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The Armington Assumption and the Size of Optimal Tariffs

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ABSTRACT

There has been commentary on the seeming success of the world trading system responding to the large shock of the 2008 financial crisis without an outbreak of retaliatory market closing. The threat of large retaliatory tariffs and fears of a 1930s style downturn in trade have been associated with numerical trade modelling which project post retaliation optimal tariffs in excesses of 100%. In the relevant numerical modelling it is common to use the Armington assumption of product heterogeneity by country. Here we argue and show by numerical calculation that the widespread use of this assumption gives a large upward bias to optimal tariffs, both first step and post retaliation, relative to alternative homogenous good models used in trade theory.

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1. Introduction

The reasons why the Armington assumption is so widely used in numerical modelling are well documented (see Whalley (1975) and Srinivasan and Whalley (1986)). First, there is the size of intra-industry trade, which for the US can run at 80% of gross trade for 2 digit HS trade data. Netting out trade flows as would be implied by use of a homogenous goods trade model in the Hecksher-Ohlin tradition seems to unrealistically shrink the role of trade. Second comes the feature of conventional goods and factors models that the implied production possibilities frontiers with conventional (Cobb-Douglas, CES) production functions are close to linear (see Johnson, 1966) resulting in specialization in production in the model for even small changes in trade policies such as tariffs. Third comes the convenience of allowing for model calibration via the elasticities of substitution in preferences among Armington goods to literature estimates of import price elasticities.

This paper explores how the use of the Armington assumption of product heterogeneity by country influences the size of optimal tariffs projected from numerical trade modelling. Optimal tariff literature can been traced back to Johnson (1953-1954), Gorman (1958) and Kuga (1973). Studies numerically calculating optimal tariffs using data and calibration are few. Hamilton and Whalley (1983) is the earliest, optimal tariffs here are up to 300% under different assumptions. Markusen and Wigle (1989) numerically explore the roles of country size, scale economies and capital mobility in optimal tariff. Perroni and Whalley (2000) calculate post-retaliation Nash tariff by region numerically and relate them to analyze the regional agreement and trade liberalization. Optimal tariffs in this paper are up to 1000%. More recently, Ossa (2011) calculates non-cooperative tariffs numerically in a “new trade” theory and analyzes GATT/WTO negotiations. Optimal tariffs here ranges are up to 30% for different preference elasticities. Whalley et al. (2011) use inside money trade imbalance model structure to numerically calculate optimal tariff for China. Optimal tariffs in this paper are up to 200%. Ossa (2014) incorporates political economy factors in a “new trade” model structure to numerically calculate optimal tariff, trade war equilibrium tariff and trade talk equilibrium tariff. Optimal tariffs in this paper are mostly less than 100%. These studies use an Armington structure in numerical computation, but none of them connects on the influence of the Armington assumption on optimal tariffs.

Our approach is to consider three groups of models which we treat as observationally equivalent in the sense that all the models within groups can all be calibrated to the same base case data set. We then compute optimal tariffs for each and compare their size.

The first group of models are pure exchange 2-country 2-good models. One model is of the Armington variety with country goods being endowed exclusively to countries with goods interpreted as manufacturing and non-manufacturing, and with trade taking place in the country goods. The other is homogeneous goods models with net trade appearing in the two goods.

The second group of models are similar general equilibrium models but with an added production structure and a balanced trade assumption. Endowments of traded goods in the pure exchange model are replaced by endowments of productive inputs. One model is again of the Armington type with product heterogeneity by country and two produced goods for each country and two factor inputs. Specialization is avoided since specialization already occurs in Armington goods. The other model incorporates homogenous goods in each country but uses production structures with fixed sector specific inputs and diminishing marginal productivity of mobile across sector labor. The model avoids specialization by using a construction in which the marginal productivity of labor equals zero as output in the sector approaches zero.

The third group of models are similar general equilibrium with production, but trade is unbalanced. We use exogenous fixed trade imbalances in both homogeneous and Armington good models. Structures in the third group are thus the same as in the second group except trade imbalance assumption. In total there are six models (three groups and two models in each group).

We then construct a base case data set for calibration of all models which identifies the US, the EU, China and ROW (the rest of the world) as separate entities. We use trade and production data for 2013 taken separately from United Nations Comtrade database and World Bank World Development Indicators database (WDI). We adjust for trade imbalances to yield data sets in both adjusted form (meeting country trade balance) and in unadjusted form incorporating trade imbalances.

We perform calibration of each model type to the relevant data set, assuming CES preferences, CES technology in goods and factor (Armington) models, and diminishing marginal productivity functions. We then use GAMS solutions software to compute optimal tariffs for alternative groups of countries into pairwise categories discussed in the text (US-ROW, EU-ROW, and China-ROW). The use of these pairwise groups reflects the difficulties of computing post retaliation (Nash) tariffs in higher dimensions than 2, and follows considerable earlier literature. We compute both first step and post retaliation (Nash) tariffs.

We report optimal tariff calculation results and these show optimal tariff in the hundreds of percent (depending specifically on elasticity parameters) for Armington type models which are much smaller for comparable homogenous good models. Differences between Armington and non-Armington model results are similar for models with production and models without production. Models with and without trade imbalances yield similar optimal tariffs. Optimal tariffs post retaliation and first step are not that different. The difference in results for Armington models reflects the large terms of trade effects present in these models.

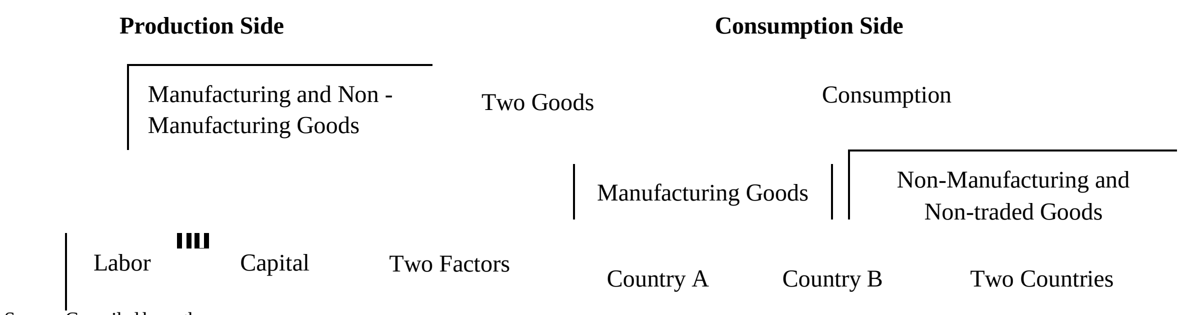
Our analysis thus suggests that optimal tariffs in models using the Armington goods assumption are significantly larger than the ones in homogeneous goods assumption, and that the Armington assumption does produce a larger upward bias regarding optimal tariffs. As computations for Armington type models have been the basis for the belief that trade retaliation, if unchecked, will lead to both very high tariff and a sharp decline of trade, the behavior of major global economies in the

2008/2009 crisis is seen as hard to explain. Our results suggest a change in model structure to homogenous goods goes a long way to accounting for this phenomena.

