# ESSAYS ON INTERNATIONAL TRADE AND THE ECONOMICS OF CONFLICT

by

ZIJUN LUO

B.A., South China Normal University, 2007

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Economics
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# Abstract

This dissertation comprises three chapters in international trade and the economics of conflict. These chapters are put together according to two dimensions. From the international relations dimension, Chapter 1 analyzes free trade, which is the most “liberal” form of international relation; Chapter 2 analyzes different types of trade agreements, which is the most common and “moderate” form of international relation; and Chapter 3 analyzes conflict, which is the most violent and “extreme” form of international relation. From the proximity dimension, free trade usually occurs between countries that are far from each other, trade agreements usually signed by countries with in a region, and conflict usually happens between two very close countries.

Chapter 1 develops a novel model of international trade in which transportation costs are driven by trade imbalance of an individual country. This task is accomplished by assuming a representative transportation firm in each country that competes with its counterparts from other countries for international operation. The model of trade imbalance driven costs complements results from traditional international trade model in that it sheds light on how trade costs are affected by country size. With multiple countries and a continuum of production firms in each country under monopolistic competition, we derive an index of transportation costs to capture bilateral trade barriers for country pairs. This index is time-variant, which makes it suitable for panel data studies. Based on the index, simulation and simplified three-country free trade model show that countries with a relatively larger size incur a trade deficit while smaller size implies a trade surplus under free trade. A gravity equation is derived and estimated using Poisson Pseudo Maximum Likelihood. Estimation results support the fitness and robustness of the theoretical model of trade using the constructed transportation cost index. Further, statistical test shows that this transportation cost index is a better approximation of bilateral trade cost than distance.

A growing number of recent regional trade agreements (RTAs) have introduced provisions concerning cross-border investments. Likewise, a substantial number of RTAs have been preceded by agreements regarding cross-border investments. In Chapter 2, we develop a partial equilibrium three-country model to examine the relationship between RTAs and FDI while also allowing for double taxation. Our analysis shows that the formation of an RTA

between two regional countries with wage asymmetry is welfare-improving for the low-wage country and the region, but can be welfare-deteriorating for the high-wage country. We extend our analysis to examine the role of repatriation taxes in the determination of firm location when an RTA is and is not established. Our final result suggests that the signing of an RTA would not induce the relocation of a plant from the high-wage country to the low-wage country unless a reduction of the repatriation tax rate also occurs.

In Chapter 3, we attempt to resolve the "inefficiency puzzle of war" by developing a general equilibrium model of bargaining and fighting with endogenous destruction. In the analysis, we consider the scenario that two contending parties engage in bargaining to avoid fighting when there are direct costs (e.g., arms buildups) and indirect costs (e.g., destruction to consumable resources) of conflict. Taking into account different modes of "destruction technology" (in terms of weapons' destructiveness) without imposing specific functional form restrictions on conflict technology and production technology, we characterize their interactions in determining the Nash equilibrium choice between fighting and bargaining. We find that bargaining is costly as the contending parties always allocate more resources to arming for guarding their settlement through bargaining (but under the shadow of conflict) than in the event of fighting. Contrary to conventional thinking that bargaining is Pareto superior over fighting, we show conditions under which fighting dominates bargaining as the Nash equilibrium choice. The positive analysis may help explain the general causes of fighting, strikes, international conflict, and wars without incomplete information or misperceptions.

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# Dedication

To my family, for their continuous support and love in my life.

# Chapter 1 - Transportation Costs and Trade Imbalance: Theory and Evidence

*For international shipments, customs authorities often charged duties on the container as well as the contents. And then there was the cost of sending emptied boxes back where they had come from, which "has always been a heavy handicap to container transport," Jean Levy, director of the French National Railway, admitted in 1948.*

-"The Box" (Levinson, 2006, pp. 32)

## 1 Introduction

International trade balance being the main concern of economists and policy makers has a long history. A handful of theories have explained why and how trade happens[1], but it seems that not much had been done to examine how trade balance or imbalance affects transportation costs and leads to changes in exports and imports. One important role that trade imbalance has on trade costs is described by the above quotation. In the extreme case, imagine a country being an absolute exporter with no imports. It is arguably true that transportation costs for this country would be significantly higher than a country with relatively balanced trade. Containers and other facilities of this absolute exporter would travel from home to foreign countries then never come back, or come back empty. In either case, it puts extra costs on outward shipments.[2]

In the international trade literature, iceberg transportation costs are usually assumed to be exogenous and constant. Empirically, distance between two countries' capital cities is often used as the approximation of this symmetric bilateral trade cost. But distance is not a good proxy of actual shipping length when at least one of the two trading partners is a big country. Further, since distance is time-invariant, such approach prohibits international trade researchers from utilizing panel data estimations.

