any β_a. Therefore, global FTA is the only stable equilibrium if and only if $\beta_a < \beta_a^{\{F\}-\{\Phi\}}$. Otherwise $\{\Phi\}$ is the only stable equilibrium.*[4]

Proof. See Appendix □

Figure 1.1 illustrates Proposition 2.

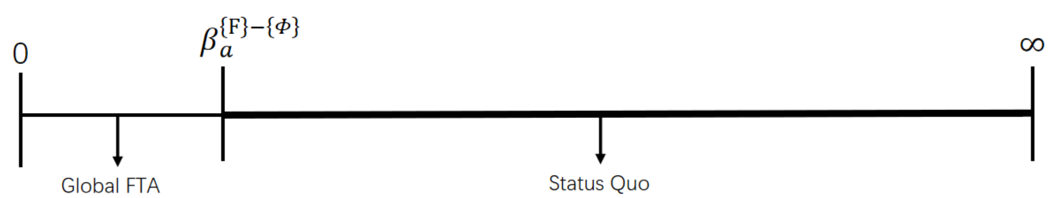

Figure 1.1: Proposition 2 (two-country model)

We suppose that one country has a positive productivity, and the other one has no productivity but only the endowment for exporting: $\beta_a > 0$ and $\beta_b = 0$. Country a is thus a highly-productive country, whereas country b is a low-productive country (i.e. the country with only endowment as its supply). We then prove that $W_b^{\{F\}-\{\Phi\}} > 0$ for any β_a, and $W_a^{\{F\}-\{\Phi\}} > 0$ if and only if β_a is sufficiently small. (i.e. $\beta_a < \beta_a^{\{F\}-\{\Phi\}}$, where $\beta_a^{\{F\}-\{\Phi\}}$ represents the cut-off point that makes country a be indifferent between $\{F\}$ and $\{\Phi\}$. $\beta_a^{\{F\}-\{\Phi\}} \approx 1.41$).

In proposition 2, we show that the low-productive country prefers FTA no matter how large the asymmetry degree is, whereas the highly-productive country prefers FTA if and only if the asymmetry degree in productivity is sufficiently small. When the asymmetry degree is too large, the highly-productive country will opt out from FTA, then the regime $\{F\}$ will fail to form.

To generalize the result in proposition 2, we use simulations to show results under the condition of $\beta_a > \beta_b > 0$. The simulation results are: (i) if $\beta_a <\approx 1.41$, the

[4] When β goes to be infinite, the supply curve will be flat.

inequality $\triangle W_a^{\{F\}-\{\Phi\}} > 0$ holds for any β_a and β_b; (ii) when $\beta_a >\approx 1.41$, then $\triangle W_a^{\{F\}-\{\Phi\}} > 0$ if and only if $\beta_a < \beta_a^{\{F\}-\{\Phi\}}$, where $\beta_a^{\{F\}-\{\Phi\}}$ is an increasing function of β_b and $\frac{d\left(\beta_a^{\{F\}-\{\Phi\}}\right)}{d\beta_b} > 0$ for a given β_b; (iii) $\triangle W_b^{\{F\}-\{\Phi\}} > 0$ for any β_a and β_b.

The simulation results indicate that the highly-productive country will prefer FTA only if the asymmetry degree in productivity is sufficiently small. The low-productive country always prefers FTA for any levels of productivity asymmetry.

Figure 1.2, based on the condition of $\beta_a > \beta_b > 0$, plots the simulation result that reveals the two areas, in which each labelled regime is uniquely stable. The grey area is the area in which the condition of $\beta_a > \beta_b > 0$ does not hold.

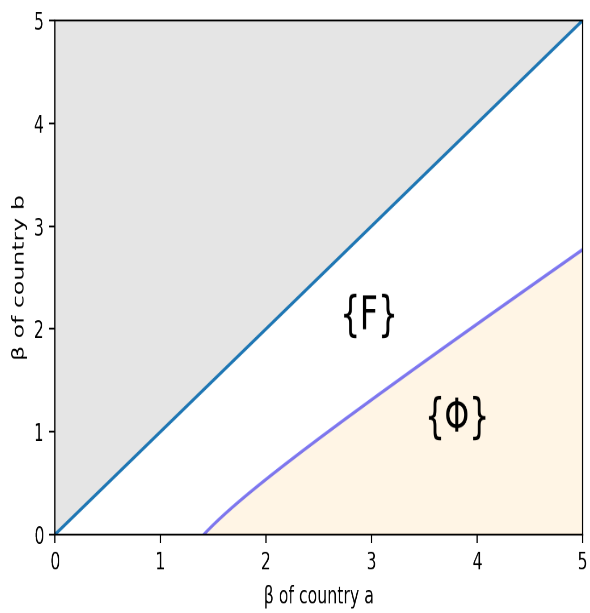

Figure 1.2: Simulation (two-country model)

Based on the assumption of $\beta_a > \beta_b > 0$, we provide the general results of comparative static in the two-country model as follows (the proof of these results are shown in the appendix):

$$\frac{dW_a}{dt_b} = \overbrace{\left(\underbrace{\overbrace{\frac{dCS_a}{dp_{aB}}}^{<0}\overbrace{\frac{dp_{aB}}{dt_b}}^{<0}}_{=\frac{dCS_a}{dt_b}>0}\right)}^{\text{benefit}} + \overbrace{\left(\underbrace{\overbrace{\frac{dPS_a}{dp_{aB}}}^{>0}\overbrace{\frac{dp_{aB}}{dt_b}}^{<0}}_{=\frac{dPS_a}{dt_b}<0}\right)}^{\text{cost}} + \underbrace{\frac{dTR_a}{dt_b}}_{=0} \tag{1.1}$$

$$\frac{dW_a}{dt_a} = \overbrace{\left(\underbrace{\overbrace{\frac{dCS_a}{dp_{aA}}}^{<0}\overbrace{\frac{dp_{aA}}{dt_a}}^{>0}}_{=\frac{dCS_a}{dt_a}<0}\right)}^{\text{cost}} + \underbrace{\frac{dPS_a}{dt_a}}_{=0} + \overbrace{\left(\underbrace{x_{bA} + t_a\overbrace{\frac{d\left(x_{bA}\right)}{dp_{bA}}}^{>0}\overbrace{\frac{dp_{bA}}{dt_a}}^{<0}}_{\frac{dTR_a}{dt_a}>0}\right)}^{\text{benefit}} \tag{1.2}$$

Based on the formulas 1.1 and 1.2, we see that there will be two costs and two benefits if country a opts out from FTA.

The first cost is that the consumer welfare (i.e. CS_a) is negatively related to its own tariff (i.e $\frac{dCS_a}{dt_a} < 0$) because raising its own tariff will lead to a higher price of good A at country a (i.e. $\frac{dp_{aA}}{dt_a} > 0$).

The second cost is that country a's producer surplus (i.e. PS_a) will decrease with a higher external tariff (i.e. $\frac{dPS_a}{dt_b} < 0$) because an external tariff is draging the price of good B down (i.e. $\frac{dp_{aB}}{dt_b} < 0$).

The first benefit is that country a's consumer surplus will increase with a higher external tariff (i.e. $\frac{dCS_a}{dt_b} > 0$) because a higher external tariff leads to a lower price of good B at country a (i.e. $\frac{dp_{aB}}{dt_b} < 0$).

The second benefit is that country a will have a higher tariff revenue thanks to a higher own tariff (i.e. $\frac{dTR_a}{dt_a} > 0$).

Next, we explain how these costs and benefits will become smaller with a larger productivity asymmetry level (i.e. a higher productivity of country a or a lower productivity of country b). We show the results of the following:[5]

$$\frac{d^2W_a}{dt_a d\beta_b}=\left(\underbrace{\overbrace{\frac{dCS_a}{dp_{aA}}}^{<0}\overbrace{\frac{d^2p_{aA}}{dt_a d\beta_b}}^{>0}+\overbrace{\frac{d^2CS_a}{dp_{aA}^2}}^{=1}\overbrace{\frac{dp_{aA}}{d\beta_b}}^{<0}\overbrace{\frac{dp_{aA}}{dt_a}}^{>0}}_{=\frac{d^2CS_a}{dt_a d\beta_b}<0\Rightarrow\text{smaller cost with a lower }\beta_b}\right)$$
$$+\left(\underbrace{t_a\left(\overbrace{\frac{d^2\left(x_{bA}\right)}{dp_{bA}d\beta_b}}^{=1}\overbrace{\frac{dp_{bA}}{dt_a}}^{<0}+\overbrace{\frac{d\left(x_{bA}\right)}{dp_{bA}}}^{>0}\overbrace{\frac{d^2p_{bA}}{dt_a d\beta_b}}^{>0}\right)+\overbrace{\frac{d\left(x_{bA}\right)}{d\beta_b}}^{>0}}_{=\frac{d^2TR_a}{dt_a d\beta_b}>0\Rightarrow\text{smaller benefit with a lower }\beta_b}\right) \tag{1.3}$$

$$\frac{d^2W_a}{dt_b d\beta_a}=\left(\underbrace{\overbrace{\frac{dCS_a}{dp_{aB}}}^{<0}\overbrace{\frac{d^2p_{aB}}{dt_b d\beta_a}}^{>0}+\overbrace{\frac{d^2CS_a}{dp_{aB}^2}}^{=1}\overbrace{\frac{dp_{aB}}{d\beta_a}}^{<0}\overbrace{\frac{dp_{aB}}{dt_b}}^{<0}}_{=\frac{d^2CS_a}{dt_b d\beta_a}<0\Rightarrow\text{smaller benefit with a higher }\beta_a}\right)$$
$$+\left(\underbrace{\overbrace{\frac{dPS_a}{dp_{aB}}}^{>0}\overbrace{\frac{dp_{aB}^2}{dt_b d\beta_a}}^{>0}+\overbrace{\frac{d^2PS_a}{dp_{aB}^2}}^{>0}\overbrace{\frac{dp_{aB}}{d\beta_a}}^{<0}\overbrace{\frac{dp_{aB}}{dt_b}}^{<0}+\overbrace{\frac{d^2PS_a}{dp_{aB}d\beta_a}}^{>0}\overbrace{\frac{dp_{aB}}{dt_b}}^{<0}}_{=\frac{d^2PS_a}{dt_b d\beta_a}>0\Rightarrow\text{smaller cost with a higher }\beta_a}\right) \tag{1.4}$$

Based on the formulas 1.3 and 1.4, we show that the two costs are being smaller with a larger degree in productivity asymmetry.

We firstly show that the inequality $\frac{d^2CS_a}{dt_a d\beta_b}<0$ implies that a lower β_b (a lower β_b represents a larger productivity asymmetry level) leads to a larger value of $\frac{dCS_a}{dt_a}$. Since $\frac{dCS_a}{dt_a}<0$, the magnitude of $\frac{dCS_a}{dt_a}$ is smaller with a lower β_b. To put this in

[5]It is noteworthy that $\frac{d^2(x_{bA})}{dt_a d\beta_b}<0$ holds even though we cannot see this directly from its decomposition form. In Appendix, we show that $\frac{d^2(x_{bA})}{dt_a d\beta_b}=-\frac{1}{\left(\beta_b+2\right)^2}$. So are $\frac{d^2CS_a}{dt_b d\beta_a}$ and $\frac{d^2PS_a}{dt_b d\beta_a}$. Also note that $\frac{d^2W_a}{dt_a d\beta_a}=0$ and $\frac{d^2W_a}{dt_b d\beta_b}=0$.

economics words, a larger asymmetry degree leads to a less sensitive CS_a response to country a's own tariff. Therefore a larger asymmetry degree will make country a's consumers more tolerable to opt out from FTA. It is because of that a lower β_b leads to a lower supply of good A, thus a lower consumption by country a's consumers.

Secondly, we show that country a's producers' aversion to the external tariff will be relieved by a higher β_a based on the inequality $\frac{d^2PS_a}{dt_b d\beta_a} > 0$. Since $\frac{dPS_a}{dt_b} < 0$, the magnitude of $\frac{dPS_a}{dt_b}$ will be smaller with a higher β_a. A higher β_a leads to a larger supply of good B, thus a less sensitive PS_a response to the higher external tariff.

Since the two benefits are also being smaller with a larger asymmetry level, we show the overall effect as follow:

$$\overbrace{\left(\left|\frac{d^2CS_a}{dt_a d\beta_b}\right| + \left|\frac{d^2PS_a}{dt_b d\beta_a}\right|\right)}^{\text{cost}} - \overbrace{\left(\left|\frac{d^2TR_a}{dt_a d\beta_b}\right| + \left|\frac{d^2CS_a}{dt_b d\beta_a}\right|\right)}^{\text{benefit}} > 0 \iff \beta_a - \beta_b > \text{a threshold} \tag{1.5}$$

The inequality 1.5 shows that if the productivity asymmetry level is sufficiently large, the two costs decrease more fastly than the two benefits. As a result, the highly-productive country a would like to opt out from FTA in order to raise the tariff levels.

1.4 Three-country Model

In this section, we will extend to a three-country model.

1.4.1 Model Set-up

The three-country model follows the mechanism under the two-country setting, but adds one more country and one more differentiated good. Henceforth, there are three countries $\{a, b, c\}$ and three differentiated goods $\{A, B, C\}$. Each country consumes all three goods but only supplies two differentiated goods. Therefore, each country imports one differentiated good that it is not able to supply domestically, and exports the other two differentiated goods. That is, country $i \in \{a, b, c\}$ imports a good $I \in \{A, B, C\}$ from its two trading partners j and k for $j \in \{a, b, c\}$, $k \in \{a, b, c\}$ and $i \neq j \neq k$. Country i exports the other two goods J and K for $J \in \{A, B, C\}$, $K \in \{A, B, C\}$, and $I \neq J \neq K$.

The quadratic and additively separable utility function is:

$$U_i(d_{iI}, \omega_i) = \sum_{I=A,B,C} \left(d_{iI} - \frac{(d_{iI})^2}{2} \right) + \omega_i \text{ for } i \in \{a, b, c\}.$$

The consumer surplus is thus a function of local prices:

$$CS_i = \sum_{I=A,B,C} \left(\frac{(1 - p_{iI})^2}{2} \right) \text{ for } i \in \{a, b, c\}.$$

The production function is:

$$cost_{iJ} = \frac{\frac{(q_{iJ})^2}{2} - e_i q_{iJ}}{\beta_i},$$

where $q_{iJ} = e_i + \beta_i p_{iJ}$ for $J \in \{A, B, C\}$ and $J \neq I$ is the supply of good J by country i (note that $q_{iI} = 0$), e_i is country i's endowments of good J (note that country i's endowment of good I is also zero), and β_i is country i's productivity, which we will allow to be asymmetric later.

It is noteworthy that country i neither produces good I nor has any endowments of good I because each country only supplies two goods. Country i therefore supplies good J and K but no I. The producer surplus is:

$$PS_i = \left(p_{iJ} q_{iJ} - \frac{\frac{(q_{iJ})^2}{2} - e_i q_{iJ}}{\beta_i} \right) + \left(p_{iK} q_{iK} - \frac{\frac{(q_{iK})^2}{2} - e_i q_{iK}}{\beta_i} \right),$$

$$\text{for } J \in \{A, B, C\}, K \in \{A, B, C\}, J \neq K \neq I.$$

We denote country i's total tariff revenues as TR_i. The total tariff revenues are from imposing tariffs on its two trading partners. We denote t_{ij} as the tariff imposed by country i on its partner country j for $j \in \{a, b, c\}$ and $i \neq j$.

We denote x_{jI} as the exports of good I by country j. Then we have TR_i:

$$TR_i = TR_{ij} + TR_{ik} = t_{ij}x_{jI} + t_{ik}x_{kI},$$
$$\text{for } j \in \{a, b, c\}, k \in \{a, b, c\}, j \neq k \neq i.$$

The welfare is:

$$W_i = CS_i + PS_i + TR_i \text{ for } i \in \{a, b, c\}.$$

The market clearing condition is:

$$d_{iI} = x_{jI} + x_{kI} = (q_{jI} - d_{jI}) + (q_{kI} - d_{kI})$$

Arbitrage does not exist in such trading markets, so that we have $p_{iI} = p_{jI} + t_{ij}$ and $p_{iI} = p_{kI} + t_{ik}$. Then we can derive the following equations that represent the price levels of good I:

$$p_{iI} = \frac{3 - e_j - e_k + (1 + \beta_j)t_{ij} + (1 + \beta_k)t_{ik}}{3 + \beta_j + \beta_k}$$

$$p_{jI} = \frac{3 - e_j - e_k - (2 + \beta_k)t_{ij} + (1 + \beta_k)t_{ik}}{3 + \beta_j + \beta_k}$$

$$p_{kI} = \frac{3 - e_j - e_k + (1 + \beta_j)t_{ij} - (2 + \beta_j)t_{ik}}{3 + \beta_j + \beta_k}.$$

Based on the price equations derived in Saggi and Yildiz (2010)'s endowment model, they find that one-third of the tariff effects on price is given to domestic consumers, and export suppliers bear on the rest two-third (i.e. $\frac{dp_{iI}}{dt_{ij}} = \frac{1}{3}$, $\frac{dp_{jI}}{dt_{ij}} = -\frac{2}{3}$). In contrast, our productivity model finds that $\frac{dp_{iI}}{dt_{ij}} = \frac{1+\beta_j}{3+\beta_j+\beta_k}$ and $\frac{dp_{jI}}{dt_{ij}} = -\frac{2+\beta_k}{3+\beta_j+\beta_k}$ of which the implications are: the tariff burdens are dependent on the magnitude of the productivity parameter β. For example, the tariff burdens from country j's exports fallen on country i's consumers increase with country j's productivity β_j because $\frac{d\left(\frac{dp_{iI}}{dt_{ij}}\right)}{d\beta_j} > 0$, but this burdens fallen on country j's suppliers decrease with its own productivity.

1.4.2 Comparative Static

We provide a general result of comparative static in this three-country model.

We will use the notations that directly represent each country and each good. We use country a as an example. There are six tariffs that affect the country's welfare: t_{ab} and t_{ac} are country a's two own tariffs imposed by country a on its two trading partners; t_{ba} and t_{ca} are country a's two external tariffs imposed by its trading partners; t_{bc} and t_{cb} are two tariffs imposed between country b and country c.We will show their roles respectively.

$$\frac{dW_a}{dt_{ab}} = \underbrace{\left(\overbrace{\frac{dCS_a}{dp_{aA}}}^{<0}\overbrace{\frac{dp_{aA}}{dt_{ab}}}^{>0}\right)}_{=\frac{dCS_a}{dt_{ab}}<0} + \underbrace{\left(x_{bA} + \overbrace{\frac{d\left(x_{bA}\right)}{dp_{bA}}}^{>0}\overbrace{\frac{dp_{bA}}{dt_{ab}}}^{<0}t_{ab} + \overbrace{\frac{d\left(x_{cA}\right)}{dp_{cA}}}^{>0}\overbrace{\frac{dp_{cA}}{dt_{ab}}}^{>0}t_{ac}\right)}_{=\frac{dTR_a}{dt_{ab}}>0} + \underbrace{\frac{dPS_a}{dt_{ab}}}_{=0} \quad (1.6)$$

$$\frac{dW_a}{dt_{ac}} = \underbrace{\left(\overbrace{\frac{dCS_a}{dp_{aA}}}^{<0}\overbrace{\frac{dp_{aA}}{dt_{ac}}}^{>0}\right)}_{=\frac{dCS_a}{dt_{ac}}<0} + \underbrace{\left(x_{cA} + \overbrace{\frac{d\left(x_{bA}\right)}{dp_{bA}}}^{>0}\overbrace{\frac{dp_{bA}}{dt_{ac}}}^{>0}t_{ab} + \overbrace{\frac{d\left(x_{cA}\right)}{dp_{cA}}}^{>0}\overbrace{\frac{dp_{cA}}{dt_{ac}}}^{<0}t_{ac}\right)}_{=\frac{dTR_a}{dt_{ac}}>0} + \underbrace{\frac{dPS_a}{dt_{ac}}}_{=0} \quad (1.7)$$

Based on the formulas 1.6 and 1.7, we see that country a's two own tariffs play the same role in affecting country a's welfare. The own tariffs are harmful to domestic consumers because they raise the prices of the imported goods by country a. Therefore the own tariffs are considered as a cost from the perspective of domestic consumers.