2. Groups of Models and the Experiments

We use three groups of models to calculate optimal tariffs. Each group of models includes alternatively the use of a homogenous goods assumption and an Armington goods assumption of product heterogeneity by country. The three groups of models are pure exchange models, balanced trade general equilibrium production models, and imbalanced trade general equilibrium production models. The basic structure of our models is two countries, two goods (manufacturing goods and non-manufacturing goods) and two input factors (labor and capital), see Figure 1. Detailed model descriptions are given in an Appendix[1]. We explore how the Armington assumption influences the size of optimal tariffs.

Fig. 1 Basic Structure of Models



Source: Compiled by authors.

2.1 Pure Exchange Models

The pure exchange models we use is a two-country and two-goods structure. In the model group, two countries are sequentially and separately identified as the US and ROW (Rest of the World), the EU (European Union) and ROW, and China and

[1] Available on request from the authors.

ROW. The two goods are manufacturing goods and non-traded non-manufacturing goods. Each country has an endowment of goods. We assume preference functions are CES (Constant Elasticity of Substitution) style. In the homogenous goods models, one country trades one good with the other country, and the same good in the two countries has the same price. In the equilibrium, all goods will be consumed, each country's total export value equals its import value. For the Armington goods models, goods from different countries are heterogeneous and there is an elasticity of substitution, in the preference function which is two-level CES. In the equilibrium, goods markets will clear, and goods prices are determined by demands and supply.

2.2 With Production General Equilibrium Models (Balanced Trade)

In this group of general equilibrium models, production and consumption are both included. The models are again two-country two-goods and two-factor structures. For the Armington models of this group, preference functions are again two-level CES. The same goods from different countries are heterogeneous and so there are no specialization problems. Production functions in the Armington goods models are CES. In order to avoid specialization problems, we use fixed sector specific inputs and diminishing marginal productivity production functions in which the marginal productivity of labor equals zero as output in the sector approaches zero. In the equilibrium, goods and factor markets in every country again clear. In this group all structures have balanced trade, and every country's total exports equals its total imports in value terms.

2.3 With Production General Equilibrium Models (Unbalanced Trade)

This group of models have the same structure as the balanced trade models above, the only difference being we capture unbalanced trade. We include an exogenous fixed trade imbalance structure into the general equilibrium model, in which each country's trade imbalance is fixed and total world trade is balanced. All other model features are the same as the balanced trade with production general equilibrium model.

Our simulation experiments use these three different groups of models, and include both the homogeneous goods assumption and the Armington goods assumption for each group. We separately compute optimal tariffs for all models. We then compare optimal tariffs under homogeneous goods assumption to optimal tariffs under the Armington goods assumption for each group of models, and we assess how the Armington assumption influences optimal tariffs.

3. Data and Model Calibration

We use 2013 as our base year and build a global benchmark general equilibrium dataset for use in calibration and simulation following the methods set out in Shoven and Whalley (1992).

Our numerical models have three different country group datasets, which are China and ROW (rest of the world), the US (United States) and ROW, the EU (European Union) and ROW. Our benchmark datasets are all two country. ROW data is obtained from total world values minus values for the other specific country. For the two goods, we assume secondary industry (manufacturing) reflects manufactured goods, and primary and tertiary industries (agriculture, extractive industries, and services) yield non-manufacturing non-traded goods. For the two factor inputs, capital and labor, we use total labor income (wage) to denote labor values for inputs by sector. All data are in billion US dollars. We adjust some of the data for mutual consistency for calibration purposes.

All data are from the World Bank database (World Development Indicators). These data are listed in Table 1. We use the agriculture and service share of GDP data and GDP data to yield production data of manufacturing goods and non-manufacturing goods, and use capital/GDP ratios to yield capital and labor inputs in production.

Trade data for each pair of countries are from the UN Comtrade database. We use individual country total export and import values to yield exports to and imports from the ROW. For China in 2013, exports are 2209.1 billion US$, imports are 1949.9 billion US$; for the US in 2013, exports are 1578.1 billion US$, imports are 2328.3 billion US$; and for the EU in 2013, exports are 2326.3 billion US$, imports are 2243.4 billion US$ (Comtrade, 2015). For the balanced trade structures, we use export values to represent every country's imports and trade. Using production and trade data, we can then calculate each country's consumption.

Table 1: Production Data Used For Calibration and Simulation (2013 Data)

Country	GDP	M	NM	Capital		Labor	
				M	NM	M	NM
			China-ROW Group				
China	9240.3	4065.7	5174.6	1992.2	2535.5	2073.5	2639.1
ROW	66351.7	18850.5	47501.2	4940.4	11926	13910.1	35575.2
			US-ROW Group				
US	16768.1	3521.3	13246.8	704.3	2649.3	2817	10597.5
ROW	58823.9	19394.9	39429	6228.3	11812.2	13166.6	27616.8
			EU-ROW Group				
EU	17972.9	5571.6	12401.3	1114.3	2480.3	4457.3	9921
ROW	57619.1	17344.6	40274.5	5818.3	11981.2	11526.3	28293.3

Note: (1) Units for production, capital, labor and endowments are all billion US$, and labor here denotes factor income (wage). (2) We use world values minus individual countries to generate ROW values. (3) "M" denotes manufactured goods, "NM" denotes non-manufactured goods.

Sources: calculated from WDI of World Bank database.

Elasticities for individual countries on the demand and production sides of the model are determined in two ways in our numerical models. We first use import demand elasticities from literatures, and use these values to yield preference and production function side elasticities of substitution. This is an indirect method to get the preference and production elasticities. We assume that elasticities of substitution in preference and production are equal. This is the usual process as calibration in other models.

We get elasticities of substitution directly from literatures. This is a direct usual way of numerical general equilibrium calibration for elasticities. Many of the estimates of domestic and import goods substitution elasticity are around 2 (Betina et al., 2006), so we again set all these elasticities in our models to 2.0 (Whalley and Wang, 2010). We change elasticities to perform sensitivity analysis.

The other way involves calculating preference and production elasticities from import demand elasticities using a search methodology. We keep the elasticities of substitution in preference and production equal. We then try different preference elasticities to calculate import demand elasticities (the method uses a one percent consumption price increase in the benchmark model to generate a new import demand, and then calculating the implied import demand elasticity), and search for a elasticity level that gives import demand elasticities equal to what we find in the literature.

According to Kee et al. (2008), the import demand elasticities for China are -1.44, the US are -2.09, the EU are -1.33 (mean of all OECD countries), and the ROW are -1.20 (mean of overall countries). In Senhadji (1998) and Tokarick (2014), the results are somewhat different, so we cannot get a uniform value for the import demand elasticities. Thus we calibrate import demand elasticities of all countries to equal 2.0 in both models.

With these data and elasticities, we can calibrate remaining model parameters. When used in model solution these regenerate the benchmark data as an equilibrium for the model. Using these parameters we use the models to calculate optimal tariffs.

4. Optimal Tariff Calculations

We compute and compare optimal tariffs using the homogeneous goods and Armington goods models for the three different model structures discussed earlier. The first model structure is a pure exchange model type, the second is a balanced trade production general equilibrium model type, and the third is a unbalanced trade production general equilibrium model type.

In the calculation of optimal tariffs, we use the two methods to determine elasticities of substitution in preference and production discussed above. The first is the indirect method from calibration to import demand elasticities, which we call it "indirect elasticities". The second is the "direct method" from literature, which we call it "direct elasticities". We perform sensitivity analysis to presenting of preference elasticities. We consider two different optimal tariffs following Hamilton and Whalley (1983). One is "first step" optimal tariff, and the other is post retaliation optimal tariffs.