[1] See, for example, Heckscher (1919), Ohlin (1933), Samuelson (1948), Vernon (1966), Melvin (1968), Vanek (1968), Dornbusch, Fischer, and Samuelson (1977), Krugman (1979, 1980), Leamer (1980), Trefler (1995), Conway (2002), Melitz (2003).

[2] This is coined by Pigou (1913) as the "backhaul problem."

Further limitation of using distances as a proxy for transportation costs is illustrated in Table 1.1. The four sample countries are chosen because distance from China to either US or New Zealand is similar, and distance from Colombia to US is significantly shorter than China to US. Table 1.1 reports the unit transport costs of two products traded between these four countries in 2007, the latest year available from the OECD Maritime Transport Cost (MTC) Database. Product 1 in the table is "Footwear, Gaiters and the like, parts thereof" while Product 2 is "Toys, games, sports requisites."

**Table 1.1 Asymmetric Transportation Costs**

| Exporter | Importer | Product 1 | Product 2 | Distance (km) |
|---|---|---|---|---|
| China | US | 0.4211 | 0.3902 | 11207 |
| US | China | 0.2126 | 0.1231 | 11207 |
| China | New Zealand | 0.4705 | 0.3580 | 10750 |
| Colombia | US | 0.5428 | 0.4183 | 3851 |

All numbers are unit transport cost (equals to total costs of transportation divided by quantities) in US dollars.

Three observations can be drawn from Table 1.1. First, unit costs of shipments between two countries are different by directions. This is revealed by the first and second rows of the table in which costs from China to US are significantly higher than those from US to China. Second, similar distance could result in big differences in unit costs of shipments. This is revealed by the comparison between the first and the third rows. Third, unit costs of shipments could be higher even for a shorter distance. This is revealed by comparing the first and the fourth rows of the table.[3]

This paper intends to build a model of international trade to synthesize existing trade theories with the second and third observations from Table 1.1. In the model, we allow the presence of representative transportation firms. These transportation firms explicitly take into account both total trade flows and trade imbalance of different countries when making their

[3] In this footnote I present some further heuristic observations on the incompetence of using distance as the proxy of trade costs. In an article (http://news.van.fedex.com/intl/mx?node=10291) on May 2008, Juan N. Cento, the President of the FedEx Express Latin America and Caribbean Division says, "(OECD) suggests that although proximity to the U.S. is a competitive advantage to Latin American…insufficient infrastructure drives up transaction and transportation costs, and this impairs Latin America countries' competitiveness with hot markets like China." In an article titled "The Tormented Isthmus" published in *The Economist* (April 16-22, 2011), the author says that "it can be cheaper to ship goods to the United States from China than from Central America, according to a World Bank study."

pricing decisions to compete with each other in the international market. Three key characters of the paper should be mentioned. First, distance is not included into the model. This assumption leaves observation 1 from Table 1.1 unanswered. Instead, we derive a transportation cost index (TCI) to capture bilateral trade costs. This time-variant index is a function of trade imbalance, which is endogenously determined by national incomes of trading partners under monopolistic competition. Second, unlike Anderson (1979) and Anderson and van Wincoop (2003) who assume all supply prices are equal to one, we use the assumption that price index to be equalized among countries and normalized to one when deriving the gravity equation under general equilibrium framework. The similarity of aggregate prices among different countries is reported in Waugh (2010). Third, the theoretical model is tested using bilateral trade flow data between countries without relying on the firm level data.[4] The empirical results are consistent with the theory.