The own tariffs do not affect the producer surplus.

Even though the own tariffs reduce country a's importing volume, their effect on the total tariff revenue is positive. Therefore the own tariffs are considered as a benefit if the government tries to raise its tariff revenue.

We then study how productivity asymmetry affects the magnitude of the cost and benefit from the own tariffs. We then have the followings:

$$\frac{d^2CS_a}{dt_{ab}d\beta_a} = \frac{d^2CS_a}{dt_{ac}d\beta_a} = 0$$

$$\frac{d^2CS_a}{dt_{ab}d\beta_b} = \overbrace{\frac{dCS_a}{dp_{aA}}}^{<0}\overbrace{\frac{d^2p_{aA}}{dt_{ab}d\beta_b}}^{>0} + \overbrace{\frac{d^2CS_a}{dp_{aA}^2}}^{=1}\overbrace{\frac{dp_{aA}}{d\beta_b}}^{<0}\overbrace{\frac{dp_{aA}}{dt_{ab}}}^{>0} < 0 \tag{1.8}$$

$$\frac{d^2CS_a}{dt_{ab}d\beta_c} = \overbrace{\frac{dCS_a}{dp_{aA}}}^{<0}\overbrace{\frac{d^2p_{aA}}{dt_{ab}d\beta_c}}^{<0} + \overbrace{\frac{d^2CS_a}{dp_{aA}^2}}^{=1}\overbrace{\frac{dp_{aA}}{d\beta_c}}^{<0}\overbrace{\frac{dp_{aA}}{dt_{ab}}}^{>0}$$

$$\frac{d^2CS_a}{dt_{ac}d\beta_c} = \overbrace{\frac{dCS_a}{dp_{aA}}}^{<0}\overbrace{\frac{d^2p_{aA}}{dt_{ac}d\beta_c}}^{>0} + \overbrace{\frac{d^2CS_a}{dp_{aA}^2}}^{=1}\overbrace{\frac{dp_{aA}}{d\beta_c}}^{<0}\overbrace{\frac{dp_{aA}}{dt_{ac}}}^{>0} < 0 \tag{1.9}$$

$$\frac{d^2CS_a}{dt_{ac}d\beta_b} = \overbrace{\frac{dCS_a}{dp_{aA}}}^{<0}\overbrace{\frac{d^2p_{aA}}{dt_{ac}d\beta_b}}^{<0} + \overbrace{\frac{d^2CS_a}{dp_{aA}^2}}^{=1}\overbrace{\frac{dp_{aA}}{d\beta_b}}^{<0}\overbrace{\frac{dp_{aA}}{dt_{ab}}}^{>0}$$

$$\frac{dTR_a^2}{dt_{ab}d\beta_a} = \frac{dTR_a^2}{dt_{ac}d\beta_a} = 0$$

$$\frac{d^2TR_a}{dt_{ab}d\beta_b} = \frac{d\left(x_{bA}\right)}{d\beta_b} + \overbrace{\frac{d\left(x_{bA}\right)}{dp_{bA}}}^{>0}\overbrace{\frac{d^2p_{bA}}{dt_{ab}d\beta_b}}^{>0}t_{ab} + \overbrace{\frac{d^2\left(x_{bA}\right)}{dp_{bA}d\beta_b}}^{=1}\overbrace{\frac{dp_{bA}}{dt_{ab}}}^{<0}t_{ab} + \overbrace{\frac{d\left(x_{cA}\right)}{dp_{cA}}}^{>0}\overbrace{\frac{d^2p_{cA}}{dt_{ab}d\beta_b}}^{>0}t_{ac}$$

$$\frac{d^2TR_a}{dt_{ab}d\beta_c} = \frac{d\left(x_{bA}\right)}{d\beta_c} + \overbrace{\frac{d\left(x_{bA}\right)}{dp_{bA}}}^{>0}\overbrace{\frac{d^2p_{bA}}{dt_{ab}d\beta_c}}^{<0}t_{ab} + \overbrace{\frac{d^2\left(x_{cA}\right)}{dp_{cA}d\beta_c}}^{=1}\overbrace{\frac{dp_{cA}}{dt_{ab}}}^{<0}t_{ac} + \overbrace{\frac{d\left(x_{cA}\right)}{dp_{cA}}}^{>0}\overbrace{\frac{d^2p_{cA}}{dt_{ab}d\beta_c}}^{<0}t_{ac}$$

$$\frac{d^2TR_a}{dt_{ac}d\beta_b} = \frac{d\left(x_{cA}\right)}{d\beta_b} + \overbrace{\frac{d^2\left(x_{bA}\right)}{dp_{bA}d\beta_b}}^{=1}\overbrace{\frac{dp_{bA}}{dt_{ac}}}^{<0}t_{ab} + \overbrace{\frac{d\left(x_{bA}\right)}{dp_{bA}}}^{>0}\overbrace{\frac{d^2p_{bA}}{dt_{ac}d\beta_b}}^{<0}t_{ab} + \overbrace{\frac{d\left(x_{cA}\right)}{dp_{cA}}}^{>0}\overbrace{\frac{d^2p_{cA}}{dt_{ac}d\beta_b}}^{<0}t_{ac}$$

$$\frac{d^2TR_a}{dt_{ac}d\beta_c} = \frac{d\left(x_{cA}\right)}{d\beta_c} + \overbrace{\frac{d^2\left(x_{cA}\right)}{dp_{cA}d\beta_c}}^{=1}\overbrace{\frac{dp_{cA}}{dt_{ac}}}^{<0}t_{ac} + \overbrace{\frac{d\left(x_{bA}\right)}{dp_{bA}}}^{>0}\overbrace{\frac{d^2p_{bA}}{dt_{ac}d\beta_c}}^{>0}t_{ab} + \overbrace{\frac{d\left(x_{cA}\right)}{dp_{cA}}}^{>0}\overbrace{\frac{d^2p_{cA}}{dt_{ac}d\beta_c}}^{>0}t_{ac}$$

Based on above formulas, since the signs of $\frac{d^2CS_a}{dt_{ab}d\beta_b} + \frac{d^2CS_a}{dt_{ab}d\beta_c} + \frac{d^2CS_a}{dt_{ac}d\beta_c} + \frac{d^2CS_a}{dt_{ac}d\beta_b}$ and $\frac{d^2TR_a}{dt_{ab}d\beta_b} + \frac{d^2TR_a}{dt_{ab}d\beta_c} + \frac{d^2TR_a}{dt_{ac}d\beta_c} + \frac{d^2TR_a}{dt_{ac}d\beta_b}$ are ambiguous, we cannot conclude the sign of $\frac{d^2W_a}{dt_a d\beta}$, which is the effect of productivity asymmetry degree on the welfare response to the own tariff change. We in later sections will assume some special conditions for β_a, β_b and β_c, based on which we are able to determine the sign. We will address this in the next section and show that our intuitions in the three-country framwork can correspond to that in the two-country framework.

We next study the roles played by the two external tariffs:

$$\frac{dW_a}{dt_{ba}} = \underbrace{\left(\overbrace{\frac{dCS_a}{dp_{aB}}}^{<0}\overbrace{\frac{dp_{aB}}{dt_{ba}}}^{<0}\right)}_{=\frac{dCS_a}{dt_{ba}}>0} + \underbrace{\left(\overbrace{\frac{dPS_a}{dp_{aB}}}^{>0}\overbrace{\frac{dp_{aB}}{dt_{ba}}}^{<0}\right)}_{=\frac{dPS_a}{dt_{ba}}<0} + \underbrace{\frac{dTR_a}{dt_{ba}}}_{=0} \tag{1.10}$$

$$\frac{dW_a}{dt_{ca}} = \underbrace{\left(\overbrace{\frac{dCS_a}{dp_{aC}}}^{<0}\overbrace{\frac{dp_{aC}}{dt_{ca}}}^{<0}\right)}_{=\frac{dCS_a}{dt_{ca}}>0} + \underbrace{\left(\overbrace{\frac{dPS_a}{dp_{aC}}}^{>0}\overbrace{\frac{dp_{aC}}{dt_{ca}}}^{<0}\right)}_{=\frac{dPS_a}{dt_{ca}}<0} + \underbrace{\frac{dTR_a}{dt_{ca}}}_{=0} \tag{1.11}$$

Through the formulas 1.10 and 1.11, the two external tariffs are viewed as a benefit by country a's consumers since $\frac{dCS_a}{dt_{ca}} > 0$ and $\frac{dCS_a}{dt_{ba}} > 0$. This meets the convention that a higher external tariff reduces a country's exports, thus its domestic supply increases. Therefore the domestic consumers will consider the external tariffs as a benefit.

However, the external tariffs are obviously harmful to producers. From the view of producers, the external tariffs are considered as a cost.

We then study the effects of productivity asymmetry on the benefit and cost from raising the external tariffs. We show the followings:

$$\frac{d^2CS_a}{dt_{ba}d\beta_a} = \overbrace{\frac{dCS_a}{dp_{aB}}}^{<0}\overbrace{\frac{d^2p_{aB}}{dt_{ba}d\beta_a}}^{>0} < 0$$

$$\frac{d^2CS_a}{dt_{ca}d\beta_a} = \overbrace{\frac{dCS_a}{dp_{aC}}}^{<0}\overbrace{\frac{d^2p_{aC}}{dt_{ca}d\beta_a}}^{>0} < 0$$

$$\frac{d^2PS_a}{dt_{ba}d\beta_a} = \overbrace{\frac{dPS_a}{dp_{aB}}}^{>0}\overbrace{\frac{dp_{aB}^2}{dt_{ba}d\beta_a}}^{>0} + \overbrace{\frac{d^2PS_a}{dp_{aB}^2}}^{>0}\overbrace{\frac{dp_{aB}}{d\beta_a}}^{<0}\overbrace{\frac{dp_{aB}}{dt_{ba}}}^{<0} + \overbrace{\frac{d^2PS_a}{dp_{aB}d\beta_a}}^{>0}\overbrace{\frac{dp_{aB}}{dt_{ba}}}^{<0} > 0$$

$$\frac{d^2PS_a}{dt_{ca}d\beta_a} = \overbrace{\frac{dPS_a}{dp_{aC}}}^{>0}\overbrace{\frac{dp_{aC}^2}{dt_{ca}d\beta_a}}^{>0} + \overbrace{\frac{d^2PS_a}{dp_{aC}^2}}^{>0}\overbrace{\frac{dp_{aC}}{d\beta_a}}^{<0}\overbrace{\frac{dp_{aC}}{dt_{ca}}}^{<0} + \overbrace{\frac{d^2PS_a}{dp_{aC}d\beta_a}}^{>0}\overbrace{\frac{dp_{aC}}{dt_{ca}}}^{<0} > 0$$

We show that a higher β_a, which represents a larger productivity asymmetry, decreases both the benefit and cost from raising higher external tariffs on country a's exports. It is because of that a larger production of country a's output leads to a less sensitive price response.

The tariffs, t_{bc} and t_{cb}, are enacted between country a's two trading partners. To see their roles in affecting country a's welfare changes, we show the followings:

$$\frac{dW_a}{dt_{bc}} = \underbrace{\left(\overbrace{\frac{dCS_a}{dp_{aB}}}^{<0}\overbrace{\frac{dp_{aB}}{dt_{bc}}}^{>0}\right)}_{=\frac{dCS_a}{dt_{bc}}<0} + \underbrace{\frac{dPS_a}{dt_{bc}}}_{=0} + \underbrace{\frac{dTR_a}{dt_{bc}}}_{=0}$$

$$\frac{dW_a}{dt_{cb}} = \underbrace{\left(\overbrace{\frac{dCS_a}{dp_{aC}}}^{<0} \overbrace{\frac{dp_{aC}}{dt_{cb}}}^{>0} \right)}_{=\frac{dCS_a}{dt_{cb}}<0} + \underbrace{\frac{dPS_a}{dt_{cb}}}_{=0} + \underbrace{\frac{dTR_a}{dt_{cb}}}_{=0}$$

We see from the above two formulas that t_{bc} and t_{cb} affect country a's welfare through the channel of consumer surplus because these two tariffs can influence the prices of good B and good C. Country b imports good B from not only country a but also country c. So does country c. These two tariffs adversely affect country a's consumer welfare. Therefore, country a expects that country b always signs an FTA with country c. We will address this again in the next section, in which we show that either $\{F\}$ or $\{bc\}$ can be a stable equilibrium, as a result, country a's consumers are happy to see that $t_{bc} = t_{cb} = 0$.

1.5 Equilibrium analysis

In the three-country framework, there are 4 regimes under bilateralism: $\{\Phi\}, \{F\}, \{ij\}, \{ih\}$ for $i \in \{a, b, c\}$, $j \in \{a, b, c\}$, $j \neq i$. If all countries announce no trade agreements, then a status quo forms, denoted as $\{\Phi\}$. If two countries, say i and j, form a bilateral free trade agreement without involving the other country k for $k \in \{a, b, c\}$, $k \neq j \neq i$, we denote this bilateral FTA as $\{ij\}$. If all three countries sign agreements with each other, a global free trade regime $\{F\}$ forms.

The last regime is $\{ih\}$, which means that country i, signing a bilateral FTA respectively with countries j and k, serves as a hub country. Country j, which signs a bilateral FTA with country i but does not sign any agreements with country k, serves as a spoke country. So does country k, which is also a spoke country.

Definition 2. In the global free trade regime, denoted by $\{F\}$, the tariffs are such that:

$$t_{ij}^{\{F\}} = 0 \text{ for } i \in \{a, b, c\}, j \in \{a, b, c\}, j \neq i$$

In the bilateral FTA $\{ij\}$ the tariffs are such that:[6]

$$t_{ij}^{\{ij\}} = t_{ji}^{\{ij\}} = 0$$

$$t_{ik}^{\{ij\}} = \underset{t_{ik}}{Argmax} \left\{ W_i^{\{ij\}} \right\} = \underset{t_{ik}}{Argmax} \left\{ CS_i^{\{ij\}} + PS_i^{\{ij\}} + TR_i^{\{ij\}} \right\}$$

In the status quo regime $\{\Phi\}$, the tariffs are such that:

$$t_i^{\{\Phi\}} = \underset{t_i}{Argmax} \left\{ W_i^{\{\Phi\}} \right\} = \underset{t_i}{Argmax} \left\{ CS_i^{\{\Phi\}} + PS_i^{\{\Phi\}} + TR_i^{\{\Phi\}} \right\}.$$
$$s.t.\ t_{ij}^{\{\Phi\}} = t_{ik}^{\{\Phi\}} = t_i^{\{\Phi\}}$$

Then based on the optimal tariffs, we can compare the welfare difference between each regime.

1.5.1 Equilibrium when all three countries are identical

Proposition 3 concludes our result under the condition of symmetry in the three-country model.

Proposition 3. *If $\beta_a = \beta_b = \beta_c$, global FTA is the only stable equilibrium.*

The intuition behind Proposition 3 is analogous to what we explain in the two-country model under a symmetric condition.

In our set-up for an asymmetric three-country trading, we define two similarly productive countries and one distinctive country. We firstly study the case that

[6]Under bilateral FTA, member countries are allowed to impose discriminatory tariffs on non-member country. In this chapter, we focus on the role played by productivity. In chapter 2, we will study the role played by discriminatory tariffs and we will study another case under which discriminatory tariffs are banned.

there exist two identically highly-productive countries and one unique low-productive country. Secondly we study the case that there exist one unique highly-productive country and two identically low-productive countries.

1.5.2 Equilibrium when there are two highly-productive countries

To avoid confusion, henceforth we denote the low-productive country as S (i.e. the country with a smaller level of productivity). We denote the highly-productive country as L (i.e. the country with a larger level of productivity).

We assume that there are two identical countries with a positive productivity and one country without any productivity. Therefore, we have two highly-productive countries and one low-productive country. We denote the two highly-productive countries as L_1 and L_2. It is noteworthy that L_1 is identical to L_2.

We then prove the following Lemma:

Lemma 1. *If $\beta_a = \beta_b = \beta > 0$ and $\beta_c = 0$ (i.e. county a and country b are country L and country c is country S), the following inequalities hold:*

$$\triangle W_S^{\{F\}-\{L_1L_2\}} > 0 \iff \beta < \beta_S^{\{F\}-\{L_1L_2\}} \approx 1.91 \tag{1.12}$$

$$\triangle W_S^{\{F\}-\{Lh\}} > 0 \text{ for any } \beta \tag{1.13}$$

$$\triangle W_{L_1}^{\{L_1L_2\}-\{\Phi\}} > 0, \triangle W_{L_1}^{\{F\}-\{L_2h\}} > 0, \triangle W_{L_1}^{\{F\}-\{Sh\}} > 0, \triangle W_{L_1}^{\{F\}-\{L_2S\}} > 0 \text{ for any } \beta \tag{1.14}$$

Proof. See Appendix □

It is noteworthy that $\{L_1h\} = \{L_2h\} = \{Lh\}$, $\{L_1S\} = \{L_2S\} = \{LS\}$ and $\{L_1L_2\} = \{LL\}$ because L_1 and L_2 are identical countries.

Based on Lemma 1, firstly it is obvious that Lemma 1 ascertains the failure of the hub-spoke regime $\{Lh\}$ and $\{Sh\}$: neither the highly-productive country nor low-productive country wants to be a spoke. Since the total world welfare (i.e. $W_a + W_b + W_c$) under global FTA is larger than that under the hub-spoke regime, as long as the hub country gains more benefits the spoke countries must bear more loss.

Secondly, we see that the highly-productive country never wants to be a non-member based on the inequality $\triangle W_{L_1}^{\{F\}-\{L_2S\}} > 0$. Also, we see that the two highly-productive countries do not have an incentive to deviate from FTA. Highly-productive countries have a larger volume of exports and a smaller volume of imports, thus benefit more from tariff reductions granted by others. Similarly, such countries have relatively less to lose from eliminating their own optimal tariffs since these tariffs apply to relatively larger import volumes.

Therefore, the equilibrium is dependent on the unique low-productive country's deviation for FTA. Based on the inequality 1.12, the unique low-productive country would like to be an outsider when the productivity asymmetry degree is too large. To this unique low-productive country, the larger the asymmetry degree in exporting volumes, the larger the increase in its export deficit from the elimination of its partners' tariff and the more the loss due to its own trade liberalization since the tariff reduction applies to a larger volume of imports (due to the larger export level of its partners).