In computation, we need to assume a predetermined direction of trade which remains unchanged in the face of tariff retaliation. We follow the process of retaliation through which optimal tariffs are calculated by each country, and revised in light of any changes in tariffs adopted by the other country. When no further retaliation occurs, an approximation to the Nash equilibrium is achieved. In calculating post retaliation optimal tariffs, we iterate over calculations of optimal tariffs by individual countries to tariff settings of other countries subject to the constraint of full general equilibrium.

We then iterate across country tariffs until convergence to a non-cooperative Nash equilibrium is achieved. Convergence is rapid in all the cases we have examined.

4.1 Pure Exchange Model Calculation

Optimal tariffs for pure exchange models are reported in Table 2 under the indirect preference elasticity determination scenario, Table 3 reports results under direct preference elasticity determination.

Using the indirect elasticity determination method, optimal tariffs for Armington models are much larger for individual countries than optimal tariffs in homogeneous goods models. This suggests the claim that the Armington assumption cause a large upward bias to optimal tariffs.

Table 2: Optimal Tariffs in Pure Exchange Models with Indirect Elasticities (Unit: %)

Countries	First Step OT	Post Retaliation OT	First Step OT	Post Retaliation OT
	Armington Goods Models		***Homogeneous Goods Models***	
	China-ROW		China-ROW	
China	77.1	65.4		18.3
ROW	117.7	104.0		11.7
	US-ROW		US-ROW	
US		88.0	12.5	7.6
ROW		78.7	40.9	35.7
	EU-ROW		EU-ROW	
EU		87.7	24.7	15.1
ROW		75.7	73.5	61.5

Notes: "China-ROW" denotes the case of China-ROW mutual retaliation; "US-ROW" denotes the case of US-ROW mutual retaliation; "EU-ROW" denotes the case of EU-ROW mutual retaliation; "OT" denotes Optimal Tariff.

Source: calculated and compiled by authors.

Taking the US and ROW country group as an example, the first step optimal tariffs for the US under homogeneous goods and Armington goods are separately 12.5% and 88%, and the post retaliation optimal tariffs are separately 7.6% and 78.7%. The first step optimal tariffs for ROW under homogeneous goods and Armington goods are separately 40.9% and 121.5%, and the post retaliation optimal tariffs are separately 35.7% and 96.2%. Hence, optimal tariffs under Armington assumption are clearly much larger than under the homogeneous goods assumption.

Under the direct elasticity determination method, optimal tariffs of Armington goods are again much larger than optimal tariffs under homogeneous goods. Bigger countries have larger optimal tariffs and this trend is more significant in homogeneous goods condition.

Taking the China-ROW group as an example. China's first step optimal tariffs and post retaliation optimal tariff are separately 8.3% and 5.5% for homogeneous goods, and are separately 109.8% and 103.8% for Armington goods. ROW's first step optimal tariff and post retaliation optimal tariffs are separately 41.9% and 44.9% for homogeneous goods, and are separately 161.4% and 127.7% for Armington goods.

Table 3: Optimal Tariffs in Pure Exchange Models with Direct Elasticities (Unit: %)

Countries	First Step OT	Post Retaliation OT	First Step OT	Post Retaliation OT
	Armington Goods Models		***Homogeneous Goods Models***	
	China-ROW		China-ROW	
China	109.8	103.8	8.3	5.5
ROW	161.4	127.5	41.9	44.9
	US-ROW		US-ROW	
US	106.2	102.5	5.9	4.4
ROW	144.6	118.4	18.6	18.2
	EU-ROW		EU-ROW	
EU	110.7	104.4	9.0	6.5
ROW	140.6	117.1	27.2	26.7

Notes: "China-ROW" denotes the case of China-ROW mutual retaliation; "US-ROW" denotes the case of US-ROW mutual retaliation; "EU-ROW" denotes the case of EU-ROW mutual retaliation; "OT" denotes Optimal Tariff.

Source: calculated and compiled by authors.

Sensitivity analysis (results are reported in an Appendix) of optimal tariffs to preference elasticities confirms that optimal tariffs under the Armington goods assumption are always larger than under the homogeneous goods assumption. Optimal tariffs are sensitive to preference elasticities, and have a negative relation with preference elasticities i.e. bigger preference elasticities will generate smaller optimal tariffs.

4.2 GE with Production and Balanced Trade Model Calculation

We next add production to pure exchange models and used a balanced trade treatment. We again compute optimal tariffs separately with indirect elasticity determination method and direct elasticity determination method, and report sensitivity analysis to preference elasticities. Table 4 and Table 5 report these results.

Table 4: Optimal Tariffs in Balanced Trade GE Models with Indirect Elasticities (Unit: %)

Countries	First Step OT	Post Retaliation OT	First Step OT	Post Retaliation OT
	Armington Goods Models		***Homogeneous Goods Models***	
	China-ROW		China-ROW	
China	73.7	72.8	4.2	2.3
ROW	85.6	78.9	34.1	32.9
	US-ROW		US-ROW	
US	89.3	88.4	3.2	2.2
ROW	93.6	90.3	6.3	5.4
	EU-ROW		EU-ROW	
EU	87.1	85.8	5.6	3.8
ROW	92.8	88.4	9.2	7.9

Notes: "China-ROW" denotes the case of China-ROW mutual retaliation; "US-ROW" denotes the case of US-ROW mutual retaliation; "EU-ROW" denotes the case of EU-ROW mutual retaliation; "OT" denotes Optimal Tariff.

Source: calculated and compiled by authors.

Using indirect elasticity determination, optimal tariffs under the Armington goods assumption are again much larger than under a homogeneous goods assumption, and bigger countries have larger optimal tariffs. Taking the EU-ROW group as an example, the EU's first step optimal tariffs for homogeneous goods and Armington goods are separately 5.6% and 87.1%, and the post retaliation optimal tariffs are separately 3.8% and 85.8%. ROW's first step optimal tariffs for homogeneous goods and Armington goods are separately 9.2% and 92.8%, and the post retaliation optimal tariffs are separately 7.9% and 88.4%.

For direct elasticity determination, optimal tariffs under Armington goods are significantly larger than of homogeneous goods, and bigger economic scale countries have larger optimal tariffs.

Table 5: Optimal Tariffs in Balanced Trade GE Models with Direct Elasticities (Unit: %)

Countries	First Step OT	Post Retaliation OT	First Step OT	Post Retaliation OT
	Armington Goods Models		***Homogeneous Goods Models***	
	China-ROW		China-ROW	
China	102.4	100.9	3.1	1.8
ROW	119.2	108.6	21.5	20.6
	US-ROW		US-ROW	
US	102.5	101.1	2.4	1.6
ROW	108.6	103.6	5.0	4.3
	EU-ROW		EU-ROW	
EU	102.8	101.2	3.6	2.4
ROW	109.5	104.0	6.9	6.0

Notes: "China-ROW" denotes the case of China-ROW mutual retaliation; "US-ROW" denotes the case of US-ROW mutual retaliation; "EU-ROW" denotes the case of EU-ROW mutual retaliation; "OT" denotes Optimal Tariff.

Source: calculated and compiled by authors.

Sensitivity analysis of optimal tariffs to preference elasticities indicate that optimal tariffs decrease as preference elasticities increase. Also, optimal tariffs using the Armington goods assumption are much larger than optimal tariffs in homogeneous goods (detailed results are reported in an Appendix[2]).