To further show how trade imbalance can affect transportation costs and hence trade costs, we look at 58 out of 74 countries within my full sample in the OECD MTC Database. For container shipments only[5], we average unit costs of all products by exporter and year from 1993 to 2007. The result is an 870-by-1 vector of trade costs, $c_{it}$. We then run the following regression:

$$c_{it} = \alpha_0 + \alpha_1 imb_{it} + u_i + v_t + \varepsilon_{it},$$

where $imb_{it}$ is the trade imbalance (in absolute value) of country $i$ at time $t$, $u_i$ and $v_t$ are country and time fixed effects. Regression result shows that $\alpha_1 = 0.7811$ at 5% significance level. This confirms the effect of trade imbalance has had on trade costs.

While my model leaves the question of asymmetric bilateral trade costs (observation 1 from Table 1.1) unanswered, it is the intention of Eaton and Kortum (2001, 2002) and Waugh (2010) to build a model and address this aspect of international trade. These papers derive their

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[4] For studies of international trade using firm level data, see, for example, Roberts and Tybout (1997) and Pavcnik (2002).

[5] The use of only 58 countries is due to data availability. Those 16 countries excluded are shown as *italic* in Table A.1 in Appendix A. Data not available for European countries is due to the fact that OECD MTC Database pooled 15 EU countries together. The reason to only work with container shipping is because container shipping is the most common form of seaborne international trade. Other methods such as clean bulk, dirt bulk, and tanker are in general lack of observations from OECD MTC.

gravity equation for estimation under Ricardian rather than monopolistic competition. As described by Waugh (2010) within a three-country framework, Eaton and Kortum (2001, 2002) assume that asymmetric trade costs are contingent to importers such that importing costs of the country with highest income (say United States) are the same but importing a good from US has lower trade costs for the country with lowest income level. On the other hand, Waugh (2010) assumes that these costs to be contingent to exporters such that exporting costs of US are the same but exporting a good from the lowest income country to US has a lower trade cost. Both approaches fit data significantly better than traditional gravity equation with symmetric trade costs although the two specification result in different implication for aggregate price, productivity, and income differences.

Hummels (2007) provides a detailed review on different modes of transportation for international shipments as well as their freight rates. He finds that recent development of air cargo makes distance a relatively small barrier to trade, which validates my approach of not incorporating distance in the model. Anderson and van Wincoop (2004) present a comprehensive review on trade costs, both internationally and domestically. They conclude that trade costs are large and are linked to many different aspects of economies involved. The current study provides insights for one of these aspects, namely trade imbalance. Based on a regression result which uses ad-valorem freight rate as dependent variable and distance as one of the independent variables, Hummels (2001) evaluates coefficients of symmetric trade barrier proxies such as distance, common language, and common border reported in existing literature, and finds that these variables yield implausibly large implied trade costs. One of the possible explanations is that these proxies capture some unknown factors in addition to trade barriers. Hummels (2001) also suggests that "import choices are made so as to minimize transportation costs," which justifies the assumption that asymmetric trade costs are contingent to importers as discussed in Eaton and Kortum (2001, 2002).

In their efforts to better understand the relationship between transportation costs and trade volumes, Baier and Bergsrand (2001) allow for additional transaction costs of international trade such as costs of distributing, marketing, and tailoring. They do so by noted that different markets for the same product are unlikely to be substituted costlessly. To accommodate such problem, they follow Bergstrand (1985) in assuming a constant elasticity of transformation function in capturing a country's international supply. They find that from late 1950s to 1980s, income growth of countries account for 67% of growth of trade while transportation cost declines only account for 8%.

Jacks and Pendakur (2010) argue that the best time period to examine whether transportation costs reduction contributed to trade growth is late nineteenth century and early twentieth. They use a semiparametric approach to construct a freight rate index to capture bilateral trade freight rate. Using data of UK and its trading partners, they find that transportation cost reduction virtually contributed nothing to trade growth.

It should be noted that there are two recent papers analyzing the relationship between export and import flows. Kasahara and Lapham (2008) and Halpern, Koren, and Szeidl (2009) develop models at the firm level to examine how productivity might be different when firms make decisions on both importing intermediate inputs and exporting final goods. These papers assume two fixed costs: one for importing intermediaries and another for exporting. The total fixed cost then gets a discount if a firm is both an importer and an exporter. Particularly, Kasahara and Lapham (2008) consider firm level productivity and shipping cost heterogeneity. Using Chilean firm level data, they find that firms with high productivity and low shipping costs tend to self-select into importing intermediaries and exporting. Using Hungarian firm level data, Halpern, Koren, and Szeidl (2009) find that imported inputs have large effects on productivity, which can be attributed to the complementary effects of these imported inputs with other goods in the production process.