With Lemma 1, we have the following proposition:

Proposition 4. *If $\beta_a = \beta_b = \beta > 0$ and $\beta_c = 0$, there exist a threshold $\beta_S^{\{F\}-\{LL\}}$ such that:*

(i) The unique low-productive country prefers regime $\{F\}$ to any other regimes if and only if $\beta < \beta_S^{\{F\}-\{LL\}}$;

(ii) $\{F\}$ is the only stable equilibrium when $\beta < \beta_S^{\{F\}-\{LL\}}$;

(iii) $\{LL\}$ *is the only stable equilibrium when* $\beta > \beta_S^{\{F\}-\{LL\}}$.

Figure 1.3 illustrates Proposition 4.

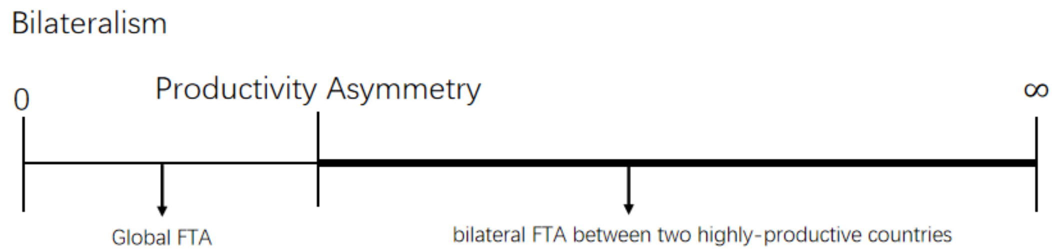

Figure 1.3: Proposition 4 (two highly-productive Countries)

In the two-counrty model, we show that the low-productive country prefers $\{F\}$ no matter what level the productivity asymmetry is. However, as Proposition 4 shown in the case of two highly-productive countries and one unique low-productive country, the unique low-productive country will deviate from $\{F\}$ when the productivity asymmetry level is too large. This implies that when the unique low-productive country has two trading partners which have a larger productivity, it will not insist on joining FTA as it does under the two-country environment in which it trades with only one highly-productive partner. To understand the underlying insights, we use the results of comparative static to show the benefits and costs by opting out from FTA:

Firstly, one obvious benefit from opting out is the tariff revenue gains:

$$\frac{dTR_S}{dt_S} > 0,$$

where t_S is the tariff imposed by country S.

Secondly, we show that:

$$\frac{dCS_S}{dt_L} > 0$$

A higher external tariff t_L (i.e. the tariffs imposed by country L, which represents the two highly-productive countries a and b) leads to a higher CS_S (i.e. the consumer surplus of country S, which represents the low-productive country c) thanks to the lower prices (i.e. $\frac{d(p_{cA})}{d\left(t_{L_1}\right)} < 0$ and $\frac{d(p_{cB})}{d\left(t_{L_2}\right)} < 0$, country c is country S). It is noteworthy that there are two external tariffs $t_{L_1}$and t_{L_2}, and they play the same role here. We therefore use t_L as a general notation that represents both two external tariffs.

The first cost from being a non-member is that:

$$\frac{d\left(CS_S\right)}{d\left(t_S\right)} < 0$$

The unique country S imposes its own tariffs t_S that are harmful to its consumers (i.e. $\frac{d(CS_S)}{d(t_S)} < 0$) due to the price response ($\frac{d(P_{cC})}{d(t_S)} > 0$).

The second cost is:

$$\frac{d\left(PS_S\right)}{d\left(t_L\right)} < 0$$

A higher external tariff t_L is causing PS_S to decrease because of the price response (i.e. $\frac{d(p_{cA})}{d\left(t_{L_1}\right)} < 0$ and $\frac{d(p_{cB})}{d\left(t_{L_2}\right)} < 0$ so that $\frac{d(PS_S)}{d(t_L)} < 0$).

We then show the effects of a larger productivity asymmetry degree on the benefits and costs:

$$\frac{d^2\left(TR_S\right)}{d\left(t_S\right)d\left(\beta_L\right)} > 0; \frac{d^2\left(CS_S\right)}{d\left(t_L\right)d\left(\beta_L\right)} > 0.$$

$$\frac{d^2\left(CS_S\right)}{d\left(t_S\right)d\left(\beta_L\right)} < 0; \frac{d^2\left(PS_S\right)}{d\left(t_L\right)d\left(\beta_L\right)} < 0.$$

Therefore a larger productivity asymmetry level (i.e. a larger β_L) will increase both the benefits and costs.

We then combine the effects on benefits and costs. We show that the following inequality holds:

$$\overbrace{\left|\frac{d^2\left(CS_S\right)}{d\left(t_{L_1L_2}\right)d\left(\beta_L\right)}\right|+\left|\frac{d^2\left(CS_S\right)}{d\left(t_L\right)d\left(\beta_L\right)}\right|+\left|\frac{d^2\left(TR_S\right)}{d\left(t_S\right)d\left(\beta_L\right)}\right|}^{Benefits}$$
$$-\overbrace{\left|\frac{d^2\left(CS_S\right)}{d\left(t_S\right)d\left(\beta_L\right)}\right|-\left|\frac{d^2\left(PS_S\right)}{d\left(t_L\right)d\left(\beta_L\right)}\right|}^{Costs}>0 \iff \beta_L > \text{a threshold} \qquad (1.15)$$

It is noteworthy that since $\frac{d(CS_S)}{d\left(t_{L_1L_2}\right)} < 0$ holds and the regimes $\{F\}$ and $\{L_1L_2\}$ eliminate $t_{L_1L_2}$, the CS_S will be highest when $t_{L_1L_2} = 0$ with holding other factors constant. We show that $\frac{d^2(CS_S)}{d\left(t_{L_1L_2}\right)d(\beta_L)} < 0$ holds.

Therefore, a higher productivity asymmetry degree grows the benefits of the unique low-productive country from being a non-member faster than the costs of the unique low-productive country from being a non-member.

We generalize Proposition 4 by assuming $\beta_a = \beta_b > \beta_c > 0$, based on which we run a simulation. Figure 1.4 illustrates the simulation result.

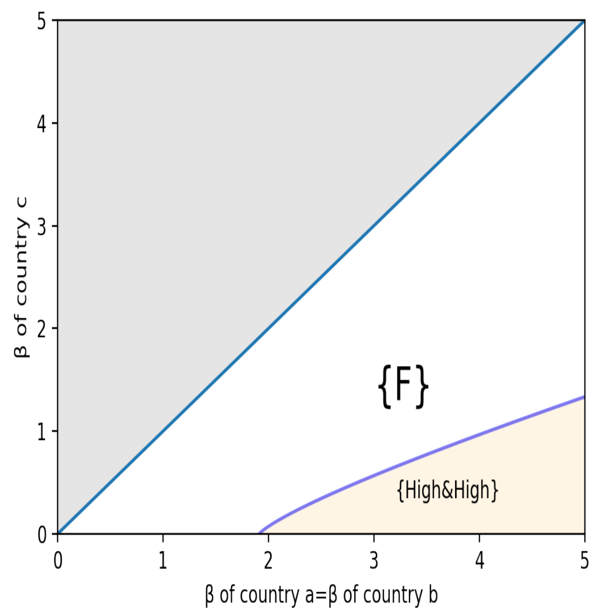

Figure 1.4: Simulation (two highly-productive countries)

1.5.3 Equilibrium when there is only one highly-productive country

In this sub-section we assume that there exist one unique highly-productive country L and two identically low-productive countries S (i.e. $\beta_a > 0$, $\beta_b = \beta_c = 0$). We prove the following Lemma:

Lemma 2. *If $\beta_a = \beta > 0$ and $\beta_b = \beta_c = 0$ (i.e. country a is the unique country L and countries b and c are country S), the following inequalities hold:*

$$\triangle W_S^{\{F\}-\{LS\}} > 0 \iff \beta < \beta_S^{\{F\}-\{LS\}} \approx 0.89 \tag{1.16}$$

$$\triangle W_L^{\{F\}-\{LS\}} > 0 \iff \beta < \beta_L^{\{F\}-\{LS\}} \approx 8.73 \tag{1.17}$$

$$\triangle W_S^{\{F\}-\{Lh\}} > 0, \triangle W_{S_1}^{\{F\}-\{S_2h\}} > 0, \triangle W_{S_1}^{\{F\}-\{LS_2\}} > 0 \text{ for any } \beta \tag{1.18}$$

$$\triangle W_L^{\{F\}-\{Sh\}} > 0 \iff \beta < \beta_L^{\{F\}-\{Sh\}} \approx 6.75 \tag{1.19}$$

$$\triangle W_S^{\{F\}-\{SS\}} > 0 \text{ for any } \beta$$

$$\triangle W_L^{\{F\}-\{SS\}} > 0 \iff \beta < \beta_L^{\{F\}-\{SS\}} \approx 1.81$$

$$W_L^{\{LS\}} - W_L^{\{SS\}} > 0 \iff \beta < \beta_L^{\{LS\}-\{SS\}} \approx 0.04 \tag{1.20}$$

Proof. See Appendix □

Firstly, we want to know whether the bilateral FTA between one highly-productive country and one low-productive country $\{LS\}$ is stable. The bilateral FTA is stable when two countries simultaneously intend to push the third country out, or one country prefers to be a non-member by itself. The inequality 1.17 says that the unique highly-productive country prefers $\{LS\}$ when the asymmetry degree is at a considerably large level. Together with the inequality 1.16, $\{LS\}$ will be stable when

$\beta > \beta_L^{\{F\}-\{LS\}}$. Then what about in the range $\beta_S^{\{F\}-\{LS\}} < \beta < \beta_L^{\{F\}-\{LS\}}$, in which the highly-productive country would like to sign FTA with the other low-productive country? Since in this range, both two low-productive countries hate to be an outsider, and also they hate to be a spoke, therefore the $\{LS\}$ is stable only if $\beta > \beta_L^{\{F\}-\{LS\}}$.

Secondly, we see that another bilateral FTA $\{SS\}$ will be stable when $\beta > \beta_L^{\{F\}-\{SS\}}$, in which the highly-productive country will opt out from FTA. Then what about the choice of country L between $\{SS\}$ and $\{LS\}$? Based on the inequality 1.20, country L always values $\{SS\}$ better than $\{LS\}$. Then we can conclude the following proposition:

Proposition 5. *If $\beta_a = \beta > 0$ and $\beta_b = \beta_c = 0$, there exists a threshold $\beta_L^{\{F\}-\{SS\}}$ such that*

(i) The unique highly-productive country prefers regime $\{F\}$ to any other regimes if and only if $\beta < \beta_L^{\{F\}-\{SS\}}$;

(ii) $\{F\}$ is the only stable equilibrium when $\beta < \beta_L^{\{F\}-\{SS\}}$;

(iii) $\{SS\}$ is the only stable equilibrium when $\beta > \beta_L^{\{F\}-\{SS\}}$.

Figure 1.5 illstrates Proposition 5.

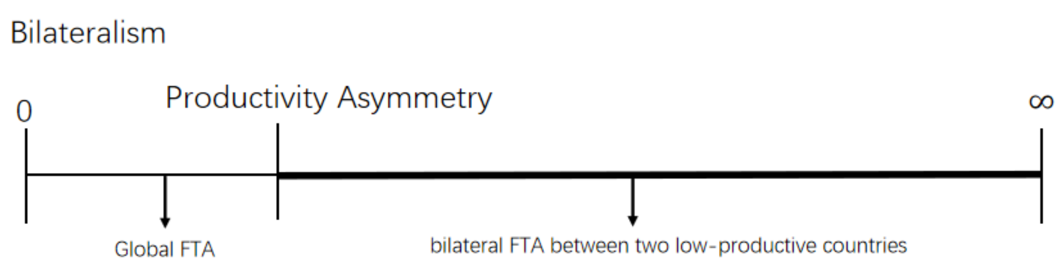

Figure 1.5: Proposition 5 (One highly-productive Country)

To better study the underlying intuitions, we also provide the results of comparative statics. Since the equilibrium hinges on the attitude from the unique highly-productive country towards being an outsider, we then study the effect of this unique country being a non-member on its welfare based on different levels of its productivity.

We show that: if the unique country L chooses to opt out from FTA, it will gain benefits including (i) a higher tariff revenue ($\frac{d(TR_L)}{d(t_L)} > 0$); (ii) a higher CS_L thanks to the higher external tariffs t_S ($\frac{d(CS_L)}{d(t_S)} > 0$).

The costs include: (i) $\frac{d(CS_L)}{d(t_L)} < 0$, a lower CS_L due to that country L's own tariffs t_L lead to an adverse price response; (ii) $\frac{d(PS_L)}{d(t_S)} < 0$, a lower PS_L due to the adverse price response from a higher external tariff.

To see how productivity asymmetry affects the benefits, we show the following inequalities:

$$\frac{d^2\left(TR_L\right)}{d\left(t_L\right)d\left(\beta_S\right)} > 0 \tag{1.21}$$

$$\frac{d^2\left(CS_L\right)}{d\left(t_S\right)d\left(\beta_S\right)} > 0 \tag{1.22}$$

To see how productivity asymmetry affects the costs, we show the following inequalities:

$$\frac{d^2\left(CS_L\right)}{d\left(t_L\right)d\left(\beta_S\right)} < 0 \tag{1.23}$$

$$\frac{d^2\left(PS_L\right)}{d\left(t_S\right)d\left(\beta_S\right)} < 0 \tag{1.24}$$

We show that a larger productivity asymmetry degree (i.e. a lower β_S) reduces both the benefits and costs. We then show the combined effect as follows:

$$\left(\overbrace{\left|\frac{d^2\left(CS_L\right)}{d\left(t_L\right)d\left(\beta_S\right)}\right| + \left|\frac{d^2\left(PS_L\right)}{d\left(t_S\right)d\left(\beta_S\right)}\right|}^{Costs}\right) - \left(\overbrace{\left|\frac{d^2\left(CS_L\right)}{d\left(t_S\right)d\left(\beta_S\right)}\right| + \left|\frac{d^2\left(TR_L\right)}{d\left(t_L\right)d\left(\beta_S\right)}\right|}^{Benefits}\right) > 0 \iff \beta_S < \text{a threshold} \tag{1.25}$$

The inequality 1.25 is in line with our result of comparative static in the two-country model. If the productivity asymmetry level is too large, the costs decrease at a faster pace than the benefits.

Figure 1.6 illustrates the simulation results based on the generalization of $\beta_a > \beta_b = \beta_c > 0$.

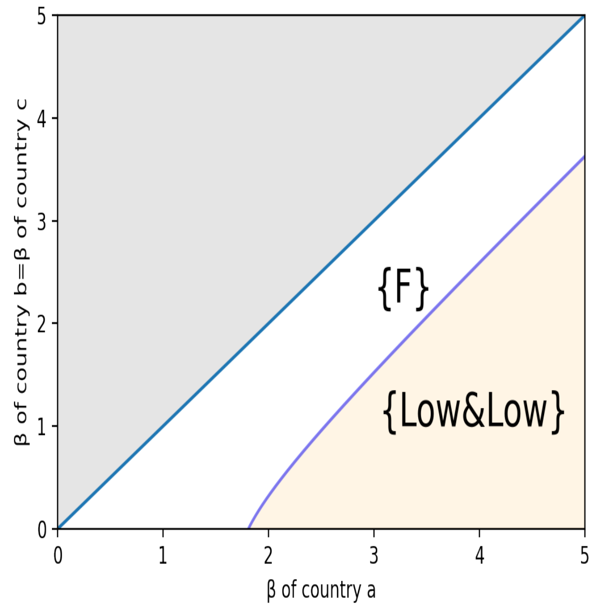

Figure 1.6: Simulation (One highly-productive Country)

1.6 Conclusion

Given the fact that a sprinkling of countries are not linked to preferential trade agreements, our world now is a coalition in which various trade agreements are affecting each country's welfare. From Bhagwati (1991)'s work that lits up our cogitation about the effects of preferential trade agreements on global free trade to Bagwell and Staiger (1997)'s contribution that ascertains the nexus between FTA and liberal multilateral trade policies, researchers have pitched into the job of understanding the effects of preferential trade agreements from various perspectives. As Saggi and Yildiz (2010) take into account the endogeneity of FTAs, we successfully extend their work by reshaping the framework with adding the slope of the endogenous supply curve which represents the heterogeneity of producing powers. We generalize previous works by studying the role of productivity asymmetry under other possible trading environment. Our major contributions lie at the investigation of the connection between the productivity and the welfare response to tariffs under different trading regimes. We corroborate the significance of a larger productivity asymmetry to abridge the appeal of global FTA. Under both trading environments that we study in this paper, the global FTA will fail to form when the productivity asymmetry level is too large. Our work may shed some lights on the future studies on how the heterogeneity in national productivity will affect the world trade liberalization.

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Chapter 2

Productivity Asymmetry, bilateralism, Multilateralism, and the Quest to Free Trade

2.1 Introduction

The World Trade Organization (WTO) which has always been advocating free trade has investigated how the design of trade negotiation can help the world trade system toward the global free trade. A number of studies have investigated the contradicting roles of GATT Article I on Most-Favored-Nation (MFN) treatment and GATT Article XXIV on Customs Unions and Free-trade Areas (Kose and Riezman, 2000; Kowalczyk and Riezman, 2009; Lake and Yildiz, 2016; Hantzsche and Young, 2019; Akdi and Erdil, 2019; Lake, 2019; Lake, Nken and Yildiz, 2020; Cole, Lake and Zissimos, 2021). On the one hand, the most-favored-nation principle may discourage countries from tariff negotiation because they can free ride on tariff cuts between other negotiating countries without reducing their own tariffs. On the other hand, given GATT Article XXIV, countries may opt out from global free trade and form a preferential trade agreement with positive external tariffs on non-member countries.

In this chapter, we propose that productivity heterogeneity across countries can affect the role played by bilateralism (i.e. discriminatory tariff) and multilateralism (i.e. non-discriminatory tariff) in affecting the formation of global free trade.

We utilize the same three-country productivity model as in the first chapter. We consider four trade regimes under the consent of bilateralism: (i) bilateral free trade agreement (i.e. two countries sign a bilateral free trade agreement (FTA) and impose a discriminatory tariff on the other non-member country); (ii) global free trade agreement (i.e. all three countries sign FTA with each other); (iii) hub-spoke agreement (i.e. one country serving as a hub signs bilateral FTAs with the other two countries which, serving as two spokes, do not sign FTA with each other); (iv) status quo (i.e. no country communicates with others).

Under multilateralism (i.e. banning bilateralism) we have three trade regimes: (i) multilateral trade agreement with non-discriminatory tariff (i.e. two countries sign a trade agreement that chooses an optimal tariff that is also imposed on the non-member country); (ii) global free trade agreement (i.e. all three countries sign FTA with each other); (iii) status quo (i.e. no country communicates with others).

Our equilibrium analysis follows from the concept of coalition proof Nash equilibrium.

The main objective of our analysis is to study how the role of bilateralism affects the formation of global free trade. We show that in a case of symmetric productivity (i.e. all countries have the same productivity), global free trade is the only equilibrium no matter if bilateralism is permitted, or not. This finding generalizes the conclusion of Saggi and Yildiz (2010).

We then investigate how different degrees of productivity heterogeneity can affect the change of equilibrium. We consider two special cases as we do in chapter one: (i) two identically highly-productive countries and one unique low-productive country and (ii) one unique highly-productive country and two identically low-productive countries. We find that when the degree of productivity heterogeneity is sufficiently large, in equilibrium, only the two similarly productive countries will form (i) a bilateral free trade agreement when discriminatory policy is approved and (ii) a multilateral agreement when discriminatory policy is prohibited.