4.3 GE with Production and Unbalanced Trade Model Calculation

We next add trade imbalances to the balanced general equilibrium models with production. We compute optimal tariffs with indirect and direct preference elasticity determination methods, and compare optimal tariffs of homogeneous goods with Armington goods. Results are reported in Tables 6 and 7.

[2] Available on request from the authors.

Under indirect preference elasticity determination, results show optimal tariffs under the Armington goods assumption as much larger than optimal tariffs of homogeneous goods, and bigger countries have larger optimal tariffs.

Table 6: Optimal Tariffs in Unbalanced Trade GE Models with Indirect Elasticities (Unit: %)

Countries	*Armington Goods Models* First Step OT	*Armington Goods Models* Post Retaliation OT	*Homogeneous Goods Models* First Step OT	*Homogeneous Goods Models* Post Retaliation OT
	China-ROW		China-ROW	
China	69.1	68.3	4.2	2.3
ROW	79.8	73.8	34.5	33.3
	US-ROW		US-ROW	
US	88.7	87.7	4.2	2.5
ROW	93.8	89.9	8.1	6.2
	EU-ROW		EU-ROW	
EU	87.1	85.8	5.6	3.8
ROW	92.7	88.3	9.2	7.9

Notes: "China-ROW" denotes the case of China-ROW mutual retaliation; "US-ROW" denotes the case of US-ROW mutual retaliation; "EU-ROW" denotes the case of EU-ROW mutual retaliation; "OT" denotes Optimal Tariff.

Source: calculated and compiled by authors.

Using direct preference elasticity determination, results are the same. Optimal tariffs of Armington goods are larger than for homogeneous goods, and bigger countries have larger optimal tariffs.

Table 7: Optimal Tariffs in Unbalanced Trade GE Models with Direct Elasticities (Unit: %)

Countries	*Armington Goods Models* First Step OT	*Armington Goods Models* Post Retaliation OT	*Homogeneous Goods Models* First Step OT	*Homogeneous Goods Models* Post Retaliation OT
	China-ROW		China-ROW	
China	102.3	101.0	3.0	1.7
ROW	118.1	108.1	20.7	19.8
	US-ROW		US-ROW	
US	102.0	100.8	3.2	2.1
ROW	107.9	103.2	6.5	5.6
	EU-ROW		EU-ROW	
EU	102.8	101.2	3.6	2.2
ROW	109.3	103.9	6.9	5.8

Notes: "China-ROW" denotes the case of China-ROW mutual retaliation; "US-ROW" denotes the case of US-ROW mutual retaliation; "EU-ROW" denotes the case of EU-ROW mutual retaliation; "OT" denotes Optimal Tariff.

Source: calculated and compiled by authors.

Sensitivity analysis of optimal tariffs to preference elasticities indicate that optimal tariffs under Armington goods are larger than those under homogeneous goods, and bigger preference elasticity generates smaller optimal tariffs.

5. Conclusions

In this paper, we explore the influence of the Armington assumption on optimal tariffs. Earlier optimal tariff theory is based on homogeneous good models, but the Armington assumption has become a prevalent structure used in numerical computation.

We use three groups of models to numerically calculate optimal tariffs in homogeneous goods and Armington goods models. These are pure exchange models, balanced trade general equilibrium models with production and unbalanced trade general equilibrium models with production. We use two different preference elasticity determination methods in calibration and generate two different sets of results in each group models. We also perform sensitivity analysis of optimal tariffs to preference elasticities.

Our simulation results suggests that optimal tariffs computed using the Armington assumption are much larger than those using the homogeneous goods assumption, and thus the Armington assumption has a significant upward bias to optimal tariffs. Bigger countries have larger optimal tariffs, which means that country scale has a positive influence to optimal tariffs. Optimal tariffs are also sensitive to preference elasiticities, and larger preference elasticities generate smaller optimal tariffs.

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Appendix

A. Detailed Model Structures

We put model descriptions in this part, include pure exchange model, balanced trade general equilibrium model and imbalanced general equilibrium model.

A1. Pure Exchange Models

In pure exchange models, we only need to take account of the consumption side. One country's endowment is a fixed amount of goods so that production is not included in the model structure. Our pure exchange models are two-country and two-goods structure. Two countries have three different groups, a China-ROW (rest of the world) group, a US-ROW group and an EU-ROW group. Two goods are manufacturing goods and non-manufacturing goods.

A1.1 Homogeneous Goods Model

Under the homogeneous goods assumption, same goods from different countries are homogeneous. Both countries will use their abundant goods to exchange for other goods with other countries. We assume the endowment of country i for goods l as Q_i^l, and it is exogenously given. For the consumption, we take the constant elasticity of substitution (CES) utility function for each country

$$U_i(X_i) = \left[\sum_l (\beta_i^l)^{\frac{1}{\sigma_i}} (X_i^l)^{\frac{\sigma_i - 1}{\sigma_i}}\right]^{\frac{\sigma_i}{\sigma_i - 1}}, \quad i \in country\ l \in goods \tag{A1}$$

where X_i^l denotes the consumption of goods l in country i. Additionally β_i^l is share parameter and σ_i is the elasticity of substitution in consumption.

The utility maximization subject to the budget constraint yields

$$X_i^l = \frac{a_i^l E_i}{(pc_i^l)^{\sigma}\left[\sum_l a_i^l (pc_i^l)^{1-\sigma}\right]} \qquad \text{(A2)}$$

where pc_i^l is consumption prices of goods l in country i. E_i is the total consumption expenditure of country i.

Equilibrium in the model characterized by market clearing prices for goods in each country such that

$$\sum_i X_i^l = \sum_i Q_i^l \qquad \text{(A3)}$$

We introduce import tariff t_i (import tariff level of country i) into the model. This yields the following relation between consumption prices and domestic sale prices (p_j^l)

$$pc_i^l = (1 + t_i)\, p_j^l \qquad \text{(A4)}$$

Import tariffs generate revenues R_i, which are given by

$$R_i = \sum_{j,i \neq j} p_j^l M_{ij}^l t_i \qquad \text{(A5)}$$

where M_{ij}^l is import of goods l in country i from country j. The representative consumer's income (I_i) in country i is given by

$$I_i = \sum_i p_i^l Q_i^l + R_i \qquad \text{(A6)}$$

In the balanced trade, total income should equal to total expenditure, so that $E_i = I_i$.

A1.2 Armington Goods Model

In the Armington goods assumption, same goods from different goods are heterogeneous so that the consumption has two levels. The first level is choosing between two different goods, and the second level is choosing goods from different countries under specific goods. We assume that only manufacturing goods are tradable, so both countries only exchange with manufacturing goods.

The same as in the homogeneous goods, We assume the endowment of country i for goods l as Q_i^l, and it is exogenously given. On the consumption side, we take a nested CES utility function for each country

$$U_i(X_i^M, X_i^{NM}) = [\alpha_{i1}(X_i^M)^{\frac{\sigma_i-1}{\sigma_i}} + \alpha_{i2}(X_i^{NM})^{\frac{\sigma_i-1}{\sigma_i}}]^{\frac{\sigma_i}{\sigma_i-1}}, \quad i \in country \qquad (A7)$$

where X_i^{NM} denotes the consumption of non-manufacturing goods in country i, X_i^M denotes the consumption of manufacturing goods in country i. Additionally α_{i1} and α_{i2} are share parameters and σ_i is the elasticity of substitution in consumption.