In this paper, we provide a simple model to link imports, exports, and trade costs, hoping to contribute to the literature in three aspects. First, the approach to model trade costs, although bilaterally symmetric, is not presumably contingent upon importers or exporters as those in Eaton and Kortum (2001, 2002) or Waugh (2010). Second, unlike Kasahara and Lapham (2008) and Halpern, Koren, and Szeidl (2009), the present model relates exports and imports at the aggregate level by stressing that trade imbalance might lead to changes of bilateral trade costs and hence affect international trade. Third, unlike Jonkeren et al (2011) that use micro data and a reduced-form approach to access the endogeneity of transport prices empirically, we derive a structural model and use aggregate data for my estimation.

The rest of the paper is organized as follows. The next section lays out the theoretical model of multiple countries with a continuum of production firms and a representative transportation firm in each country, followed by a simplified three-country model in Section 3. Section 4 presents the empirical specification and tests the theoretical model using Poisson Pseudo Maximum Likelihood. The last section concludes.

## 2 Theoretical Model

There are $N$ countries in the world and these countries can freely trade with each other. The population of country $i$ is $L_i$. Each country has two types of firms – a continuum of production firms and a representative transportation firm. Production firms can potentially serve the domestic market and/or international markets. Consumers and firms in all countries play a sequential game. In the first stage, transportation firms determine their shipping prices and bid for operation. In the second stage, consumers and production firms make consumption and production decisions simultaneously. The model is solved backwardly.

### *2.1 Consumption*

Assume identical representative consumers with C.E.S. utility function in all countries as in Dixit and Stiglitz (1977), Krugman (1979), Melitz (2003), and Chaney (2008). The representative consumer of country $i$ maximizes utility

$$U_i = \left(\sum_y q_y^{\sigma-1/\sigma}\right)^{\sigma/\sigma-1}$$

subject to the budget constraint

$$\sum_y p_y q_y = I_i \,,$$

where $p_y$ and $q_y$ are respectively price and quantity demanded of good $y$, $\sigma$ is the constant elasticity of substitution between any two good, and $I_i$ is the income of consumer $i$. As is well-known, in equilibrium,

$$q_y = p_y^{-\sigma} I_i \left(P^i\right)^{\sigma-1}, \tag{1.1}$$

where $P^i \equiv \left(\sum_y p_y^{1-\sigma}\right)^{1/1-\sigma}$ is the cost-of-living aggregate price index of country $i$.

## *2.2 Production*

In each country, there is a continuum of production firms with each firm only produces one product. Follow Melitz (2003), each firm has a sunk cost of entry before it draws a productivity level $\varphi$ from a common distribution $g(\varphi)$. $\varphi$ is the constant marginal product of labor. If a firm decides to export, there is an additional common fixed sunk cost of exporting to each market. Assume the wage rate to be 1. Once a firm is operating/exporting, the variable profit of such firm in country *j* with productivity $\varphi$ is given by

$$\pi_j^d = p_j^d q_j - q_j / \varphi - f \qquad \text{for domestic sales}$$

$$\pi_j^x = p_j^x \sum_i q_{ji} - \left(\sum_i T_{ji} q_{ji}\right) \Big/ \varphi - f \qquad \text{for international sales}$$

where $p_j^z$ ($z = d, x$) is the price of the firm's product, with superscript *d* denotes domestic, and *x* international, $f$ is the fixed cost of operating common to all firms, $T_{ji}$ is iceberg transportation cost common to all products produced in country *j*. $T_{ji}$ units must be shipped for 1 unit of country *j*'s product to reach country *i*, and this rate is to be determined by transportation firms in the first stage of the game. Solving for the prices of domestic and international sales, we have

$$p^d = \frac{\sigma}{(\sigma - 1)\varphi}, \tag{1.2a}$$

$$p^x = \frac{\sigma T_{ji}}{(\sigma - 1)\varphi}. \tag{1.2b}$$

As in Melitz (2003), the free entry condition and the zero-profit condition of exporting identify a cutoff level of productivity $\varphi_x$, below which firms serve only domestically. Since the evolution of productivity is not the concern of this paper, there is no need to solve for this cut-off productivity level explicitly.