We find that the consent of bilateralism under different trading environments can affect the formation of global FTA differently. In the case of two highly-productive countries and one low-productive country, the consent of bilateralism supports the formation of global FTA because bilateralism approves the discriminatory policy that leads to a higher loss to the non-member country regardless of the productivity heterogeneity. However, in the case of one unique highly-productive country and two low-productive countries, the consent of bilateralism can prevent the formation of global free trade because the unique highly-productive country is more likely to be non-member under an environment of discrimination.

We also find that as the productivity asymmetry rises above a sufficiently large level, global free trade will fail to form no matter if bilateralism is possible, or not. The intuitions are in line with that in chapter 1. As in the case of two highly-productive countries and one unique low-productive country, a larger productivity asymmetry level will increase both the benefits and costs from being a non-member by the unique low-productive country. A larger productivity asymmetry degree grows the benefits of the unique low-productive country from being a non-member faster than the costs of the unique low-productive country from being a non-member. Therefore, the unique low-productive country will opt out from FTA when the productivity asymmetry level is too large.

As in the case of one unique highly-productive country and two low-productive countries, a larger productivity asymmetry level will decrease both the benefits and costs from being a non-member by the unique highly-productive country. A larger productivity asymmetry degree reduces the costs faster than the benefits. Therefore, the unique highly-productive country will opt out from FTA when the productivity asymmetry level is too large.

The chapter proceeds as follows. Section 2.2 presents the literature review. Section 2.3 presents the equilibrium analysis. Section 2.4 concludes.

2.2 Literature Review

Our study in chapter 2 adds contributions to the same strand of literature in chapter 1. However, the main purposes of chapter 1 and chapter 2 are differently. In chapter 1, we focus on the role of productivity asymmetry, whereas in chapter 2 we study the role of bilateralism. In chapter 2, we add one condition under which a discriminatory tariff policy is banned and bilateral FTA is no longer possible. Therefore, in chapter 2, we can study the equilibrium under multilateralism.

This chapter is also mostly related to Saggi and Yildiz (2010). They study the role of bilateralism under the framework of endowment heterogeneity. We extend their model to a framework of productivity heterogeneity. Moreover, Saggi and Yildiz (2010) only study one trading environment in which there exist two larger countries and one small country. We add one more trading environment in which there are one unique highly-productive country and two low-productive countries.

2.3 Equilibrium analysis

In this section, we will study the role played by bilateralism and multilateralism that could affect the formation of FTA under the conditions of asymmetric productivity in different trading environments. We will use the same three-country model described in section 1.4.

Under the consent of bilateralism there are 4 regimes: $\{\Phi\}, \{F\}, \{ij\}, \{ih\}$ for

$i \in \{a, b, c\}$, $j \in \{a, b, c\}$, $j \neq i$. If all countries announce no trade agreements, then a status quo forms, denoted as $\{\Phi\}$. If two countries, say i and j, form a bilateral free trade agreement without involving the other country k for $k \in \{a, b, c\}$, $k \neq j \neq i$, we denote this bilateral FTA as $\{ij\}$. If all three countries sign agreements with each other, a global free trade regime $\{F\}$ forms. The last regime is $\{ih\}$, which means that country i, signing a bilateral FTA respectively with countries j and k, serves as a hub country. Country j, which signs a bilateral FTA with country i but does not sign any agreements with country k, serves as a spoke country. So does country k, which is also a spoke country.

Under multilateralism (i.e. when bilateralism is banned), there are 3 regimes: $\{\Phi\}, \{F\}, \{ij\}^m$. The two regimes $\{\Phi\}$ and $\{F\}$ are same with those under bilateralism. In the regime $\{ij\}^m$ in which all countries are prohibitted to impose discriminatory tariff, country i and country j will jointly maximize their welfares with an optimal tariff that will be also imposed on the non-member country k. It is noteworthy that under multilateralism the regimes $\{ij\}$ and $\{ih\}$ are no longer existing because they impose discriminatory tariffs on non-member countries.

We denote $t^{\{r\}}$ as the tariff under the regime $\{r\}$.

Definition 3. In the global free trade regime, denoted by $\{F\}$, the tariffs are such that:

$$t_{ij}^{\{F\}} = 0 \text{ for } i \in \{a, b, c\}, j \in \{a, b, c\}, j \neq i$$

In the bilateral FTA $\{ij\}$ the tariffs are such that:

$$t_{ij}^{\{ij\}} = t_{ji}^{\{ij\}} = 0$$

$$t_{ik}^{\{ij\}} = \underset{t_{ik}}{Argmax} \left\{ W_i^{\{ij\}} \right\} = \underset{t_{ik}}{Argmax} \left\{ CS_i^{\{ij\}} + PS_i^{\{ij\}} + TR_i^{\{ij\}} \right\}$$

In the status quo regime $\{\Phi\}$, the tariffs are such that:

$$t_i^{\{\Phi\}} = \underset{t_i}{Argmax}\left\{W_i^{\{\Phi\}}\right\} = \underset{t_i}{Argmax}\left\{CS_i^{\{\Phi\}} + PS_i^{\{\Phi\}} + TR_i^{\{\Phi\}}\right\}$$
$$s.t.\ t_{ij}^{\{\Phi\}} = t_{ik}^{\{\Phi\}} = t_i^{\{\Phi\}}$$

In the multilateral agreement $\{ij\}^m$, the tariffs are such that:

$$t_i^{\{ij\}^m} = \underset{t_i}{Argmax}\left(W_i^{\{ij\}^m} + W_j^{\{ij\}^m}\right)$$
$$s.t.\ t_{ij} = t_{ik} = t_i$$

Then based on the optimal tariffs, we next compare the welfare difference between each regime.

We denote $W_i^{\{r\}}$ as the welfare of country i under the regime $\{r\}$, and $\triangle W_i^{\{r\}-\{s\}} = W_i^{\{r\}} - W_i^{\{s\}}$ as the welfare difference between regime $\{r\}$ and $\{s\}$. If $W_i^{\{r\}-\{s\}} = 0$, we conclude that country i is indifferent between $\{r\}$ and $\{s\}$; if $\triangle W_i^{\{r\}-\{s\}} > 0$, we conclude that country i prefers $\{r\}$ to $\{s\}$.

2.3.1 Equilibrium when all three countries are identical

Proposition 6 concludes our first result based on the condition of symmetry:

Proposition 6. *If $\beta_a = \beta_b = \beta_c$ and $e_a = e_b = e_c$, global FTA is the only stable equilibrium under both bilateralism and multilateralism.*

Proposition 6 is in line with the conventional intuition: under the condition of symmetry (i.e. $\beta_a = \beta_b = \beta_c$ and $e_a = e_b = e_c$) the world welfare gains will be spread equally into each country. As countries are announcing their strategies simultaneously, no one has an incentive to deviate for the FTA that brings considerably more consumer and producer surplus than opting out. As a result, the final regime will be global FTA that will reach a Pareto optimal outcome.

Proposition motivates a question: is global FTA still uniquely stable under a condition of asymmetry? We then will solve for the equilibrium regimes under the condition of asymmetry from the perspective of productivity. It is noteworthy that we want to isolate the effects solely from the productivity heterogeneity. Therefore, henceforth we will assume that countries have identical endowment by assuming $e_i = 1$ for all i.

In our set-up for an asymmetric three-country trading, we define two similarly productive countries and one distinctive country. We firstly study the case that there exist two identically highly-productive countries and one unique low-productive country. Secondly we study the case that there exist two identically low-productive countries and one unique highly-productive country.

2.3.2 Equilibrium when there are two highly-productive countries

To avoid confusion, henceforth we denote the low-productive country as S (i.e. the country with a smaller level of productivity). We denote the highly-productive country as L (i.e. the country with a larger level of productivity).

We assume that there are two identical countries with a positive productivity and one country without any productivity. Therefore, we have two highly-productive countries and one low-productive country. We denote the two highly-productive countries as L_1 and L_2. It is noteworthy that L_1 is identical to L_2.

We then prove the following Lemma:

Lemma 3. *If $\beta_a = \beta_b = \beta > 0$ and $\beta_c = 0$ (i.e. countries a and b are country L and country c is country S), under the consent of bilateralism the following inequalities* *hold:*

$$\triangle W_S^{\{F\}-\{L_1L_2\}} > 0 \iff \beta < \beta_S^{\{F\}-\{L_1L_2\}} \approx 1.91 \tag{2.1}$$

$$\triangle W_S^{\{F\}-\{Lh\}} > 0 \textit{ for any } \beta \tag{2.2}$$

$$\triangle W_{L_1}^{\{L_1L_2\}-\{\Phi\}} > 0, \triangle W_{L_1}^{\{F\}-\{L_2h\}} > 0, \triangle W_{L_1}^{\{F\}-\{Sh\}} > 0, \triangle W_{L_1}^{\{F\}-\{L_2S\}} > 0 \textit{ for any } \beta \tag{2.3}$$

Proof. See Appendix □

Lemma 3 is a re-statement of Lemma 1. We thus have the following proposition which is a re-statement of proposition 4:

Proposition 7. *If $\beta_a = \beta_b = \beta > 0$, $\beta_c = 0$ and bilateralism is available, there exist a threshold $\beta_S^{\{F\}-\{LL\}}$ such that:*

(i) The unique low-productive country prefers regime $\{F\}$ to any other regimes if and only if $\beta < \beta_S^{\{F\}-\{LL\}}$;

(ii) $\{F\}$ is the only stable equilibrium when $\beta < \beta_S^{\{F\}-\{LL\}}$;

(iii) $\{LL\}$ is the only stable equilibrium when $\beta > \beta_S^{\{F\}-\{LL\}}$.

We then will discuss the formation of final regime under multilateralism (i.e. when bilateralism is prohibited). Since under multilateralism countries are not permitted to impose discriminatory tariffs on the non-member country, the regimes of bilateral FTA and hub-spoke are no longer an option. We prove the following lemma:

Lemma 4. *If $\beta_a = \beta_b = \beta > 0$ and $\beta_c = 0$, under multilateralism the following inequalities hold:*

$$\triangle W_S^{\{F\}-\{L_1L_2\}^m} > 0 \iff \beta < \beta_S^{\{F\}-\{L_1L_2\}^m} \approx 0.12 \tag{2.4}$$

$$\triangle W_{L_1}^{\{F\}-\{L_1L_2\}^m} > 0, \triangle W_{L_1}^{\{L_1L_2\}^m-\{\Phi\}} > 0, \triangle W_{L_1}^{\{F\}-\{L_2S\}^m} > 0 \textit{ for any } \beta$$

Proof. See Appendix □

Based on Lemma 4, still the two highly-productive countries have no incentives to deviate for FTA. The intuition is analogous to that underlies under bilateralism. With Lemma 4, we have the following proposition:

Proposition 8. *If $\beta_a = \beta_b = \beta > 0$, $\beta_c = 0$ and bilateralism is not available, there exist a threshold $\beta_S^{\{F\}-\{L_1L_2\}^m}$ such that*

(i) The unique low-productive country prefers regime $\{F\}$ to any other regimes if and only if $\beta < \beta_S^{\{F\}-\{L_1L_2\}^m}$;

(ii) $\{F\}$ is the only stable equilibrium when $\beta < \beta_S^{\{F\}-\{L_1L_2\}^m}$;

(iii) $\{LL\}^m$ is the only stable equilibrium when $\beta > \beta_S^{\{F\}-\{L_1L_2\}^m}$.

Figure 2.1 illustrates Propositions 7 and 8.

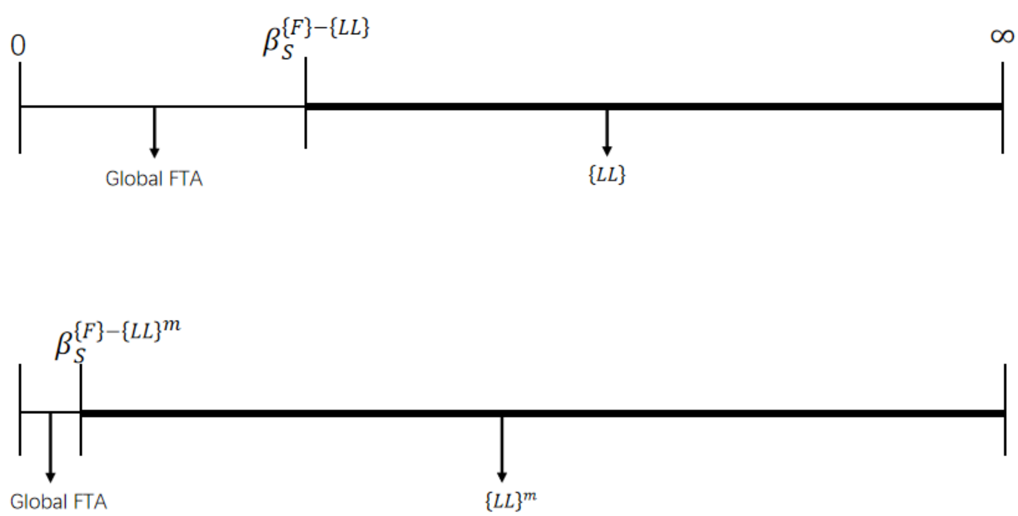

Figure 2.1: Propositions 7 and 8 (two highly-productive Countries)

Combining propositions 7 and 8, the parameter space of global FTA being stable under multilateralism is considerably smaller than that under bilateralism. Since multilateralism bans the discriminatory policy, non-member country under multilateralism is levied by a same tariff as the member country is. As a result, the non-member is more tolerable to be an outsider under a non-discriminatory environment. As shown in Lemma 4, under multilateralism the unique low-productive country only wants to join global FTA when the asymmetry degree is almost vanishing.

Since the unique low-productive country has two trading partners which have larger exporting volumes, it will not insist on joining FTA as it does under the two-country model in chapter 1 in which it trades with only one larger-exporting partner.

The underlying intuitions follow what we explain in the comparative static in chapter 1. We combine the effects on benefits and costs. We show that the following inequality holds:

$$\overbrace{\left|\frac{d^2\left(CS_S\right)}{d\left(t_L\right)d\left(\beta_L\right)}\right| + \left|\frac{d^2\left(TR_S\right)}{d\left(t_S\right)d\left(\beta_L\right)}\right|}^{Benefits} - \overbrace{\left|\frac{d^2\left(CS_S\right)}{d\left(t_S\right)d\left(\beta_L\right)}\right| - \left|\frac{d^2\left(PS_S\right)}{d\left(t_L\right)d\left(\beta_L\right)}\right|}^{Costs} > 0 \iff \beta_L > \text{a threshold}$$

Therefore, a higher productivity asymmetry degree grows the benefits of the unique low-productive country from being a non-member faster than the costs of the unique low-productive country from being a non-member.

We generalize the asymmetry condition as $\beta_a = \beta_b > \beta_c > 0$, based on which we run a simulation. Figure 2.2 illustrates the simulation result under bilateralism.

2.3.3 Equilibrium when there is only one highly-productive country

We assume that there exist one unique highly-productive country and two identically low-productive countries (i.e. $\beta_a > \beta_b = \beta_c = 0$). We thus can prove the following Lemma:

Lemma 5. *If $\beta_a = \beta > 0$ and $\beta_b = \beta_c = 0$ (i.e. country a is the unique country L and countries b and c are country S), under bilateralism the following inequalities*

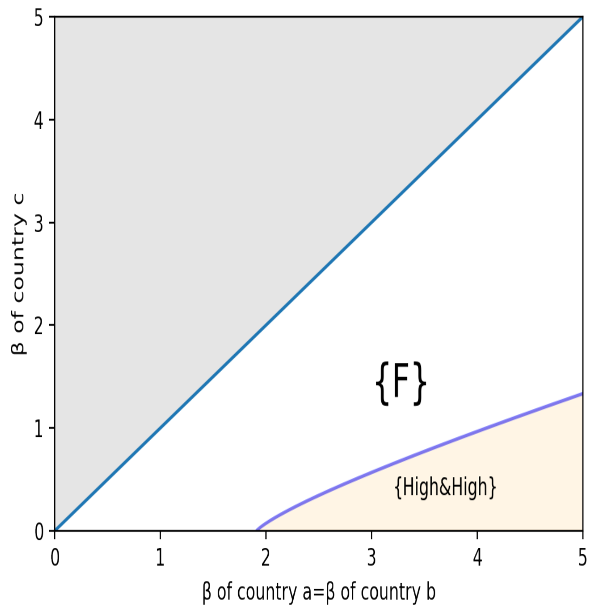

Figure 2.2: Simulation (two highly-productive countries)

hold:

$$\triangle W_S^{\{F\}-\{LS\}} > 0 \iff \beta < \beta_S^{\{F\}-\{LS\}} \approx 0.89 \tag{2.5}$$

$$\triangle W_L^{\{F\}-\{LS\}} > 0 \iff \beta < \beta_L^{\{F\}-\{LS\}} \approx 8.73 \tag{2.6}$$

$$\triangle W_S^{\{F\}-\{Lh\}} > 0, \triangle W_{S_1}^{\{F\}-\{S_2h\}} > 0, \triangle W_{S_1}^{\{F\}-\{LS_2\}} > 0 \ for\ any\ \beta \tag{2.7}$$

$$\triangle W_L^{\{F\}-\{Sh\}} > 0 \iff \beta < \beta_L^{\{F\}-\{Sh\}} \approx 6.75 \tag{2.8}$$

$$\triangle W_S^{\{F\}-\{SS\}} > 0 \ for\ any\ \beta$$

$$\triangle W_L^{\{F\}-\{SS\}} > 0 \iff \beta < \beta_L^{\{F\}-\{SS\}} \approx 1.81$$

$$W_L^{\{LS\}} - W_L^{\{SS\}} > 0 \iff \beta < \beta_L^{\{LS\}-\{SS\}} \approx 0.04 \tag{2.9}$$

Proof. See Appendix □

Lemma 5 is a re-statement of Lemma 2. We have the following proposition 9 which is a re-statement of proposition 5.

Proposition 9. *If $\beta_a = \beta > 0$, $\beta_b = \beta_c = 0$ and bilateralism is available, there exist a threshold $\beta_L^{\{F\}-\{SS\}}$ such that*

(i) The unique highly-productive country prefers regime $\{F\}$ to any other regimes if and only if $\beta < \beta_L^{\{F\}-\{SS\}}$;

(ii) $\{F\}$ is the only stable equilibrium when $\beta < \beta_L^{\{F\}-\{SS\}}$;

(iii) $\{SS\}$ is the only stable equilibrium when $\beta > \beta_L^{\{F\}-\{SS\}}$.