There is a second level consumption for manufacturing goods (Non-manufacturing goods are assumed to be non-tradable and so it has only one level consumption). Here, X_i^M denotes the composite of manufacturing goods, which is defined as another reflecting the country from which goods come. We assume this level 2 composite consumption is also of CES form and represented as,

$$X_i^M = [\sum_j \beta_{ij} (x_{ij}^M)^{\frac{\sigma'_i-1}{\sigma'_i}}]^{\frac{\sigma'_i}{\sigma'_i-1}}, \quad j = country \qquad (A8)$$

where x_{ij}^M is the consumption of manufactory goods from country j in country i. If $i = j$ this implies that this country consumes its domestically produced tradable goods. β_{ij} is the share parameter for country j's manufacturing goods consumed in country i. σ'_i is the elasticity of substitution in level 2 preferences in country i.

The utility optimization problem above yields

$$X_i^M = \frac{a_{i1} E_i}{(P_i^M)^{\sigma_i}[a_{i1}(P_i^M)^{1-\sigma_i} + a_{i2}(pc_i^{NM})^{1-\sigma_i}]} \tag{A9}$$

$$X_i^{NM} = \frac{a_{i2} E_i}{(pc_i^{NM})^{\sigma_i}[a_{i1}(P_i^M)^{1-\sigma_i} + a_{i2}(pc_i^{NM})^{1-\sigma_i}]} \tag{A10}$$

where P_i^M and pc_i^{NM} are the separate consumption prices of manufacturing goods and non-manufacturing goods in country i. E_i is the total consumption expenditure of country i.

Under the Armington goods assumption models, the demands of composite manufacturing goods which enter the second level preferences and come from different countries are

$$x_{ij}^M = \frac{\beta_{ij}(X_i^M P_i^M)}{(pc_{ij}^M)^{\sigma'_i}[\sum_j \beta_{ij}(pc_{ij}^M)^{(1-\sigma'_i)}]} \tag{A11}$$

where pc_{ij}^M is the consumption price in country i of manufacturing goods produced in country j, $X_i^M P_i^M$ is the total expenditure on manufacturing goods in country i. The consumption price for the composite of manufacturing goods is

$$P_i^M = \left[\sum_{j=1}^{15} \beta_{ij}(pc_{ij}^M)^{(1-\sigma'_i)}\right]^{\frac{1}{1-\sigma'_i}} \tag{A12}$$

and the total consumption expenditure of country i is

$$E_i = P_i^M X_i^M + pc_i^N X_i^N \tag{A13}$$

Equilibrium in the model characterized by market clearing prices for goods in each country such that

$$\sum_i Q_i^M = \sum_i \sum_j x_{ji}^M, \quad Q_i^N = X_i^N \tag{A14}$$

We introduce import tariff t_i (import tariff level of country i) into the model. This yields the following relation between consumption prices and domestic sale prices (p_j^l) in country i

$$pc_i^l = (1 + t_i) p_j^l \tag{A15}$$

Import tariffs generate revenues R_i, which are given by

$$R_i = \sum_{j, i \neq j} p_j^M x_{ij}^M t_i \tag{A16}$$

The representative consumer's income (I_i) in country i is given by

$$I_i = \sum_l p_i^l Q_i^l + R_i \tag{A17}$$

In the balanced trade assumption, total income equals total expenditure, so $E_i = I_i$.

A2. Balanced Trade Production General Equilibrium Models

We add production part into pure exchange model and get the balanced general equilibrium model. Our balanced general equilibrium models are two-country, two-goods with factors structure. Two countries include China-ROW group, the US-ROW group and the EU-ROW group. Two goods are manufacturing goods and non-manufacturing goods. In the homogeneous goods model, it has one factors which is labor. In the Armington goods model, it has two factors which are labor and capital.

A2.1 Homogeneous Goods Model

On the production side of the model, in order to avoid specialization problem, we use the fixed sector specific inputs and diminishing marginal productivity production function, which only use labor in production

$$Q_i^l = A_i^l (L_i^l)^{\beta_i^l}, \quad \beta_i^l < 1; \; l \in goods, \; i \in country \qquad (A18)$$

where Q_i^l is the output of the *lth* industry (including both tradable and non-tradable goods) in country i, L^{li} is the labor inputs in sector l, A_i^l are the scale parameters, β_i^l is the share parameter. Simple calculation implies the factor input demand equations as

$$L_i^l = \left(\frac{Q_i^l}{A_i^l}\right)^{\frac{1}{\beta_i^l}} \qquad (A19)$$

On the consumption side, we take the constant elasticity of substitution (CES) utility function for each country

$$U_i(X_i) = \left[\sum_l (\alpha_i^l)^{\frac{1}{\sigma_i}} (X_i^l)^{\frac{\sigma_i - 1}{\sigma_i}}\right]^{\frac{\sigma_i}{\sigma_i - 1}}, \quad i \in country \qquad (A20)$$

where X_i^l denotes the consumption of goods l in country i. Additionally α_i^l is share parameter and σ_i is the elasticity of substitution in consumption.

The utility maximization subject to the budget constraint yields

$$X_i^l = \frac{\alpha_i^l E_i}{(pc_i^l)^{\sigma}\left[\sum_l \alpha_i^l (pc_i^l)^{1-\sigma}\right]} \qquad \text{(A21)}$$

where pc_i^l is consumption prices of goods l in country i . E_i denotes the total consumption expenditure of country i. World prices (pc^l) for same goods in all countries are the same in homogeneous goods assumption,

$$pc_i^l = pc^l \qquad \text{(A22)}$$

Equilibrium in the model characterized by market clearing prices for goods and factors in each country such that

$$\sum_i X_i^l = \sum_i Q_i^l \qquad \text{(A23)}$$

$$\sum_l L_i^l = L_i \qquad \text{(A24)}$$

where L_i denotes total endowment of labor in country i . A zero profit condition must also be satisfied in each industry in each country, such that

$$p_i^l Q_i^l = w_i L_i^l \qquad l = M N M, \qquad \text{(A25)}$$

where p_i^l is production price of goods l in country i , and w_i is labor price in country i .

We introduce import tariff t_i (import tariff level of country i) into the model. This yields the following relation between consumption price and production price

$$pc_i^l = (1+t_i)\, p_j^l = pc^l \qquad \text{(A26)}$$

Import tariffs generate revenues R_i, which are given by

$$R_i = \sum_l \sum_{j,i\neq j} p_j^l M_{ij}^l t_{ij}^l \quad (A27)$$

where M_{ij}^l is import of goods l in country i from country j . The representative consumer’s income (I_i) in country i is given by

$$I_i = w_i L_i + R_i \quad (A28)$$

In the balanced trade assumption, total income equals total expenditure, that is $E_i = I_i$.