## *2.3 Transportation*

There is one representative transportation firm in each country. These transportation firms bid on the international market by offering their profit-maximizing prices. Also, each transportation firm is assumed to be able to handle imports to and exports from its home country only.[6]

First, define

$$S_i \equiv L_i \left(P^i\right)^{\sigma-1}$$

as country size adjusted by cost-of-living price index and call this the adjusted country size. The import of country *i* from country *j*, which can be derived from equations (1.1) and (1.2b), is given by

$$q_{ji} = S_i \left(\frac{\sigma T_{ji}}{\sigma-1}\right)^{-\sigma} \int_{\varphi_x}^{\infty} \varphi^{\sigma} d\varphi \tag{1.3}$$

where $T_{ji} \equiv 1 + t_{ji}$, and $t_{ji}$ is the unit shipping price set by the transportation firm handling shipments between country *i* and country *j*. If we aggregate $q_{ji}$ over *j* assuming all countries have the same productivity distribution[7], and let $\tilde{\varphi}^{\sigma}$ denote the integral term in equation (1.3), we have the total import of country *i* equals to

$$Q_i^{im} = S_i \tilde{\varphi}^{\sigma} \sum_j \left(\frac{\sigma T_{ji}}{\sigma-1}\right)^{-\sigma} \tag{1.4}$$

for all $j \neq i$. Also, we can calculate the total export of country *j* by aggregating $q_{ji}$ over *i*, after switching subscripts, to get

$$Q_i^{ex} = \tilde{\varphi}^{\sigma} \sum_j S_j \left(\frac{\sigma T_{ij}}{\sigma-1}\right)^{-\sigma} . \tag{1.5}$$

Furthermore, the trade imbalance, in absolute terms, between any trading partners *i* and *j* is

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[6] This assumption is theoretically equivalent to the assumption that all ships and containers have to be fully loaded and cleared at any port. In other words, I rule out the possibility that shipments from the United States to France be partially clearing at UK although UK might be along the route from US to France.

[7] This assumption is maintained throughout the paper. This assumption implies that the model with continuous firms is simplified into a version with only two representative production firms in any given country, one serves domestically only, and the other serves both domestic and international markets.

$$\delta_{ij} = \delta_{ji} = \left( \frac{\sigma T_{ij}}{\sigma - 1} \right)^{-\sigma} \left| S_i - S_j \right| \tilde{\varphi}^{\sigma} \tag{1.6}$$

where $T_{ij} = T_{ji}$ in equilibrium. Aggregating equation (1.6) over *j*, we get the total trade imbalance of country *i* as

$$\Delta_i = \left( \frac{\sigma}{\sigma - 1} \right)^{-\sigma} \tilde{\varphi}^{\sigma} \sum_j \left( T_{ij} \right)^{-\sigma} \left| S_i - S_j \right|. \tag{1.7}$$

Assume that each of the representative transportation firms competes for operation in the international market by offering a bid that equals to the optimal price it would offer *as if* the representative transportation firm handles all exports from and imports to its home country, taking into account trade imbalance. Specifically, profit of the transportation firm in country *i* is given by

$$\pi_i^T = \left( t_i - C^T \right) Q_i - \theta \Delta_i - f^T,$$

where $t_i$ is the bid offered by the firm and hence the price charged to international shipments, $C^T$ is the constant marginal cost of operating hereafter normalize to 0, and $f^T$ is sunk cost of operation. Both $C^T$ and $f^T$ are common to all transportation firms, $Q_i = Q_i^{im} + Q_i^{ex}$ is calculated according to equations (1.4) and (1.5), $\theta(>0)$ is the marginal inefficiency due to trade imbalance, and $\Delta_i$ is from equation (1.7). We assume transportation firms bid with no charge. Further, assume these firms operate with inputs other than labor (for example, capital) so there is no competition between transportation and production firms. Note that with *N* countries, we need either one of the following assumptions: (i) All these countries are locating in an (*N*-1)-dimensional Euclidean space with equal distance to each other, or (ii) Freight rates are not a function of distance. We rewrite the profit of transportation firm *i*, after plugging in equations (1.4), (1.5), and (1.7), to obtain