We then derive the stable equilibrium when bilateralism is prohibited. We prove the following Lemma:

Lemma 6. *If $\beta_a = \beta > 0$ and $\beta_b = \beta_c = 0$, under multilateralism the following inequalities hold:*

$$\triangle W_{S_1}^{\{F\}-\{LS_2\}^m} > 0, \triangle W_S^{\{F\}-\{LS\}^m} > 0, \triangle W_S^{\{SS\}^m-\{\Phi\}} > 0 \text{ for any } \beta$$

$$\triangle W_L^{\{F\}-\{SS\}^m} > 0 \iff \beta < \beta_L^{\{F\}-\{SS\}^m} \approx 2.32$$

Based on Lemma 6, both two low-productive countries like neither being a non-member nor pushing the other low-productive country out. Thus we have the following proposition:

Proposition 10. *If $\beta_a = \beta > 0$, $\beta_b = \beta_c = 0$ and bilateralism is not available, there exist a threshold $\beta_L^{\{F\}-\{SS\}^m}$ such that*

(i) The unique highly-productive country prefers regime $\{F\}$ to any other regimes if and only if $\beta < \beta_L^{\{F\}-\{SS\}^m}$;

(ii) $\{F\}$ is the only stable equilibrium when $\beta < \beta_L^{\{F\}-\{SS\}^m}$;

(iii) $\{SS\}^m$ is the only stable equilibrium when $\beta > \beta_L^{\{F\}-\{SS\}^m}$.

Figure 2.3 illstrates Propositions 9 and 10.

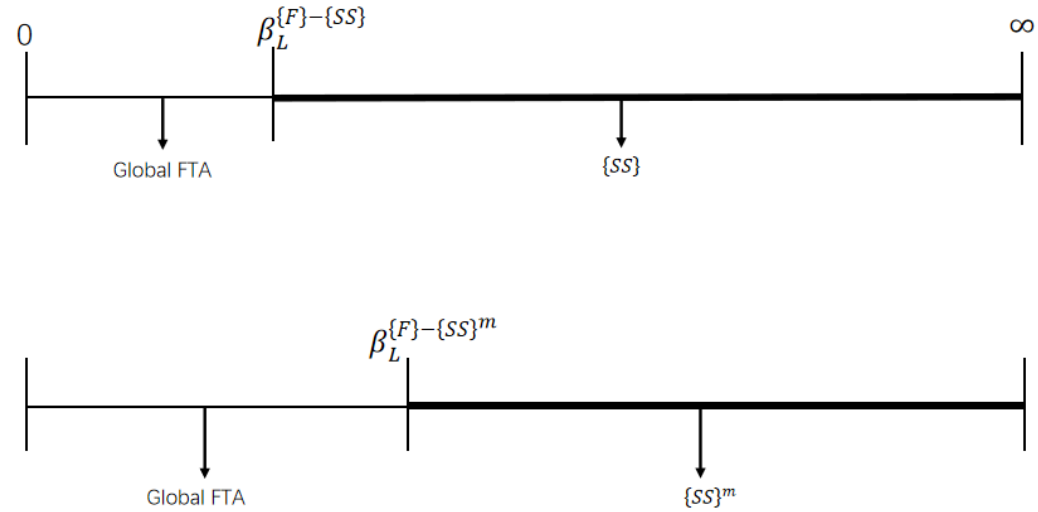

Figure 2.3: Proposition 9 and 10 (One Unique highly-productive Country)

We follow the general results of comparative static in chapter 1 section 1.5.3 and show that a larger productivity asymmetry degree (i.e. a lower β_S) reduces both the benefits and costs. We show the combined effect as follows:

$$\left(\overbrace{\left|\frac{d^2\left(CS_L\right)}{d\left(t_L\right)d\left(\beta_S\right)}\right|+\left|\frac{d^2\left(PS_L\right)}{d\left(t_S\right)d\left(\beta_S\right)}\right|}^{Costs}\right)-\left(\overbrace{\left|\frac{d^2\left(CS_L\right)}{d\left(t_S\right)d\left(\beta_S\right)}\right|+\left|\frac{d^2\left(TR_L\right)}{d\left(t_L\right)d\left(\beta_S\right)}\right|}^{Benefits}\right)>0 \iff \beta_S < \text{a threshold} \tag{2.10}$$

The inequality 2.10 is in line with the result of comparative static in the two-country model in chapter 1. If the productivity asymmetry level is too large, the costs decrease at a faster pace than the benefits.

Figure 2.4 illustrates the simulation results based on the generalization of $\beta_a > \beta_b = \beta_c > 0$ under bilateralism.

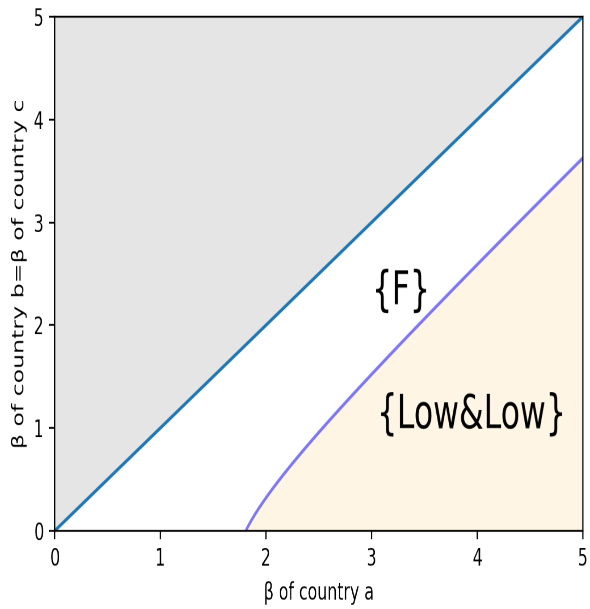

Figure 2.4: Simulation (One highly-productive Country)

2.4 Conclusion

In chapter 2, we study the role of bilateralism in affecting the formation of global free trade. We show that global free trade is the only equilibrium in the case of symmetric productivity no matter if bilateralism is prohibited, or not. However, in the case of asymmetric productivity, the consent of bilateralism can either help or hinder the formation of global free trade. We study two special cases: (i) one highly-productive country and two low-productive countries and (ii) two highly-productive countries and one low-productive country. We find that in the case of two highly-productive countries and one low-productive country, the consent of bilateralism can help the formation of global free trade; but in the case of one highly-productive country and two low-productive countries, the consent of bilateralism can prevent the formation of global free trade. The role of productivity asymmetry suggests: (i) a sufficiently large productivity asymmetry degree will break the formation of a global free trade;

(ii) a trade agreement between two similarly-productive countries will form with a sufficiently large productivity asymmetry degree.

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Chapter 3

Productivity Asymmetry and Trade Liberalization: The Case of Customs Unions

3.1 Introduction

A customs union (CU) serves as an international trade agreement under which free trade that eliminates external tariffs is granted for member countries, but not for non-member countries. To WTO members, a customs union is one of the overwhelming preferential trade agreements (PTA) that permit countries to grant trade liberalization to their member trading partner countries that they can simultaneously retain a trade barrier to their non-member partners. Another mainstream PTA is the bilateral free trade agreement (FTA) that also eliminates external tariffs among member countries. CU, however, functions differently with bilateral FTA under which member countries independently determine their optimal tariffs imposed on non-members, whereas under CU member countries must jointly determine the optimal external tariffs from the perspective of the aggregate welfare of all members. CU has been less prevalent than bilateral FTA, but the importance of CU never declines. The WTO database demonstrates that 118 countries accompany with at least one CU according to Ovádek and Willemyns (2019). Specifically, CUs have played important roles in affecting the trade regimes of European Union countries and Latin America. However, researchers have understudied CUs. This paper aims to remedy this rift and earn a better access to fully comprehend the intuitions behind CUs' effects on global trading market.

In this chapter, we study the role played by productivity heterogeneity across countries in affecting the formations of customs unions and global free trade. Studying the three-country equilibrium analysis in our chapter 2, we start with the speculation: when customs unions replace bilateral FTA, global FTA only forms when the productivity asymmetry degree is sufficiently small.

We use the same three-country model as in chapter 1. We consider three trading regimes when customs union is the only possible PTA: (i) customs union (i.e. two countries sign a CU agreement and impose a discriminatory tariff on the other nonmember country); (ii) global free trade agreement (i.e. all three countries sign free trade with each other); (iii) status quo (i.e. no country communicates with others).

Under multilateralism (i.e. banning PTAs that impose discriminatory tariffs), we have three trade regimes: (i) multilateral trade agreement with non-discriminatory tariff (i.e. two countries sign a trade agreement that chooses an optimal tariff that is also imposed on the non-member country); (ii) global free trade agreement (i.e. all three countries sign FTA with each other); (iii) status quo (i.e. no country communicates with others).

Our equilibrium analysis follows from the concept of coalition proof Nash equilibrium.

The main objective of our analysis is to study how the role of CU affects the formation of global free trade under a condition of different productivity across countries. We start with the special case of symmetric productivity (i.e. all countries have the same productivity), and we find that global free trade is the only equilibrium no matter CU is permitted or not. This finding generalizes the conclusion of Saggi, Woodland, and Yildiz (2013) in which they show the stable formation of global free trade under symmetric endowment.

We then investigate how different degrees of productivity heterogeneity can affect the change of equilibrium. We consider two special cases as we do in chapter 1: (i) two identically highly-productive countries and one unique low-productive country and (ii) one unique highly-productive country and two identically low-productive countries. We find that when the degree of productivity heterogeneity is sufficiently large, in equilibrium only the two similarly-productive countries will form (i) a CU when discriminatory policy is approved and (ii) a multilateral agreement when discriminatory policy is prohibited.

We find that the consent of CU under different trading environments can affect the formation of global FTA similarly. In the case of two highly-productive countries and one low-productive country, regardless of the productivity heterogeneity, the consent of CU supports the formation of global FTA. Also, in the case of one unique highly-productive country and two low-productive countries, the consent of CU still supports the formation of global free trade.

We also find that as the productivity asymmetry rises above a sufficiently large level, global free trade will fail to form no matter CU is possible or not. The intuitions are in line with that in chapter 1. As in the case of two highly-productive countries and one unique low-productive country, a larger productivity asymmetry level will increase both the benefits and costs from being a non-member by the unique low-productive country. A larger productivity asymmetry degree grows the benefits of the unique low-productive country from being a non-member faster than the costs of the unique low-productive country from being a non-member. Therefore the unique low-productive country will opt out from FTA when the productivity asymmetry level is too large.

As in the case of one unique highly-productive country and two low-productive countries, a larger productivity asymmetry level will decrease both the benefits and costs from being a non-member by the unique highly-productive country. A larger productivity asymmetry degree reduces the costs faster than the benefits. Therefore the unique highly-productive country will opt out from FTA when the productivity asymmetry level is too large.

The chapter proceeds as follows. Section 3.2 describe the literature review. Section 3.3 presents the equilibrium analysis when only CU is the available PTA. Section 3.4 presents the equilibrium analysis when both bilateral FTA and CU are available. Section 3.5 concludes chapter 3.

3.2 Literature Review

A few works focus on the study of the economic effects from customs union formation. Akdi and Erdil (2019) find that CU has an impact in EU-Turkey trade relations with regard to periodicity. Hantzsche and Young (2019) estimate the economic effects of Brexit on UK which instead forms a customs union with EU and they find that leaving the EU to join such a customs union would result in the UK economy being around 3 per cent smaller than it would have been had the UK stayed in the EU. Aromolaran and Olebogeng (2021) find that in the Southern African Customs Union the major capital flow components of foreign portfolio investment and foreign direct investment respectively generate a unidirectional causality in respect of GDP per capita with causation running from the respective capital flow components.

Our study is mostly related to Saggi, Woodland, and Yildiz (2013). To isolate the effect of CUs, they allow asymmetric endowment levels, and thus their main contribution affirms the necessity of CUs that can nudge small countries (i.e. countries with lower endowments) to sign FTA with large countries. Under our model that adds the heterogeneity in supply curve and allows asymmetry in productivity, one of our findings is consistent with their finding that CUs are necessary to help achieve global FTA. We, however, differ with them in terms of that we add production into the model.

One result in this chapter is in contrast with that in chapter 2 which studies the role of bilateralism instead of CU. Under the trading environment in which there is only one low-productive country, in chapter 2 we find that the consent of bilateralism can prevent the formation of global free trade. However, in this chapter we find that the consent of CU instead of bilateral FTA will always help achieve the formation of global free trade.

3.3 Equilibrium analysis

In this section, we will study the role played by CU and multilateralism that could affect the formation of FTA under the conditions of asymmetric productivity in different trading environments.

In the three-country framework, there are 3 regimes when CU is approved: $\{\Phi\}, \{F\}, \{ij\}^u$ for $i \in \{a, b, c\}$, $j \in \{a, b, c\}$, $j \neq i$. If all countries announce no trade agreements, then a status quo forms, denoted as $\{\Phi\}$. If two countries, say i and j, form a custom union without involving the other country k for $k \in \{a, b, c\}$, $k \neq j \neq i$, we denote this CU as $\{ij\}^u$. If all three countries sign agreements with each other, a global free trade regime $\{F\}$ forms.

However, under multilateralism (i.e. when CU is banned), there are 3 regimes: $\{\Phi\}, \{F\}, \{ij\}^m$. The two regimes $\{\Phi\}$ and $\{F\}$ are same with those under the consent of CU. In the regime $\{ij\}^m$ in which all countries are prohibitted to impose discriminatory tariff, country i and country j will jointly maximize their welfares with an optimal tariff that will be also imposed on the non-member country k.

We denote $t^{\{r\}}$ as the tariff under the regime $\{r\}$.

Definition 4. In the global free trade regime, denoted by $\{F\}$, the tariffs are such that:

$$t_{ij}^{\{F\}} = 0 \text{ for } i \in \{a, b, c\}, j \in \{a, b, c\}, j \neq i$$

In the custom union $\{ij\}^u$ the tariffs are such that:

$$t_{ij}^{\{ij\}^u} = t_{ji}^{\{ij\}^u} = 0$$

$$t_{ik}^{\{ij\}^u} = \underset{t_{ik}}{Argmax} \left\{ W_i^{\{ij\}^u} + W_j^{\{ij\}^u} \right\}$$

In the status quo regime $\{\Phi\}$, the tariffs are such that:

$$t_i^{\{\Phi\}} = \underset{t_i}{Argmax} \left\{ W_i^{\{\Phi\}} \right\} = \underset{t_i}{Argmax} \left\{ CS_i^{\{\Phi\}} + PS_i^{\{\Phi\}} + TR_i^{\{\Phi\}} \right\}$$
$$s.t.\ t_{ij}^{\{\Phi\}} = t_{ik}^{\{\Phi\}} = t_i^{\{\Phi\}}$$

In the multilateral agreement $\{ij\}^m$, the tariffs are such that:

$$t_i^{\{ij\}^m} = \underset{t_i}{Argmax} \left(W_i^{\{ij\}^m} + W_j^{\{ij\}^m} \right)$$
$$s.t.\ t_{ij} = t_{ik} = t_i$$

Then based on the optimal tariffs, we next compare the welfare difference between each regime.

We denote $W_i^{\{r\}}$ as the welfare of country i under the regime $\{r\}$, and $\triangle W_i^{\{r\}-\{s\}} = W_i^{\{r\}} - W_i^{\{s\}}$ as the welfare difference between regime $\{r\}$ and $\{s\}$. If $W_i^{\{r\}-\{s\}} = 0$, we conclude that country i is indifferent between $\{r\}$ and $\{s\}$; if $\triangle W_i^{\{r\}-\{s\}} > 0$, we conclude that country i prefers $\{r\}$ to $\{s\}$.

3.3.1 Equilibrium when all three countries are identical

Proposition 11 concludes our first result based on the condition of symmetry:

Proposition 11. *If $\beta_a = \beta_b = \beta_c$ and $e_a = e_b = e_c$, global FTA is the only stable equilibrium no matter custom unions are approved or not.*

Proposition 11 is in line with the conventional intuition: under the condition of symmetry (i.e. $\beta_a = \beta_b = \beta_c$ and $e_a = e_b = e_c$) the world welfare gains will be spread equally into each country. As countries are announcing their strategies simultaneously, no one has an incentive to deviate for the FTA that brings considerably more consumer and producer surplus than opting out. As a result, the final regime will be global FTA that will reach a Pareto optimal outcome.

Proposition motivates a question: is global FTA still uniquely stable under a condition of asymmetry? We then will solve for the equilibrium regimes under the condition of asymmetry from the perspective of productivity. It is noteworthy that we want to isolate the effects solely from the productivity heterogeneity. Therefore, henceforth we will assume that countries have identical endowment by assuming $e_i = 1$ for all i.

In our set-up for an asymmetric three-country trading, we define two similarly productive countries and one distinctive country. We firstly study the case that there exist two identically highly-productive countries and one unique low-productive country. Secondly we study the case that there exist two identically low-productive countries and one unique highly-productive country.

3.3.2 Equilibrium when there are two highly-productive countries

To avoid confusion, henceforth we denote the low-productive country as S (i.e. the country with a smaller level of supply for the differentiated goods). We denote the highly-productive country as L (i.e. the country with a larger level of supply).

We assume that there are two identical countries with a positive productivity and one country without any productivity. Therefore, we have two highly-productive countries and one low-productive country. We denote the two highly-productive countries as L_1 and L_2. It is noteworthy that L_1 is identical to L_2. Henceforth, if L_1 signs a CU with L_2, the regime is denoted as $\{L_1L_2\}^u = \{LL\}^u$.

We then prove the following Lemma:

Lemma 7. *If $\beta_a = \beta_b = \beta > 0$ and $\beta_c = 0$ (i.e. countries a and b are country L, country c is country S), when CU is available the following inequalities hold:*

$$\triangle W_S^{\{F\}-\{L_1L_2\}^u} > 0 \iff \beta < \beta_S^{\{F\}-\{L_1L_2\}^u} \approx 4.53 \tag{3.1}$$

$$\triangle W_{L_1}^{\{F\}-\{L_1L_2\}^u} > 0, \triangle W_{L_1}^{\{L_1L_2\}^u-\{\Phi\}} > 0, \triangle W_{L_1}^{\{F\}-\{L_2S\}^u} > 0 \; \textit{for any } \beta \tag{3.2}$$

Proof. See Appendix □

We denote as $\beta_S^{\{F\}-\{L_1L_2\}^u}$ the cut-off point that makes country S be indifferent between regime $\{F\}$ and regime $\{LL\}^u$.

Firstly we see that Lemma 7 ascertains that the highly-productive country never wants to be a non-member based on the inequality $\triangle W_{L_1}^{\{F\}-\{L_2S\}^u} > 0$. Secondly, we see that both two highly-productive countries do not have an incentive to deviate from global FTA. Highly-productive countries have a larger volume of exports and a smaller volume of imports, thus benefit more from tariff reductions granted by others. Similarly, such countries have relatively less to lose from eliminating their own optimal tariffs since these tariffs apply to relatively larger import volumes.

Therefore, the equilibrium is dependent on the unique low-productive country's deviation for global FTA. Based on the inequality 3.1, the unique low-productive country would like to be an outsider when the asymmetry degree in productivity is too large. To the unique low-productive country which has to trade with two larger exporters, the larger the asymmetry degree in exporting volumes, the larger the increase in its export deficit from the elimination of its partners' tariff and the more the loss due to its own trade liberalization since the tariff reduction applies to a larger volume of imports (due to the larger export level of its partners).

We thus have the following proposition:

Proposition 12. *If $\beta_a = \beta_b = \beta > 0$, $\beta_c = 0$ and customs unions are available, there exist a threshold of β such that*

(i) The unique low-productive country prefers regime $\{F\}$ to any other regimes if and only if $\beta < \beta_S^{\{F\}-\{LL\}^u}$;

(ii) $\{F\}$ is the only stable equilibrium when $\beta < \beta_S^{\{F\}-\{LL\}^u}$;

(iii) $\{LL\}^u$ is the only stable equilibrium when $\beta > \beta_S^{\{F\}-\{LL\}^u}$.