A2.2 Armington Goods Model

On the production side of the model, we assume a CES technology for production of each good in each country,

$$Q_i^l = \phi_i^l \left[\delta_i^l (L_i^l)^{\frac{\sigma_i^l-1}{\sigma_i^l}} + (1-\delta_i^l)(K_i^l)^{\frac{\sigma_i^l-1}{\sigma_i^l}}\right]^{\frac{\sigma_i^l}{\sigma_i^l-1}}, \quad i \in country, l \in goods \quad (A29)$$

where Q_i^l is the output of the lth industry (including both tradable and non-tradable goods) in country i , L_i^l and K_i^l are the labor and capital inputs in sector l , ϕ_i^l are the scale parameters, δ_i^l are the distribution parameters and σ_i^l is the elasticity of factor substitution. First order conditions imply the factor input demand equations.

$$K_i^l = \frac{Q_i^l}{\phi_i^l}\left[\delta_i^l\left[\frac{(1-\delta_i^l) w_i^L}{\delta_i^l w_i^K}\right]^{(1-\sigma_i^l)} + (1-\delta_i^l)\right]^{\frac{\sigma_i^l}{1-\sigma_i^l}} \quad (A30)$$

$$L_i^l = \frac{Q_i^l}{\phi_i^l}\left[\delta_i^l + (1-\delta_i^l)\left[\frac{\delta_i^l w_i^K}{(1-\delta_i^l) w_i^L}\right]^{(1-\sigma_i^l)}\right]^{\frac{\sigma_i^l}{1-\sigma_i^l}} \quad (A31)$$

where w_i^K and w_i^L are the prices of capital and labor in country i.

On the consumption side, we use the Armington assumption of product heterogeneity across countries. Whatever case, we take the CES utility function for each country

$$U_i(X_i^{NM}, X_i^{M}) = \left[(\beta_{i1})^{\frac{1}{\sigma_i}} (X_i^{NM})^{\frac{\sigma_i - 1}{\sigma_i}} + (\beta_{i2})^{\frac{1}{\sigma_i}} (X_i^{M})^{\frac{\sigma_i - 1}{\sigma_i}} \right]^{\frac{\sigma_i}{\sigma_i - 1}}, \quad i \in country \qquad (A32)$$

where X_i^{NM} denotes the consumption of non-manufacturing goods in country i, X_i^{M} denotes the consumption of manufacturing goods in country i. Additionally β_{i1} and β_{i2} are share parameters and σ_i is the elasticity of substitution in consumption.

There is a second level consumption for manufacturing goods (Non-manufacturing goods are assumed to be non-tradable and so it has only one level consumption). Here, X_i^M will denote the composite of manufacturing goods,

which is defined as another reflecting the country from which goods come. We assume this level 2 composite consumption

is also of CES form and represented as, (A33)

$$X_i^M = \left[\sum_j (\beta_{ij})^{\frac{1}{\sigma'_i}} (x_{ij}^M)^{\frac{\sigma'_i - 1}{\sigma'_i}} \right]^{\frac{\sigma'_i}{\sigma'_i - 1}}, \quad j = country$$

where x_{ij}^M is the consumption of manufactory goods from country j in country i. If $i = j$ this implies that this country consumes its domestically produced tradable goods. β_{ij} is the share parameter for country j's manufactoring goods consumed

in country i. σ'_i is the elasticity of substitution in level 2 preferences in country i.

The utility optimization problem above yields

$M \quad a \; E_{1i}$

$$X_i = (P_i^M)^{a}\left[a_{1i}(P_{i1}^M)^{-a} + a_{2i}(pc_i)^{NM}\right]^{1-a_i} \tag{A34}$$

$$X_i^{NM} = \frac{a_i E_i}{(pc_i^{NM})^{\sigma}[a_{i1}(P_i^M)^{1-\sigma} + a_{i2}(pc_i^{NM})^{1-\sigma}]} \quad \text{(A35)}$$

where P_i^M and pc_i^{NM} are the separate consumption prices of manufacturing goods and non-manufacturing goods in country i. E_i is the total consumption expenditure of country i.

Under the Armington goods assumption models, the demands of composite manufacturing goods which enter the second level preferences and come from different countries are

$$x_{ij}^M = \frac{\beta_{ij}(X_i^M P_i^M)}{(pc_{ij}^M)^{\sigma_i}[\sum_j \beta_{ij}(pc_{ij}^M)^{(1-\sigma_i)}]} \quad \text{(A36)}$$

where pc_{ij}^M is the consumption price in country i of manufacturing goods produced in country j, $X_i^M P_i^M$ is the total expenditure on manufacturing goods in country i. The consumption price for the composite of manufacturing goods is

$$P_i^M = \left[\sum_{j=1}^{15} \beta_{ij}(pc_{ij}^M)^{(1-\sigma_i)}\right]^{\frac{1}{1-\sigma_i}} \quad \text{(A37)}$$

and the total consumption expenditure of country i is

$$E_i = P_i^M X_i^M + pc_i^{NM} X_i^{NM} \quad \text{(A38)}$$

Equilibrium in the model characterized by market clearing prices for goods and factors in each country such that

$$Q_i^M = \sum_j x_{ji}^M, \quad Q_i^{NM} = X_i^{NM} \quad \text{(A39)}$$

$$\sum_l K_i^l = \bar{K}_i, \quad \sum_l L_i^l = \bar{L}_i \tag{A40}$$

A zero profit condition must also be satisfied in each industry in each country, such that

$$p_i^l Q_i^l = w_i^K K_i^l + w_i^L L_i^l \quad l = M, N, \tag{A41}$$

We introduce import tariff t_i (import tariff level of country i) into the model. This yields the following relation between consumption prices and production prices in country i for country j's exports.

$$pc_{ij}^M = (1 + t_i) p_j^M \tag{A42}$$

Import tariffs generate revenues R_i, which are given by

$$R_i = \sum_{j, i \neq j} p_j^M x_{ij}^M t_i \tag{A43}$$

The representative consumer's income (I_i) in country i is given by

$$I_i = w_i^K \bar{K}_i + w_i^L \bar{L}_i + R_i \tag{A44}$$

In the balanced trade assumption, total income equals total expenditure, so $E_i = I_i$.

A3. Unbalanced Trade Production General Equilibrium Models

We add an exogenous fixed trade imbalance assumption into the balanced general equilibrium model and then get the imbalanced general equilibrium models. All other parts of the model structure are the same as in balanced general equilibrium models. Exogenous fixed trade imbalance assumption means that one country's trade imbalance are exogenously determined and fixed in a level and do not change.

In the homogeneous goods model, we have a two countries, two goods and one factor structure. Two countries are China-ROW group, the US-ROW group and the EU-ROW group. Two goods are manufacturing goods and non-manufacturing goods. One factor is labor. Production function in the model is a fixed sector specific inputs and diminishing marginal productivity type, consumption function in the model is a CES type.

In the Armington goods model, we use a two countries, two goods and two factors structure. Two countries are China-ROW group, the US-ROW group and the EU-ROW group. Two goods are manufacturing goods and non-manufacturing goods. Two factors are labor and capital. Production function in the model is a CES type, and consumption function is a two-level nested CES type.

In the balanced trade general equilibrium models, total income equals total expenditure. But in the imbalanced trade general equilibrium models, total income will not equal total expenditure. We assume a trade surplus S_i for country i, and this trade surplus value are fixed and exogenously determined. If S_i is bigger than 0, it denotes trade surplus, and if S_i is smaller than 0, it denotes trade deficit. In the equilibrium, we have

$$E_i \square I_i \square S_i \tag{A45}$$

Additionally, total world trade surplus should equal to 0, so that

$$\square_i \quad S_{i0} \quad \square \qquad \text{(A46)}$$

B. Sensitivity Analysis Results

We report detailed sensitivity analysis results here. Three groups of models are analyzed separately one by one.