$$\pi_i^T = \left( \frac{\sigma T_i}{\sigma - 1} \right)^{-\sigma} \left[ \left( T_i - 1 \right) \left( \left( N - 1 \right) S_i + \sum_j S_j \right) - \theta \sum_j \left| S_i - S_j \right| \right] \tilde{\varphi}^{\sigma} - f^T.$$

Solving for $T_i$ that maximizes $\pi_i^T$, we have

$$T_i^* = \frac{\sigma}{\sigma - 1}\left[1 + \frac{\theta \sum_j \left|S_i - S_j\right|}{(N-1)S_i + \sum_j S_j}\right] \quad \forall i \neq j. \tag{1.8}$$

The shipping price offered by country *i*'s transportation firm is hence given by $T_i^* - 1$. Equation (1.8) exhibits the tradeoff between total trade volume and trade imbalance. Note that the denominator of the fraction term inside the bracket can be rewritten into $(N-2)S_i + S_w$, where $S_w \equiv \sum_i S_i$, for all *i*. Thus the denominator is increasing in adjusted country size and the adjusted size of the world. The numerator is non-monotonic in the adjusted country size $S_i$, given all $S_j$, for all $j \neq i$. Since the competition between these transportation firms is Betrend price competition in nature, $T_i^*$ is also the solution that satisfies $\pi_i^T - f^T = 0$. In other words, once these transportation firms started to operate, they are operating with zero variable profits.

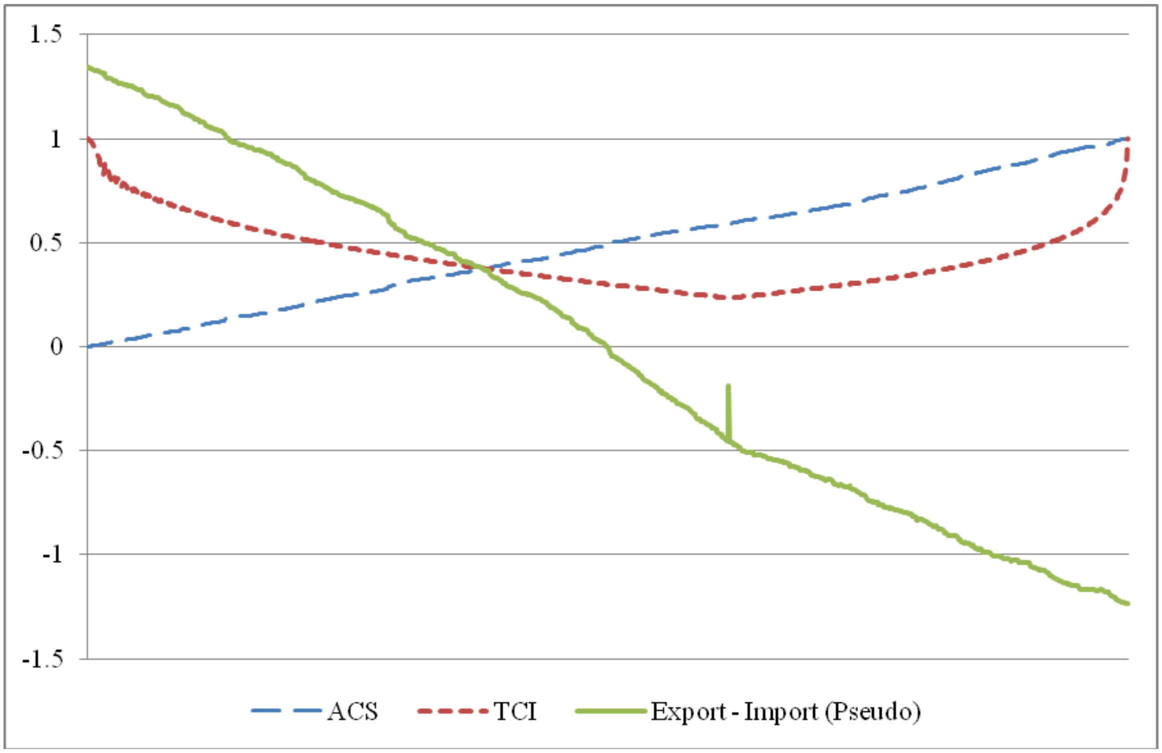
Using equation (1.8), we can generate a vector of transportation prices in each year that are indirectly related to trade flows around the world. Specifically, define