We then will discuss the formation of the final regime under multilateralism (i.e. when customs unions are prohibited). Since under multilateralism countries are not permitted to impose discriminatory tariffs on the non-member country, we speculate that global FTA will be less likely to form. We then prove the following lemma:

Lemma 8. *If $\beta_a = \beta_b = \beta > 0$ and $\beta_c = 0$, under multilateralism the following inequalities hold:*

$$\triangle W_S^{\{F\}-\{L_1L_2\}^m} > 0 \iff \beta < \beta_S^{\{F\}-\{L_1L_2\}^m} \approx 0.12 \tag{3.3}$$

$$\triangle W_{L_1}^{\{F\}-\{L_1L_2\}^m} > 0, \triangle W_{L_1}^{\{L_1L_2\}^m-\{\Phi\}} > 0, \triangle W_{L_1}^{\{F\}-\{L_2S\}^m} > 0 \text{ for any } \beta$$

Proof. See Appendix □

Based on Lemma 8, still the two highly-productive countries have no incentives to deviate from global FTA. The intuition is analogous to that underlies under Lemma 7. With Lemma 8, we have the following proposition:

Proposition 13. *If $\beta_a = \beta_b = \beta > 0$, $\beta_c = 0$ and customs unions are not available, there exist a threshold of β such that*

(i) The unique low-productive country prefers regime $\{F\}$ to any other regimes if and only if $\beta < \beta_S^{\{F\}-\{L_1L_2\}^m}$;

(ii) $\{F\}$ is the only stable equilibrium when $\beta < \beta_S^{\{F\}-\{L_1L_2\}^m}$;

(iii) $\{LL\}^m$ is the only stable equilibrium when $\beta > \beta_S^{\{F\}-\{L_1L_2\}^m}$.

Figure 3.1 illustrates Propositions 12 and 13.

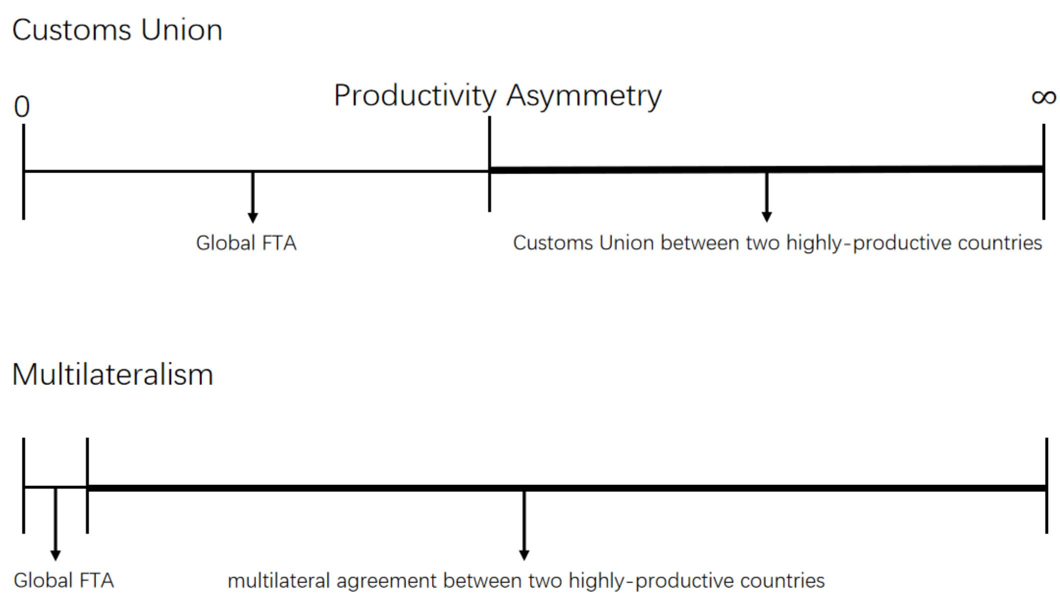

Figure 3.1: Propositions 12 and 13 (two highly-productive Countries)

Combining propositions 12 and 13, the parameter space of global FTA being stable under multilateralism is considerably smaller than that under CUs. Since multilateralism bans the discriminatory policy, the non-member country under multilateralism is levied by a same tariff as the member country is. As a result, the non-member is more tolerable to be an outsider under a non-discriminatory environment. As shown in Lemma 8, under multilateralism the unique low-productive country only wants to join global FTA when the asymmetry degree is almost vanishing.

To further understand the underlying insight, we show the results of comparative static.

Firstly, one obvious benefit from being a non-member by the unique low-productive country is the tariff revenue gains:

$$\frac{dTR_S}{dt_S} > 0,$$

where t_S is the tariff imposed by country S.

Secondly, a higher external tariff leads to a higher consumer surplus of country S:

$$\frac{dCS_S}{dt_L} > 0,$$

where t_L is the external tariff imposed by country L. This second benefit is because of the lower local prices (i.e. $\frac{d(p_{cA})}{d\left(t_{L_1}\right)} < 0$ and $\frac{d(p_{cB})}{d\left(t_{L_2}\right)} < 0$, country c is country S). It is noteworthy that there are two external tariffs $t_{L_1}$and t_{L_2}, and they play the same role here. We therefore use t_L as a general notation that represents both two external tariffs.

The first cost from being a non-member by country S is that:

$$\frac{d\left(CS_S\right)}{d\left(t_S\right)} < 0,$$

the unique country S imposes its own tariffs t_S that are harmful to its consumers (i.e.

$\frac{d(CS_S)}{d(t_S)} < 0$) due to the adverse price response ($\frac{d(P_{cC})}{d(t_S)} > 0$).

The second cost is:

$$\frac{d\left(PS_S\right)}{d\left(t_L\right)} < 0,$$

a higher external tariff t_L is causing PS_S to decrease because of the price response (i.e. $\frac{d(p_{cA})}{d\left(t_{L_1}\right)} < 0$ and $\frac{d(p_{cB})}{d\left(t_{L_2}\right)} < 0$ so that $\frac{d(PS_S)}{d(t_L)} < 0$).

We then show the effects of a larger productivity asymmetry degree on the benefits and costs:

$$\frac{d^2\left(TR_S\right)}{d\left(t_S\right)d\left(\beta_L\right)} > 0; \frac{d^2\left(CS_S\right)}{d\left(t_L\right)d\left(\beta_L\right)} > 0.$$

$$\frac{d^2\left(CS_S\right)}{d\left(t_S\right)d\left(\beta_L\right)} < 0; \frac{d^2\left(PS_S\right)}{d\left(t_L\right)d\left(\beta_L\right)} < 0.$$

Therefore a larger productivity asymmetry level (i.e. a larger β_L) will increase both the benefits and costs.

We then combine the effects on benefits and costs. We show that the following inequality holds:

$$\overbrace{\left|\frac{d^2\left(CS_S\right)}{d\left(t_L\right)d\left(\beta_L\right)}\right| + \left|\frac{d^2\left(TR_S\right)}{d\left(t_S\right)d\left(\beta_L\right)}\right|}^{Benefits} - \overbrace{\left|\frac{d^2\left(CS_S\right)}{d\left(t_S\right)d\left(\beta_L\right)}\right| - \left|\frac{d^2\left(PS_S\right)}{d\left(t_L\right)d\left(\beta_L\right)}\right|}^{Costs} > 0 \iff \beta_L > \text{a threshold}$$

Therefore, a higher productivity asymmetry degree grows the benefits of the unique low-productive country from being a non-member faster than the costs of the unique low-productive country from being a non-member.

We generalize the condition of asymmetry to be $\beta_a = \beta_b > \beta_c > 0$, based on which we run a simulation. Figure 3.2 illustrates the simulation result under CU.

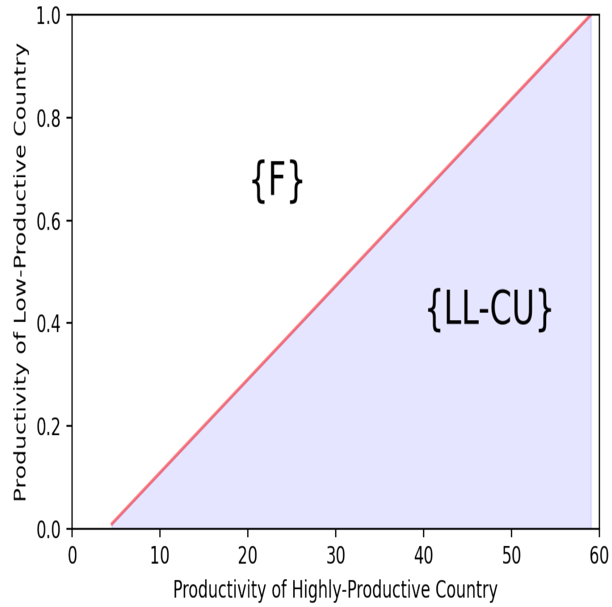

Figure 3.2: Simulation (two highly-productive countries)

3.3.3 If there is only one highly-productive country

We assume that there exist one unique highly-productive country and two identically low-productive countries (i.e. $\beta_a > \beta_b = \beta_c = 0$). We thus can prove the following Lemma:

Lemma 9. *If $\beta_a = \beta > 0$, $\beta_b = \beta_c = 0$ and CUs are approved, the following inequalities hold:*

$$\triangle W_S^{\{F\}-\{LS\}^u} > 0 \iff \beta < \beta_S^{\{F\}-\{LS\}^u} \approx 0.186831 \tag{3.4}$$

$$\triangle W_L^{\{F\}-\{LS\}^u} > 0 \; for \; any \; \beta \tag{3.5}$$

$$\triangle W_{S_1}^{\{F\}-\{LS_2\}^u} > 0 \; for \; any \; \beta \tag{3.6}$$

$$\triangle W_S^{\{F\}-\{SS\}^u} > 0 \; for \; any \; \beta$$

$$\triangle W_L^{\{F\}-\{SS\}^u} > 0 \iff \beta < \beta_L^{\{F\}-\{SS\}^u} \approx 6.175$$

Proof. See Appendix □

The CU is stable when two countries simultaneously intend to push the third country out, or one country prefers to be a non-member by itself. The inequality 3.5 says that the unique highly-productive country prefers $\{F\}$ to $\{LS\}^u$ all the time. Together with the inequality 3.6, $\{LS\}^u$ will never be stable.

We see that another form of CU $\{SS\}^u$ will be stable when $\beta > \beta_L^{\{F\}-\{SS\}^u}$, in which the highly-productive country will opt out from global FTA. We thus can conclude the following proposition:

Proposition 14. *If $\beta_a = \beta > 0$, $\beta_b = \beta_c = 0$ and CUs are approved, there exist a threshold of β such that*

(i) The unique highly-productive country prefers regime $\{F\}$ to any other regimes if and only if $\beta < \beta_L^{\{F\}-\{SS\}^u}$;

(ii) $\{F\}$ is the only stable equilibrium when $\beta < \beta_L^{\{F\}-\{SS\}^u}$;

(iii) $\{SS\}^u$ is the only stable equilibrium when $\beta > \beta_L^{\{F\}-\{SS\}^u}$.

Before we discuss the intuitions for Proposition 14, we derive the stable equilibrium when CUs are prohibited. We prove the following Lemma:

Lemma 10. *If $\beta_a = \beta > 0$ and $\beta_b = \beta_c = 0$, under multilateralism the following inequalities hold:*

$$\triangle W_{S_1}^{\{F\}-\{LS_2\}^m} > 0, \triangle W_S^{\{F\}-\{LS\}^m} > 0, \triangle W_S^{\{SS\}^m-\{\Phi\}} > 0 \text{ for any } \beta \tag{3.7}$$

$$\triangle W_L^{\{F\}-\{SS\}^m} > 0 \iff \beta < \beta_L^{\{F\}-\{SS\}^m} \approx 2.32 \tag{3.8}$$

Based on Lemma 10, both two low-productive countries like neither being a non-member nor pushing the other less-productive country out. Thus we have the following proposition:

Proposition 15. *If $\beta_a = \beta > 0$, $\beta_b = \beta_c = 0$ and CUs are not available, there exist a threshold of β such that*

(i) The unique highly-productive country prefers regime $\{F\}$ to any other regimes if and only if $\beta < \beta_L^{\{F\}-\{SS\}^m}$;

(ii) $\{F\}$ is the only stable equilibrium when $\beta < \beta_L^{\{F\}-\{SS\}^m}$;

(iii) $\{SS\}^m$ is the only stable equilibrium when $\beta > \beta_L^{\{F\}-\{SS\}^m}$.

Figure 3.3 illstrates Propositions 14 and 15.

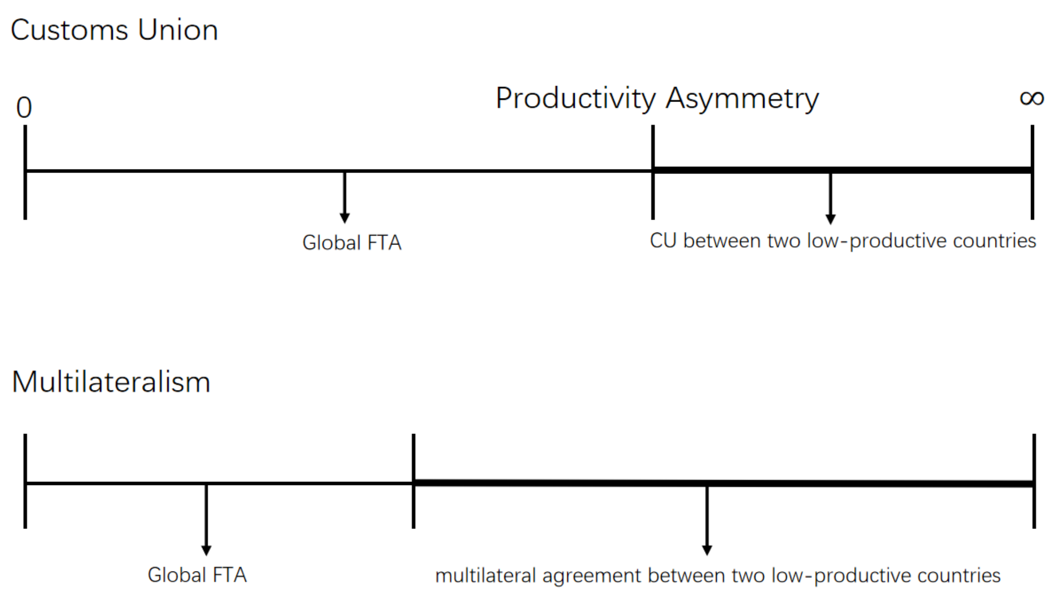

Figure 3.3: Propositions 14 and 15 (One highly-productive Country)

Propositions 14 and 15 are in contrast with chapter 2 that studies the role of another PTA which is bilateral FTA. In chapter 2 propositions 9 and 10 (shown in figure 2.3) show that the consent of bilateral FTA can prevent the formation of global free trade when there is only one highly-productive country. However, CU will always help form the global free trade no matter there is only one highly-productive country or there are two highly-productive countries.

We provide the results of comparative statics. Since the equilibrium hinges on the attitude from the unique highly-productive country towards being an outsider, we then study the effect of this unique country being a non-member on its welfare based on different levels of its productivity.

We show that: if the unique country L chooses to opt out from FTA, it will gain benefits including (i) a higher tariff revenue ($\frac{d(TR_L)}{d(t_L)} > 0$); (ii) a higher CS_L thanks to the higher external tariffs t_S ($\frac{d(CS_L)}{d(t_S)} > 0$).

The costs include: (i) $\frac{d(CS_L)}{d(t_L)} < 0$, a lower CS_L due to that country L's own tariffs t_L lead to an adverse price response; (ii) $\frac{d(PS_L)}{d(t_S)} < 0$, a lower PS_L due to the adverse price response from a higher external tariff.

To see how productivity asymmetry affects the benefits, we show the following inequalities:

$$\frac{d^2 (TR_L)}{d (t_L) \, d (\beta_S)} > 0 \tag{3.9}$$

$$\frac{d^2 (CS_L)}{d (t_S) \, d (\beta_S)} > 0 \tag{3.10}$$

To see how productivity asymmetry affects the costs, we show the following inequalities:

$$\frac{d^2 (CS_L)}{d (t_L) \, d (\beta_S)} < 0 \tag{3.11}$$

$$\frac{d^2 (PS_L)}{d (t_S) \, d (\beta_S)} < 0 \tag{3.12}$$

We show that a larger productivity asymmetry degree (i.e. a lower β_S) reduces both the benefits and costs. We then show the combined effect as follows:

$$\left(\overbrace{\left|\frac{d^2\left(CS_L\right)}{d\left(t_L\right)d\left(\beta_S\right)}\right| + \left|\frac{d^2\left(PS_L\right)}{d\left(t_S\right)d\left(\beta_S\right)}\right|}^{Costs}\right) - \left(\overbrace{\left|\frac{d^2\left(CS_L\right)}{d\left(t_S\right)d\left(\beta_S\right)}\right| + \left|\frac{d^2\left(TR_L\right)}{d\left(t_L\right)d\left(\beta_S\right)}\right|}^{Benefits}\right) > 0 \iff \beta_S < \text{a threshold} \tag{3.13}$$

The inequality 3.13 is in line with the result of comparative static in the two-country model in chapter 1. If the productivity asymmetry level is too large, the costs decrease at a faster pace than the benefits.

Figure 3.4 illustrates the simulation results based on the generalization of $\beta_a > \beta_b = \beta_c > 0$ under CU.

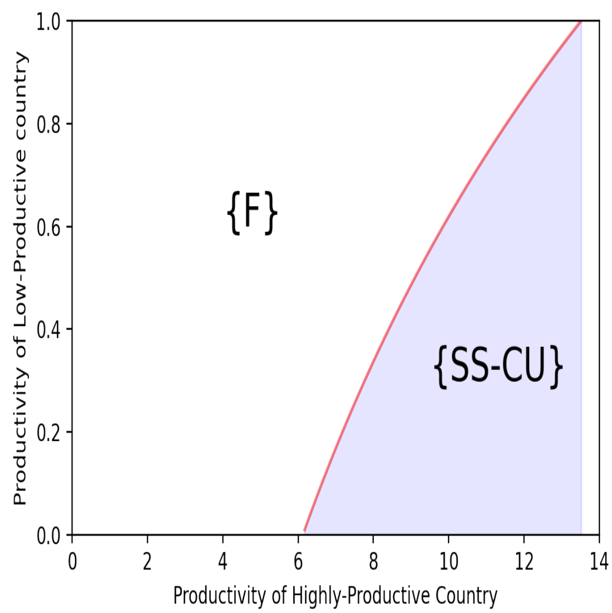

Figure 3.4: Simulation (One highly-productive Country)

3.4 Bilateral FTA

One question that deserves comments is: does the freedom to pursue bilateral FTA affect the formation of CU and global FTA? To anwser this question, we in this section allow countries to choose to form bilateral FTA or CU freely. Under a bilateral FTA, member countries independently choose their optimal external tariffs as follows:

$$t_{ik}^{\{ij\}} = \underset{t_{ik}}{Argmax} \left\{ W_i^{\{ij\}} \right\},$$
$$s.t.\ t_{ij} = 0$$

where $\{ij\}$ is a bilateral FTA under which countries i and j are member countries. Compared to the CU $\{ij\}^u$:

$$t_{ik}^{\{ij\}^u} = \underset{t_{ik}}{Argmax} \left\{ W_i^{\{ij\}^u} + W_j^{\{ij\}^u} \right\}.$$
$$s.t.\ t_{ij} = 0$$

We show the following:

$$t_{ik}^{\{ij\}^u} > t_{ik}^{\{ij\}} \tag{3.14}$$

The inequality 3.14 provides a natural speculation: if bilateral FTAs are available, CU will never be stable. According to chapter 2 that studys how bilateralism affects the formation of global FTA, the thresholds of asymmetry degree in productivity are much smaller than the corresponding thresholds in this chapter. To further indicate the findings, we still need to discuss under different trading environments.