B1. Pure Exchange Models

Sensitivity analysis of optimal tariffs to preference elasticities and check confers optimal tariffs in Armington goods assumption are always larger than in homogeneous goods assumption. Optimal tariffs are sensitive to preference elasticities, and have a negative relation with preference elasticities (See Table B1 and Figure B1).

Table B1: Sensitivity of Optimal Tariff to Preference Elasticities under Pure Exchange Models (%)

Country/Elasticity		1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5
						Homogeneous Goods						
China-ROW	China	10.9	8.3	6.7	5.7	4.9	4.4	4.0	3.6	3.4	3.1	2.9
	ROW	56.7	41.9	33.6	28.3	24.7	22.0	19.9	18.3	17.0	15.9	15.0
US-ROW	US	7.7	5.9	4.8	4.1	3.6	3.2	3.0	2.7	2.5	2.4	2.2
	ROW	24.4	18.6	15.3	13.2	11.7	10.6	9.8	9.1	8.5	8.1	7.7
EU-ROW	EU	11.9	9.0	7.2	6.1	5.3	4.7	4.3	3.9	3.6	3.4	3.2
	ROW	35.7	27.2	22.3	19.1	16.9	15.3	14.0	13.0	12.2	11.5	11.0
						Armington Goods						
China-ROW	China	294	110	62.8	43.0	32.3	25.7	21.2	18.0	15.6	13.7	12.2
	ROW	384	161	97.7	68.8	52.6	42.3	35.3	30.1	26.2	23.2	20.7
US-ROW	US	239	106	62.0	42.9	32.5	26.0	21.6	18.4	16.0	14.1	12.6
	ROW	341	145	87.4	61.4	46.7	37.4	31.1	26.4	22.9	20.1	17.9
EU-ROW	EU	285	111	64.6	44.7	33.8	26.9	22.3	19	16.5	14.5	12.9
	ROW	335	141	84.6	59.3	45.1	36.1	29.9	25.4	22	19.4	17.2

Notes: "China-ROW" denotes the case of China-ROW mutual retaliation; "US-ROW" denotes the case of US-ROW mutual retaliation; "EU-ROW" denotes the case of EU-ROW mutual retaliation.

Source: calculated and compiled by authors.

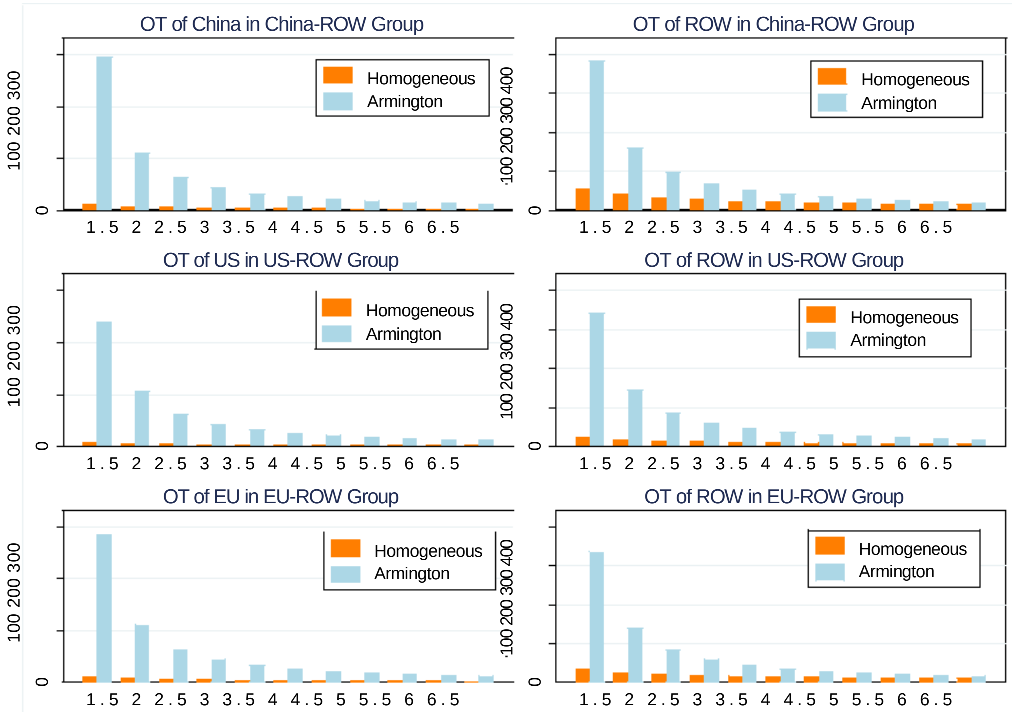


Fig. B1 Sensitivity of Optimal Tariffs to Preference Elasticities under Pure Exchange Models

Source: calculated and compiled by authors.

B2. With Production Balanced Trade GE Models

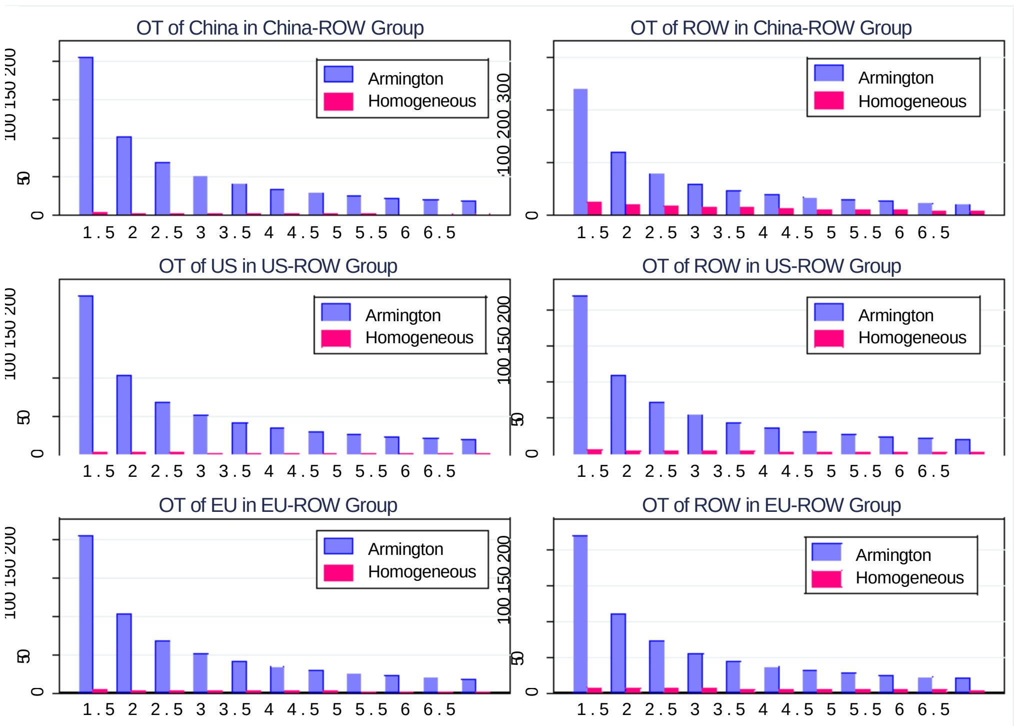
Sensitivity analysis of optimal tariffs to preference elasticities indicate that optimal tariffs decrease as preference elasticities increase. Also, optimal tariffs using the Armington goods assumption are much larger than optimal tariffs in homogeneous goods (See Table B2 and Figure B2).