3.4.1 Two Country L and One Country S

In this pattern, we have two identically highly-productive countries and one unique low-productive country. Therefore, if $\beta_a = \beta_b = \beta > \beta_c = 0$, we then prove the following two inequalities hold.

$$\triangle W_L^{\{LL\}-\{LL\}^u} > 0 \text{ for any } \beta$$

$$\triangle W_S^{\{F\}-\{LL\}} > 0 \iff \beta < \beta_S^{\{F\}-\{LL\}} \approx 1.91$$

Based on these two inequalities and together with Lemma 1 in chapter 1, we show the following propistion:

Proposition 16. *If $\beta_a = \beta_b = \beta > \beta_c = 0$ and CUs and bilateral FTAs are both available, there exist a threshold of β such that*

(i) $\{F\}$ is the only stable equilibrium when $\beta < \beta_S^{\{F\}-\{LL\}}$;

(ii) $\{LL\}$ is the only stable equilibrium when $\beta > \beta_S^{\{F\}-\{LL\}}$;

(iii) The consent of bilateral FTA makes global FTA be less likely to form.

Proposition 16 is an extension of Proposition 4 in chapter 1, which does not include CU as an alternative PTA. We further find that the CU can be a superior PTA in nudging the formation of global FTA.

3.4.2 Two Country S and One Country L

In the second trading pattern, we have two identically low-productive countries and one unique highly-productive country. If $\beta_a = \beta > \beta_b = \beta_c = 0$, we prove the following two inequalities hold:

$$\triangle W_S^{\{SS\}-\{SS\}^u} > 0 \text{ for any } \beta$$

$$\triangle W_L^{\{F\}-\{SS\}} > 0 \iff \beta < \beta_L^{\{F\}-\{SS\}} \approx 1.81$$

Based on these two inequalities and together with Lemma 2 in chapter 1, we have the following propistion:

Proposition 17. *If $\beta_a = \beta > \beta_b = \beta_c = 0$ and CUs and bilateral FTAs are both available, there exist a threshold of β such that*

(i) $\{F\}$ is the only stable equilibrium when $\beta < \beta_L^{\{F\}-\{SS\}}$;

(ii) $\{SS\}$ is the only stable equilibrium when $\beta > \beta_L^{\{F\}-\{SS\}}$;

(iii) The consent of bilateral FTA makes global FTA be less likely to form.

Proposition 17 is an extension of Proposition 5 in chapter 1, which does not include CU as an alternative PTA. We again find that the CU can be a superior PTA in nudging the formation of global FTA.

3.5 Conclusion

In chapter 3, we study the role played by a popular preferential trade agreement (PTA) which is custom unions in affecting the formation of global free trade. In our three-country model, we focus on how country-specific productivity affects the role of custom unions. Our main findings show that the consent of CUs can nudge the formation of global free trade no matter if there is only one highly-productive country, or there are two highly-productive countries.

Moreover, we study the case when both CUs and bilateral FTA are approved meantime. We find that the global free trade will be less likely to form because bilateral FTA will be always preferred to CUs.

Another finding in this chapter shows that a too large productivity asymmetry degree will trigger the failure of global free trade no matter if CUs are available, or not.

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APPENDICES

APPENDIX A: Chapter 1

Proof of Proposition 2:

Proof. Under two-country model, we have:

$$W_a = \overbrace{\frac{1}{2}(1-p_{aA})^2 + \frac{1}{2}(1-p_{aB})^2}^{CS_a} + \overbrace{e_a p_{aB} + \frac{\beta_a}{2}(p_{aB})^2}^{PS_a} + \overbrace{t_a \overbrace{(e_b - 1 + (1+\beta_b)\, p_{bA})}^{x_{bA}}}^{TR_a}$$

$p_{bA} = \frac{1-t_a}{(\beta_b+2)}$, $p_{aA} = \frac{1+(\beta_b+1)t_a}{(\beta_b+2)}$

$p_{bB} = \frac{1+(\beta_a+1)t_b}{(\beta_a+2)}$, $p_{aB} = \frac{1-t_b}{(\beta_a+2)}$

$t_a^{\{\Phi\}} = \frac{1}{(3+\beta_b)}$, $t_b^{\{\Phi\}} = \frac{1}{(3+\beta_a)}$

$$W_a^{\{F\}-\{\Phi\}} = \frac{1}{(\beta_a+2)^2} t_b \left(1 + \beta_a - \left(\frac{1}{2} + \frac{\beta_a}{2}\right) t_b\right) + \frac{1}{(2)^2} t_a \left(-1 + \frac{3}{2} t_a\right)$$

$$W_b^{\{F\}-\{\Phi\}} = \frac{1}{(2)^2} t_a \left(1 - \frac{1}{2} t_a\right) + \frac{1}{(\beta_a+2)^2} t_b \left(-\beta_a - 1 + \frac{(\beta_a+3)(1+\beta_a)}{2} t_b\right)$$

$\square$

Proof of the results of comparative static in the two-country model:

Proof. $\frac{dW_a}{dt_a} = \overbrace{-\frac{(\beta_b+1)^2}{(\beta_b+2)^2}(1-t_a)}^{\frac{dCS_a}{dt_a}<0} + \overbrace{\frac{(1+\beta_b)(1-2t_a)}{(\beta_b+2)}}^{\frac{dTR_a}{dt_a}} + \overbrace{0}^{\frac{dPS_a}{dt_a}=0}$

Note that $t_a^{\{\Phi\}} = \frac{1}{(3+\beta_b)}$ with assuming $e_a = e_b = 1$, thus $\frac{dTR_a}{dt_a} = \frac{(1+\beta_b)(1-2t_a)}{(\beta_b+2)} > 0$.

$$\frac{d^2W_a}{dt_a d\beta_b} = \left(\overbrace{-\frac{2(1-t_a)(\beta_b+1)}{(\beta_b+2)^3}}^{\frac{d^2CS_a}{dt_a d\beta_b}<0}\right) + \left(\overbrace{\frac{1-2t_a}{(\beta_b+2)^2}}^{\frac{d^2TR_a}{dt_a d\beta_b}}\right)$$

$$\frac{dW_a}{dt_b} = \left(\overbrace{\frac{t_b+\beta_a+1}{(\beta_a+2)^2}}^{\frac{dCS_a}{dt_b}>0}\right) + \left(\overbrace{\frac{-(2+2\beta_a-\beta_a t_b)}{(\beta_a+2)^2}}^{\frac{dPS_a}{dt_b}<0}\right) + \overbrace{0}^{\frac{dTR_a}{dt_b}=0}$$

$$\frac{d^2W_a}{dt_b d\beta_a} = \left(\overbrace{-\frac{\beta_a+2t_b}{(\beta_a+2)^3}}^{\frac{d^2CS_a}{dt_b d\beta_a}<0}\right) + \left(\overbrace{\frac{(2-t_b)\beta_a+2t_b}{(\beta_a+2)^3}}^{\frac{d^2PS_a}{dt_b d\beta_a}>0}\right) \qquad \square$$

Under Three-country Model we have:

$$e_a = e_b = e_c = 1$$

$$CS_a = \frac{(1-\frac{1+(1+\beta_b)t_{ab}+(1+\beta_c)t_{ac}}{3+\beta_b+\beta_c})^2}{2} + \frac{(1-\frac{1-(2+\beta_c)t_{ba}+(1+\beta_c)t_{bc}}{3+\beta_a+\beta_c})^2}{2} + \frac{(1-\frac{1-(2+\beta_b)t_{ca}+(1+\beta_b)t_{cb}}{3+\beta_a+\beta_b})^2}{2}$$

$$PS_a = \frac{1-(2+\beta_c)t_{ba}+(1+\beta_c)t_{bc}}{3+\beta_a+\beta_c} + \frac{\beta_a}{2}\left(\frac{1-(2+\beta_c)t_{ba}+(1+\beta_c)t_{bc}}{3+\beta_a+\beta_c}\right)^2$$

$$+\frac{1-(2+\beta_b)t_{ca}+(1+\beta_b)t_{cb}}{3+\beta_a+\beta_b} + \frac{\beta_a}{2}\left(\frac{1-(2+\beta_b)t_{ca}+(1+\beta_b)t_{cb}}{3+\beta_a+\beta_b}\right)^2$$

$$TR_a = t_{ab}\left((\beta_b+1)\frac{1-(2+\beta_c)t_{ab}+(1+\beta_c)t_{ac}}{3+\beta_b+\beta_c}\right) + t_{ac}\left((\beta_c+1)\frac{1+(1+\beta_b)t_{ab}-(2+\beta_b)t_{ac}}{3+\beta_b+\beta_c}\right)$$

Proof of Lemma 1:

Proof. All below equations can be solved by Newton method or Bisection method with one unique positive solution (note that country a and country b are country L and country c is country S):

$$\triangle W_c^{\{F\}-\{ab\}} = \triangle W_S^{\{F\}-\{LL\}} = \frac{(4\beta^3+27\beta^2+58\beta+40)(4+2\beta)(3+2\beta)^2-(4\beta^4+40\beta^3+144\beta^2+220\beta+121)(9+15\beta+7\beta^2+\beta^3)}{(2\beta^2+10\beta+11)^2(3+\beta)^2(4+2\beta)(3+2\beta)^2}$$

$$\triangle W_S^{\{F\}-\{LL\}} > 0 \iff \beta <\approx 1.91498008$$

$$\triangle W_c^{\{F\}-\{ah\}} = \triangle W_S^{\{F\}-\{Lh\}} = \frac{60\beta^7+764\beta^6+4088\beta^5+11944\beta^4+20626\beta^3+21112\beta^2+11907\beta+2871}{2(\beta+3)^2(2\beta+3)^2(2\beta^2+10\beta+11)^2(4\beta^2+13\beta+11)} > 0$$

$$\triangle W_a^{\{F\}-\{bh\}} = \triangle W_{L_1}^{\{F\}-\{L_2h\}} = \frac{\left(16\beta^8+274\beta^7+1948\beta^6+7663\beta^5+18395\beta^4+27673\beta^3+25480\beta^2+13104\beta+2871\right)}{2(\beta+3)^2(2\beta+3)^2(4\beta^2+13\beta+11)^2(2\beta^2+10\beta+11)} > 0$$

$$\triangle W_a^{\{F\}-\{ch\}} = \triangle W_{L_1}^{\{F\}-\{Sh\}} = \frac{(4+4\beta)(10+3\beta)(11+3\beta)(3+\beta)^2-(3+\beta)^2(11+3\beta)^2(1+\beta)}{2(3+\beta)^2(11+3\beta)^2(3+\beta)^2(11+3\beta)} > 0$$

$$\triangle W_a^{\{F\}-\{bc\}} = \frac{264\beta^9+4537\beta^8+30751\beta^7+126052\beta^6+358230\beta^5+726157\beta^4+3184\beta^7}{2\left(\beta+3\right)^2\left(\beta+4\right)\left(2\beta+3\right)^2\left(3\beta+11\right)^2\left(4\beta^2+13\beta+11\right)^2} + \frac{20696\beta^6+51143\beta^5+45106\beta^4+984933\beta^3+819102\beta^2+398343\beta+84942}{2\left(\beta+3\right)^2\left(\beta+4\right)\left(2\beta+3\right)^2\left(3\beta+11\right)^2\left(4\beta^2+13\beta+11\right)^2} > 0$$

□

Proposition 4 is self-enforcing based on Lemma 1.

Proof of the comparative static result in the case of $\{L, L, S\}$:

Proof. Here country c is the unique country S. t_{ca} and t_{cb} are own tariffs t_S. t_{bc} and t_{ac} are external tariffs t_L. $\beta_a = \beta_b = \beta_L$, $\beta_c = \beta_S$.

$$p_{cA} = p_{aA} - t_{ac} = \frac{1+(1+\beta_b)t_{ab}-(2+\beta_b)t_{ac}}{3+\beta_b+\beta_c}$$

$$p_{cB} = p_{bB} - t_{bc} = \frac{1+(1+\beta_a)t_{ba}-(2+\beta_a)t_{bc}}{3+\beta_a+\beta_c}$$

$$p_{cC} = \frac{1+(1+\beta_a)t_{ca}+(1+\beta_b)t_{cb}}{3+\beta_a+\beta_b}.$$

$$CS_c = \frac{1}{2}\left(1-p_{cA}\right)^2 + \frac{1}{2}\left(1-p_{cB}\right)^2 + \frac{1}{2}\left(1-p_{cC}\right)^2$$

$$CS_c = \frac{1}{2}\left(1-\frac{1+(1+\beta_b)t_{ab}-(2+\beta_b)t_{ac}}{3+\beta_b+\beta_c}\right)^2 + \frac{1}{2}\left(1-\frac{1+(1+\beta_a)t_{ba}-(2+\beta_a)t_{bc}}{3+\beta_a+\beta_c}\right)^2 + \frac{1}{2}\left(1-\frac{1+(1+\beta_a)t_{ca}+(1+\beta_b)t_{cb}}{3+\beta_a+\beta_b}\right)^2$$

$$\frac{dp_{cA}^2}{dt_{ab}d\beta_c} = -\frac{\beta_b+1}{\left(3+\beta_b+\beta_c\right)^2} < 0, \quad \frac{dp_{cA}^2}{dt_{ab}d\beta_b} = \frac{\beta_c+2}{\left(3+\beta_b+\beta_c\right)^2} > 0$$

$$\frac{dCS_c}{dt_{ab}} = -\frac{\left(\beta_b+1\right)\left(1-\frac{1+(1+\beta_b)t_{ab}-(2+\beta_b)t_{ac}}{3+\beta_b+\beta_c}\right)}{3+\beta_b+\beta_c} < 0$$

$$\frac{d^2CS_c}{dt_{ab}d\beta_c} = \frac{\left(\beta_b+1\right)\left(1+\beta_b+\beta_c+2\left(\beta_b+2\right)t_{ac}-2\left(\beta_b+1\right)t_{ab}\right)}{\left(3+\beta_b+\beta_c\right)^3}$$

$$\frac{d^2CS_c}{dt_{ab}d\beta_b} = -\frac{\left(\left(2\beta_c+3\right)t_{ac}-\left(2\beta_c+4\right)t_{ab}+\beta_c+3\right)\beta_b+\left(3\beta_c+5\right)t_{ac}-\left(2\beta_c+4\right)t_{ab}+\beta_c^2+4\beta_c+5}{\left(3+\beta_b+\beta_c\right)^3}$$

$$\frac{dp_{cA}}{dt_{ac}} = -\frac{\beta_b + 2}{3 + \beta_b + \beta_c} < 0$$

$$\frac{dCS_c}{dt_{ac}} = \frac{(\beta_b + 2)\left(1 - \frac{1+(1+\beta_b)t_{ab}-(2+\beta_b)t_{ac}}{3+\beta_b+\beta_c}\right)}{3 + \beta_b + \beta_c} > 0$$

$$\frac{dp_{cB}}{dt_{ba}} = \frac{\beta_a + 1}{\beta_c + \beta_a + 3} > 0,\ \frac{dCS_c}{dt_{ba}} < 0$$

$$\frac{dCS_c}{dt_{bc}} = \frac{(\beta_a + 2)\left(1 - \frac{1+(1+\beta_a)t_{ba}-(2+\beta_a)t_{bc}}{3+\beta_a+\beta_c}\right)}{3 + \beta_a + \beta_c} > 0$$

$$\frac{dp_{cC}}{dt_c} = \frac{2(\beta_L + 1)}{2\beta_L + 3} > 0,\ \frac{dCS_c}{dt_{ca}} = -\frac{2(\beta_L + 1)\left(1 - \frac{2(\beta_L+1)t_{cb}+1}{2\beta_L+3}\right)}{2\beta_L + 3} < 0$$

$$\frac{d^2 p_{cC}}{dt_{ca} d\beta_L} = \frac{2}{(2\beta_L + 3)^2} > 0,\ \frac{d^2 CS_c}{dt_{ca} d\beta_L} = \frac{8(t_c - 1)(\beta_L + 1)}{(2\beta_L + 3)^3} < 0$$

$$PS_c = p_{cB} + \frac{\beta_c}{2}(p_{cB})^2 + p_{cA} + \frac{\beta_c}{2}(p_{cA})^2$$

$$p_{cB} = p_{bB} - t_{bc} = \frac{1+(1+\beta_a)t_{ba}-(2+\beta_a)t_{bc}}{3+\beta_a+\beta_c}$$

$$p_{cA} = p_{aA} - t_{ac} = \frac{1+(1+\beta_b)t_{ab}-(2+\beta_b)t_{ac}}{3+\beta_b+\beta_c}$$

$$PS_c = \frac{1+(1+\beta_a)t_{ba}-(2+\beta_a)t_{bc}}{3+\beta_a+\beta_c} + \frac{\beta_c}{2}\left(\frac{1+(1+\beta_a)t_{ba}-(2+\beta_a)t_{bc}}{3+\beta_a+\beta_c}\right)^2$$
$$+\frac{1+(1+\beta_b)t_{ab}-(2+\beta_b)t_{ac}}{3+\beta_b+\beta_c} + \frac{\beta_c}{2}\left(\frac{1+(1+\beta_b)t_{ab}-(2+\beta_b)t_{ac}}{3+\beta_b+\beta_c}\right)^2$$

$$\frac{dp_{cB}}{dt_{ba}} = \frac{1 + \beta_a}{3 + \beta_a + \beta_c} > 0,\ \frac{d^2 p_{cB}}{dt_{ba} d\beta_a} = \frac{\beta_c + 2}{(3 + \beta_a + \beta_c)^2} > 0$$

$$\frac{dp_{cB}}{dt_{bc}} = \frac{-\beta_a - 2}{\beta_c + \beta_a + 3} < 0,\ \frac{d^2 p_{cB}}{dt_{bc} d\beta_a} = -\frac{\beta_c + 1}{(\beta_a + \beta_c + 3)^2} < 0,$$

$$\frac{dp_{cA}}{dt_{ab}} = \frac{\beta_b + 1}{\beta_c + \beta_b + 3} > 0,\ \frac{d^2 p_{cA}}{dt_{ab} d\beta_b} = \frac{\beta_c + 2}{(\beta_b + \beta_c + 3)^2} > 0,$$

$$\frac{dp_{cA}}{dt_{ac}} = \frac{-\beta_b - 2}{\beta_c + \beta_b + 3} < 0,\ \frac{d^2 p_{cA}}{dt_{ac} d\beta_b} = -\frac{\beta_c + 1}{(\beta_b + \beta_c + 3)^2} < 0.$$

$$TR_c = t_{cb}(e_b + \beta_b p_{bC} - 1 + p_{bC}) + t_{ca}(e_a + \beta_a p_{aC} - 1 + p_{aC})$$

$$TR_c = t_{cb}\left((\beta_b + 1)\frac{1+(1+\beta_a)t_{ca}-(2+\beta_a)t_{cb}}{3+\beta_a+\beta_b}\right) + t_{ca}\left((\beta_a + 1)\frac{1-(2+\beta_b)t_{ca}+(1+\beta_b)t_{cb}}{3+\beta_a+\beta_b}\right)$$

$$\frac{dX_{bC}}{dt_{ca}} = \frac{(\beta_a + 1)(\beta_b + 1)}{\beta_b + \beta_a + 3} > 0,\ \frac{d^2 X_{bC}}{dt_{ca} d\beta_a} = \frac{(\beta_b + 1)(\beta_b + 2)}{(\beta_a + \beta_b + 3)^2} > 0, \text{ where } X \text{ is export.}$$

$$\frac{dX_{bC}}{dt_{cb}} = \frac{(-\beta_a - 2)(\beta_b + 1)}{\beta_b + \beta_a + 3} < 0,\ \frac{d^2 X_{bC}}{dt_{cb} d\beta_a} = -\frac{(\beta_b + 1)^2}{(\beta_a + \beta_b + 3)^2} < 0,$$

$$\frac{d^2 X_{bC}}{dt_{cb} d\beta_b} = -\frac{(\beta_a + 2)^2}{(\beta_b + \beta_a + 3)^2} < 0$$

$$\frac{dTR_c}{dt_c} = -\frac{2(\beta_L + 1)(2t_c - 1)}{2\beta_L + 3},\ \frac{d^2 TR_c}{dt_c d\beta_L} = -\frac{2(2t_c - 1)}{(2\beta_L + 3)^2} \qquad \square$$