Table B2: Sensitivity of Optimal Tariff to Preference Elasticities under Balanced Trade GE Models (%)

Country/Elasticity		1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5
						Homogeneous Goods						
China-ROW	China	3.5	3.1	2.8	2.6	2.3	2.1	2.0	1.9	1.7	1.6	1.6
	ROW	25.7	21.5	18.4	16.1	14.5	12.8	11.7	10.7	9.8	9.1	8.5
US-ROW	US	2.7	2.4	2.1	1.9	1.7	1.6	1.5	1.4	1.3	1.2	1.2
	ROW	5.5	5.0	4.5	4.2	3.9	3.6	3.4	3.2	3.0	2.8	2.7
EU-ROW	EU	4.1	3.6	3.2	2.9	2.7	2.5	2.3	2.1	2.0	1.9	1.8
	ROW	7.5	6.9	6.4	5.9	5.5	5.2	4.9	4.6	4.4	4.2	4.0
						Armington Goods						
China-ROW	China	204.9	102.4	68.3	51.2	41.1	34.2	29.3	25.7	22.8	20.6	18.7
	ROW	240.3	119.2	79.4	59.6	47.8	39.9	34.3	30.1	26.8	24.2	22.1
US-ROW	US	205.2	102.5	68.3	51.2	41.0	34.1	29.3	25.6	22.8	20.5	18.6

	ROW	217.6	108.6	72.5	54.4	43.6	36.4	31.2	27.4	24.4	22.0	20.0
EU-ROW	EU	205.8	102.8	68.5	51.4	41.1	34.3	29.4	25.7	22.9	20.6	18.7
	ROW	219.8	109.5	73.0	54.8	43.9	36.6	31.5	27.6	24.5	22.1	20.2

Notes: "China-ROW" denotes the case of China-ROW mutual retaliation; "US-ROW" denotes the case of US-ROW mutual retaliation; "EU-ROW" denotes the case of EU-ROW mutual retaliation.



Source: calculated and compiled by authors.

Fig. B2 Sensitivity of Optimal Tariffs to Preference Elasticities under Balanced GE Models

Source: calculated and compiled by authors.

B3. With Production Unbalanced Trade GE Models

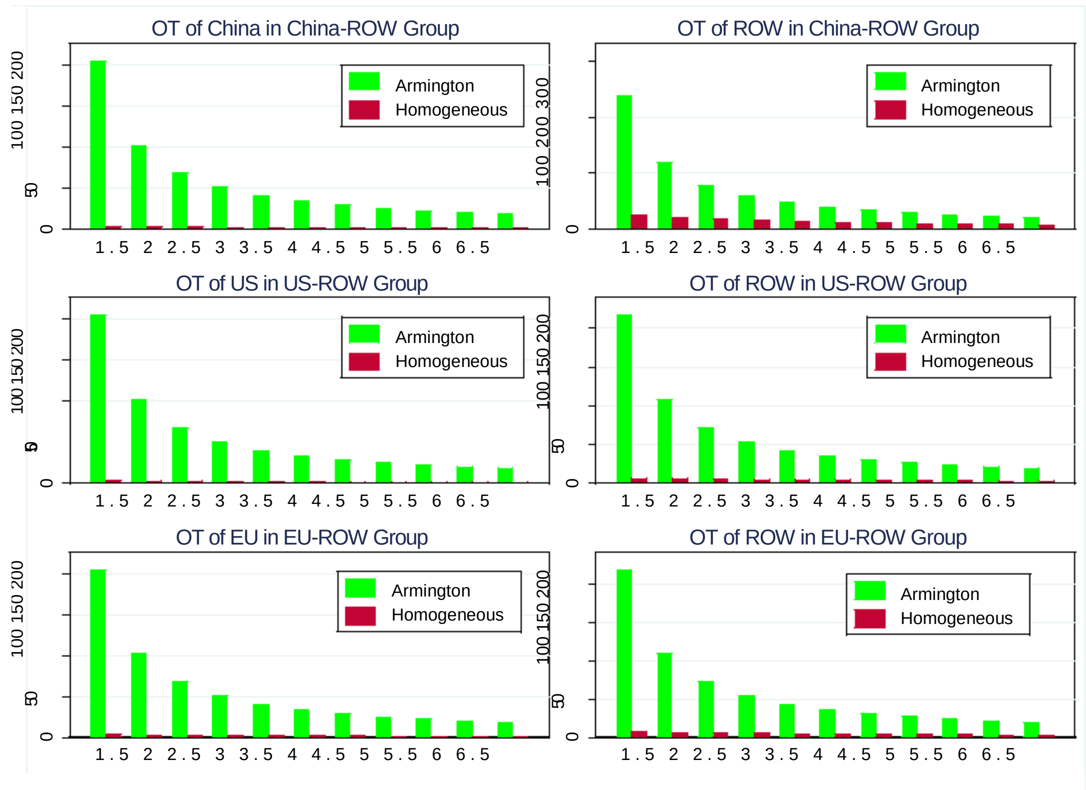
Sensitivity analysis of optimal tariffs to preference elasticities indicate that optimal tariff of Armington goods are larger than the ones of homogeneous goods, and bigger preference elasticity generates smaller optimal tariffs (See Table B3 and Figure B3).

Table B3: Sensitivity of Optimal Tariff to Preference Elasticities under Unbalanced Trade GE Models (%)

Country/Elasticity		1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5
						Homogeneous Goods						
China-ROW	China	3.4	3.0	2.7	2.5	2.3	2.1	2.0	1.8	1.7	1.6	1.5
	ROW	24.8	20.7	17.8	15.5	13.8	12.4	11.3	10.3	9.5	8.8	8.2
US-ROW	US	3.6	3.2	2.9	2.6	2.4	2.2	2	1.9	1.7	1.6	1.6

	ROW	7.1	6.5	5.9	5.4	5.0	4.7	4.4	4.1	3.9	3.7	3.5
EU-ROW	EU	4.1	3.6	3.2	2.9	2.6	2.4	2.3	2.1	2.0	1.8	1.7
	ROW	7.5	6.9	6.3	5.9	5.5	5.1	4.8	4.6	4.3	4.1	3.9
Armington Goods												
China-ROW	China	204.8	102.3	68.2	51.2	41.0	34.2	29.3	25.6	22.8	20.5	18.7
	ROW	237.9	118.1	78.7	59.1	47.4	39.6	34.0	29.9	26.6	24.0	21.9
US-ROW	US	204.1	102.0	68.0	51.0	40.8	34.0	29.2	25.5	22.7	20.4	18.6
	ROW	216.5	107.9	71.9	53.9	43.2	36.0	30.9	27.1	24.1	21.7	19.8
EU-ROW	EU	205.7	102.8	68.5	51.4	41.1	34.3	29.4	25.7	22.9	20.6	18.7
	ROW	219.4	109.3	72.9	54.7	43.8	36.6	31.4	27.5	24.5	22.1	20.1

Notes: "China-ROW" denotes the case of China-ROW mutual retaliation; "US-ROW" denotes the case of US-ROW mutual retaliation; "EU-ROW" denotes the case of EU-ROW mutual retaliation.



Source: calculated and compiled by authors.

Fig. B3 Sensitivity of Optimal Tariffs to Preference Elasticities under Unbalanced GE Models

Source: calculated and compiled by authors.