Proof of Lemma 2:

Proof. $\triangle W_c^{\{F\}-\{ac\}} = \triangle W_S^{\{F\}-\{LS\}} > 0 = \frac{\left(2-\frac{1}{(4+\beta)}\right)}{2(3+\beta)^2(4+\beta)} - \frac{1}{2(3+\beta)^2(2\beta^2+10\beta+11)} - \frac{23}{2178}$

$\triangle W_a^{\{F\}-\{ac\}} = \triangle W_L^{\{F\}-\{LS\}} = -\frac{1}{198} - \frac{(1+\beta)\left(2+\frac{1}{(2\beta^2+10\beta+11)}\right)}{2(3+\beta)^2(2\beta^2+10\beta+11)} + \frac{(1+\beta)\left(2-\frac{1}{(4+\beta)}\right)}{2(3+\beta)^2(4+\beta)}$

$\triangle W_c^{\{F\}-\{ab\}} = \triangle W_{S_1}^{\{F\}-\{LS_2\}} = \frac{14}{363} - \frac{(2+\beta)}{2(3+\beta)^2(4+\beta)} + \frac{\left(4\beta^2+20\beta+21\right)(2+\beta)^2}{2(2\beta^2+10\beta+11)^2(3+\beta)^2} > 0$

$\triangle W_c^{\{F\}-\{ah\}} = \triangle W_S^{\{F\}-\{Lh\}} = \frac{(2+\beta)\left(4\beta^2+19\beta+20\right)}{2(3+\beta)^2(2\beta^2+10\beta+11)^2} - \frac{1}{2(3+\beta)^2(2\beta^2+10\beta+11)} > 0$

$\triangle W_a^{\{F\}-\{ch\}} = \triangle W_L^{\{F\}-\{Sh\}} = \frac{(4+4\beta)(10+3\beta)(11)(3)^2-(3+\beta)^2(11+3\beta)^2}{22(3+\beta)^2(11+3\beta)^2(3)^2}$

$\triangle W_c^{\{F\}-\{bc\}} = \triangle W_S^{\{F\}-\{SS\}} = \dfrac{(\beta+9)\left(63\beta^3+273\beta^2+289\beta+303\right)}{288\left(\beta+3\right)^2\left(3\beta+11\right)^2} > 0$

$\triangle W_a^{\{F\}-\{bc\}} = \triangle W_L^{\{F\}-\{SS\}} = \frac{(4\beta+4)\left(1-\frac{1}{(3\beta+11)}\right)}{(3+\beta)^2(3\beta+11)} - \frac{1}{36} > 0 \iff \beta < \beta_L^{\{F\}-\{SS\}} \approx 1.81$

$$W_L^{\{LS\}} - W_L^{\{SS\}} = -\frac{(36\beta^8+912\beta^7+9460\beta^6+51460\beta^5+156465\beta^4)}{44\left(\beta+4\right)^2\left(3\beta+11\right)^2\left(2\beta^2+10\beta+11\right)^2} - \frac{(260436\beta^3+210595\beta^2+55902\beta-2662)}{44\left(\beta+4\right)^2\left(3\beta+11\right)^2\left(2\beta^2+10\beta+11\right)^2}$$

□

Proposition 5 is self-enforcing based on Lemma 2.

Proof of the comparative static result in the case of $\{L, S, S\}$:

Proof. Here country a is the unique country L. t_{ab} and t_{ac} are own tariffs t_L. t_{ba} and t_{ca} are external tariffs t_S. $\beta_a = \beta_L$, $\beta_b = \beta_c = \beta_S$.

$p_{aA} = \frac{1+(1+\beta_b)t_{ab}+(1+\beta_c)t_{ac}}{3+\beta_b+\beta_c}$,

$p_{aB} = p_{bB} - t_{ba} = \frac{1-(2+\beta_c)t_{ba}+(1+\beta_c)t_{bc}}{3+\beta_a+\beta_c}$,

$p_{aC} = p_{cC} - t_{ca} = \frac{1-(2+\beta_b)t_{ca}+(1+\beta_b)t_{cb}}{3+\beta_a+\beta_b}$.

$\frac{dp_{aA}}{dt_{ab}} = \frac{(1+\beta_b)}{3+\beta_b+\beta_c}$, $\frac{d^2p_{aA}}{dt_{ab}d\beta_b} = \dfrac{\beta_c+2}{\left(\beta_b+\beta_c+3\right)^2} > 0$.

$\frac{dp_{aB}}{dt_{ba}} = \frac{-(2+\beta_c)}{3+\beta_a+\beta_c} < 0$, $\frac{dp_{aB}^2}{dt_{ba}d\beta_a} = \dfrac{\beta_c+2}{\left(\beta_a+\beta_c+3\right)^2} > 0$.

$\frac{dp_{aC}}{dt_{ca}} = \frac{-(2+\beta_b)}{3+\beta_a+\beta_b} < 0$, $\frac{dp_{aC}^2}{dt_{ca}d\beta_a} = \dfrac{\beta_b+2}{\left(\beta_a+\beta_b+3\right)^2} > 0$.

$CS_a = \frac{(\alpha - p_{aA})^2}{2} + \frac{(\alpha - p_{aB})^2}{2} + \frac{(\alpha - p_{aC})^2}{2}$,

$CS_a = \frac{(1 - \frac{1+(1+\beta_b)t_{ab}+(1+\beta_c)t_{ac}}{3+\beta_b+\beta_c})^2}{2} + \frac{(1 - \frac{1-(2+\beta_c)t_{ba}+(1+\beta_c)t_{bc}}{3+\beta_a+\beta_c})^2}{2} + \frac{(1 - \frac{1-(2+\beta_b)t_{ca}+(1+\beta_b)t_{cb}}{3+\beta_a+\beta_b})^2}{2}$.

$\frac{dCS_a}{dt_{ab}} = -\frac{(\beta_b + 1)\left(\overbrace{1 - \frac{1 + (1+\beta_b)t_{ab} + (1+\beta_c)t_{ac}}{3 + \beta_b + \beta_c}}^{=p_{aA}}\right)}{\beta_c + \beta_b + 3} < 0$

$\frac{dCS_a}{dt_{ba}} = \frac{(2+\beta_c)\left(1 - \frac{1-(2+\beta_c)t_{ba}+(1+\beta_c)t_{bc}}{3+\beta_a+\beta_c}\right)}{3 + \beta_a + \beta_c} > 0$

$\frac{dCS_a}{dt_{ca}} = \frac{(\beta_b+2)\left(1 - \frac{1-(2+\beta_b)t_{ca}+(1+\beta_b)t_{cb}}{3+\beta_a+\beta_b}\right)}{3 + \beta_a + \beta_b} > 0$

$\frac{d^2CS_a}{dt_{ba}d\beta_a} = -\frac{(2+\beta_c)\left(1 + \beta_a + \beta_c - 2\left((\beta_c+1)\, t_{bc} - (\beta_c+2)\, t_{ba}\right)\right)}{(3+\beta_a+\beta_c)^3}$

$\frac{d^2CS_a}{dt_{ca}d\beta_a} = \frac{(\beta_b+2)}{(\beta_a+\beta_b+3)^2}\left(\frac{(1-(2+\beta_b)t_{ca}+(1+\beta_b)t_{cb})}{(\beta_a+\beta_b+3)} - \left(1 - \frac{1-(2+\beta_b)t_{ca}+(1+\beta_b)t_{cb}}{3+\beta_a+\beta_b}\right)\right)$

$PS_a = e_a p_{aB} + \frac{\beta_a}{2}(p_{aB})^2 + e_a p_{aC} + \frac{\beta_a}{2}(p_{aC})^2$,

$p_{aB} = p_{bB} - t_{ba} = \frac{1-(2+\beta_c)t_{ba}+(1+\beta_c)t_{bc}}{3+\beta_a+\beta_c}$, $p_{aC} = p_{cC} - t_{ca} = \frac{1-(2+\beta_b)t_{ca}+(1+\beta_b)t_{cb}}{3+\beta_a+\beta_b}$

$PS_a = \frac{1-(2+\beta_c)t_{ba}+(1+\beta_c)t_{bc}}{3+\beta_a+\beta_c} + \frac{\beta_a}{2}\left(\frac{1-(2+\beta_c)t_{ba}+(1+\beta_c)t_{bc}}{3+\beta_a+\beta_c}\right)^2$
$+ \frac{1-(2+\beta_b)t_{ca}+(1+\beta_b)t_{cb}}{3+\beta_a+\beta_b} + \frac{\beta_a}{2}\left(\frac{1-(2+\beta_b)t_{ca}+(1+\beta_b)t_{cb}}{3+\beta_a+\beta_b}\right)^2$

$$\frac{dPS_a}{dt_{ab}} = \frac{dPS_a}{dt_{ac}} = 0$$

$$\frac{dPS_a}{dt_{ba}} = -\frac{\beta_a \cdot (\beta_c+2)\,(1-(2+\beta_c)t_{ba}+(1+\beta_c)t_{bc})}{(3+\beta_a+\beta_c)^2} - \frac{\beta_c+2}{\beta_c+\beta_a+3} < 0$$

$$\frac{dPS_a}{dt_{ca}} = \frac{\beta_a \cdot (-\beta_b-2)\,(1-(\beta_b+2)\,t_{ca}+(\beta_b+1)\,t_{cb})}{(\beta_b+\beta_a+3)^2} - \frac{\beta_b+2}{\beta_b+\beta_a+3} < 0$$

$\frac{d^2PS_a}{dt_{ba}d\beta_a} =$
$$\frac{(\beta_c+2)\left(\left(\overbrace{2-(\beta_c+2)\,t_{ba}+(\beta_c+1)\,t_{bc}}^{>0}\right)\beta_a - (\beta_c^2+4\beta_c+3)\,t_{bc} + (\beta_c^2+5\beta_c+6)\,t_{ba}\right)}{(\beta_a+\beta_c+3)^3}$$

Thus, $\frac{d^2PS_a}{dt_{ba}d\beta_a} > 0 \iff \beta_a > threshold$, so is $\frac{dPS_a^2}{dt_{ca}d\beta_a}$.

$\frac{dPS_a^2}{dt_{ca}d\beta_a} = \frac{(\beta_b+2)\left((2-(\beta_b+2)\,t_{ca}+(\beta_b+1)\,t_{cb})\,\beta_a - (\beta_b^2+4\beta_b+3)\,t_{cb} + (\beta_b^2+5\beta_b+6)\,t_{ca}\right)}{(\beta_a+\beta_b+3)^3}$

$$\frac{dPS_a^2}{dt_{ba}d\beta_a} > 0 \iff \beta_a \text{ is sufficiently large}$$

$$\frac{dPS_a^2}{dt_{ca}d\beta_a} > 0 \iff \beta_a \text{ is sufficiently large}$$

$\square$

APPENDIX B
Chapter 2

Proofs

Proof of Lemma 4:

Proof. $\triangle W_c^{\{F\}-\{ab\}^m} = \frac{\left(-\beta^7-17\beta^6-108\beta^5-342\beta^4-578\beta^3-492\beta^2-147\beta+27\right)}{(3+\beta)^2(\beta^2+5\beta+7)^2(3+2\beta)^2(4+2\beta)}, \beta_c^{\{F\}-\{ab\}^m} \approx 0.12407;$

$$\triangle W_c^{\{F\}-\{ac\}^m} = \frac{(\beta+1)\left(-2+\frac{(4+2\beta)}{(7+4\beta)}\right)}{(3+2\beta)^2(7+4\beta)} + \frac{\left(1-\frac{1}{2(4+\beta)}\right)}{(3+\beta)^2(4+\beta)} + \frac{\frac{(\beta+1)}{(3+\beta)^2}\left(1-\frac{\frac{1}{2}(\beta+1)}{(4+\beta)(2+\beta)-1}\right)}{(4+\beta)(2+\beta)-1} > 0$$

$$\triangle W_a^{\{F\}-\{bc\}^m} = \triangle W_{L_1}^{\{F\}-\{L_2S\}^m} = \frac{(11+3\beta)^2(3+\beta)^2\left(4\beta^2+4\beta^2+19\beta+6\beta+20\right)-2(3+2\beta)^2\left(4\beta^2+23\beta+18\right)}{2(3+2\beta)^2(4\beta^2+13\beta+11)^2(3+\beta)^2(11+3\beta)^2} > 0$$

□

Proposition 8 is self-enforcing based on Lemma 4.

Proof of Lemma 6:

Proof. $\triangle W_a^{\{F\}-\{bc\}^m} = \triangle W_L^{\{F\}-\{SS\}^m} = \frac{(\beta+1)^2(2\beta^2+11\beta+13)}{(\beta+3)^2(\beta^2+6\beta+7)^2} - \frac{1}{36} > 0 \iff \beta < \beta_L^{\{F\}-\{SS\}^m} \approx 2.32$

$$\triangle W_S^{\{F\}-\{LS\}^m} = \frac{13}{882} - \frac{2\beta^4+16\beta^3+39\beta^2+20\beta-23}{2(\beta+3)^2(\beta+4)^2(\beta^2+5\beta+7)^2} > 0$$

$$\triangle W_c^{\{F\}-\{ab\}^m} = \triangle W_{S_1}^{\{F\}-\{LS_2\}^m} = \left(2-\frac{1}{7}\right)\frac{1}{126} + \frac{\left(2-\frac{1}{(4+\beta)(2+\beta)-(1+\beta)}\right)}{2(3+\beta)^2((4+\beta)(2+\beta)-(1+\beta))} - \frac{(\beta+2)}{2(3+\beta)^2(4+\beta)} > 0$$

□

Proposition 10 is self-enforcing based on Lemma 6.

APPENDIX C
Chapter 3

Proofs

Proof of Lemma 7:

Proof. All below equations can be solved by Newton method or Bisection method with one unique positive solution. Also note that country a and country b are country L and country c is country S:

$$\triangle W_c^{\{F\}-\{ab\}^u} = \triangle W_S^{\{F\}-\{LL\}^u} = \frac{-2\beta^5+3\beta^4+32\beta^3+6\beta^2-102\beta-81}{2(\beta+3)^2(\beta+5)(2\beta+5)(2\beta+3)^2} > 0 \iff \beta < 4.53243$$

$$\triangle W_a^{\{F\}-\{ab\}^u} = \triangle W_{L_1}^{\{F\}-\{L_1L_2\}^u} = \frac{\left(\frac{\left(2\beta^2+10\beta+11\right)}{(5+2\beta)}-2\right)}{2(3+\beta)^2(5+2\beta)} + \frac{(1+\beta)\left(2-\frac{1}{(4+2\beta)}\right)}{2(3+2\beta)^2(4+2\beta)} + \frac{(1+\beta)\left(2-\frac{1}{(5+2\beta)}\right)}{2(3+\beta)^2(5+2\beta)} > 0$$

$$\triangle W_a^{\{F\}-\{ac\}^u} = \triangle W_L^{\{F\}-\{LS\}^u} = \frac{-5\beta^9-93\beta^8-713\beta^7-2897\beta^6-6639\beta^5-8132\beta^4-3108\beta^3+5097\beta^2+7815\beta+3375}{2(\beta+5)^2(\beta+3)^2(\beta+4)^2(2\beta+5)^2(2\beta+3)^2}$$

$$\triangle W_a^{\{F\}-\{bc\}^u} = \frac{264\beta^9+4537\beta^8+30751\beta^7+126052\beta^6+358230\beta^5+726157\beta^4+3184\beta^7}{2(\beta+3)^2(\beta+4)(2\beta+3)^2(3\beta+11)^2(4\beta^2+13\beta+11)^2} \qquad \square$$

Proposition 12 is self-enforcing base on Lemma 7.

Proof of Lemma 9:

Proof. $\triangle W_a^{\{F\}-\{bc\}^u} = \triangle W_L^{\{F\}-\{SS\}^u} =$

$$-\frac{1}{36} + \frac{2(2\beta+2)\left(1-\frac{1}{(5+\beta)}\right)}{(3+\beta)^2(5+\beta)} > 0 \iff \beta < \beta_L^{\{F\}-\{SS\}^u} \approx 6.175$$

$$\triangle W_c^{\{F\}-\{ac\}^u} = \triangle W_S^{\{F\}-\{LS\}^u} > 0 = \frac{\left(2-\frac{1}{(4+\beta)}\right)}{2(3+\beta)^2(4+\beta)} - \frac{1}{2(3+\beta)^2(2\beta^2+10\beta+11)} - \frac{23}{2178}$$

$$\triangle W_a^{\{F\}-\{ac\}^u} = \triangle W_L^{\{F\}-\{LS\}^u} = -\frac{1}{198} - \frac{(1+\beta)\left(2+\frac{1}{(2\beta^2+10\beta+11)}\right)}{2(3+\beta)^2(2\beta^2+10\beta+11)} + \frac{(1+\beta)\left(2-\frac{1}{(4+\beta)}\right)}{2(3+\beta)^2(4+\beta)}$$

$$\triangle W_c^{\{F\}-\{ab\}^u} = \triangle W_{S_1}^{\{F\}-\{LS_2\}^u} = \frac{14}{363} - \frac{(2+\beta)}{2(3+\beta)^2(4+\beta)} + \frac{\left(4\beta^2+20\beta+21\right)(2+\beta)^2}{2(2\beta^2+10\beta+11)^2(3+\beta)^2} > 0$$

$$\triangle W_c^{\{F\}-\{bc\}^u} = \triangle W_S^{\{F\}-\{SS\}^u} = \frac{(\beta+9)\left(63\beta^3+273\beta^2+289\beta+303\right)}{288\left(\beta+3\right)^2\left(3\beta+11\right)^2} > 0 \qquad \square$$

Proposition 14 is self-enforcing based on Lemma 9.