$$\Omega_{it} \equiv \frac{\sum_j abs\left|S_{it} - S_{jt}\right|}{NS_{it} + \sum_j S_{jt}} \tag{1.9}$$

as the transportation cost index (TCI) of country *i* at time *t* which is positively related to $T_{it}^*$. For time *t*, we can generate this index associated with all countries given data of adjusted country sizes. Without loss of generosity, we drop time dimension in the rest of this section. Note that in the generation, once the lowest value is calculated, say from country *m*, $S_m$ should be removed and the values of the index change for all countries that remain. Then the second lowest $T_i^*$ can be calculated. This is a continuous bidding process. The resulting TCI is an *N*-1 dimensional vector. We can further construct an $N \times N$ TCI matrix, denoted as $\omega$, to determine the transportation cost resulting from trade imbalance between country *i* and country *j* for any given year. If

$\Omega_m = \min\{\Omega_i\}$ for all $i$, then $\omega_{mj} = \omega_{im} = \Omega_m$ for all $i$ and $j$. We then find the second lowest $\Omega_i$, say $i = n$, and hence $\omega_{nj} = \omega_{in} = \Omega_n$ for all $i, j \neq m$. This process continues and will result in a $N \times N$ matrix of TCI at any given year.

**Figure 1.1 Simulation Result with 1000 Draws**




To illustrate, we generate 1000 random draws from uniform distribution to represent adjusted-country-size (ACS) and calculate the TCI and trade surplus/deficit[8] of each country based on these draws. Results are depicted in Figure 1.1 with ACS plotting increasingly and the pseudo value of trade surplus/deficit scaling down by $10^3$. Three results stand out from Figure 1.1. First, the lowest TCI occurs in the mid-range of ACS, the 615th from the bottom and the value being around 0.5. Repeating the simulation for 1000 times, we find that on average the lowest TCI occurs at 618.2280 with a standard error equals to 3.0799.

[8] Noting that trade values are positively related to ACS but negatively related to TCI, I use $S_i / \omega_{ji}$ to represent trade value from country *j* to country *i*.

Second, the trend of the ACS line and the pseudo trade surplus/deficit line are negatively related. Hence, in general, countries with larger ACS suffer trade deficits while countries with smaller ACS incur trade surplus.

Third, the general trend of the pseudo trade surplus/deficit line breaks and jumps upward for the country with the lowest TCI. In theory, this can result in either a trade surplus or trade deficit depending upon the adjusted sizes of all countries. The next section further uses a three-country world trade model to show the implication of these three results from simulation.

## 3 Three Country Model

Set aside the ($N$-1)-dimensional Euclidean space assumption, for a world with only three countries, the current model shows that when the three countries are of equal distance to each other, the transportation costs can be different, which is conform with observation 2 in Table 1.1. This model also implies that, transportation costs, or more generally the bilateral trade costs, can be lower even with longer distance, which is conform to observation 3 in Table 1.1. These features are significantly different from traditional trade models which assume constant iceberg transportation costs and use distance as the proxy. In this section, we use a three-country model, with the assumption that they are of equal distance to each other and $S_A > S_B > S_C$, to analyze the implication of the proposed new model of international trade.

First, defining $S_W \equiv S_A + S_B + S_C$, we have from equation (1.9) that for each country

$$\Omega_A = \frac{2S_A - S_B - S_C}{S_A + S_W};\ \Omega_B = \frac{S_A - S_C}{S_B + S_W};\ \Omega_C = \frac{S_A + S_B - 2S_C}{S_C + S_W}.$$

These values lead to the following proposition:

**PROPOSITION 1.1.** *In a three country world with transportation costs resulting from trade imbalance, the representative transportation firm in country with medium adjusted size offers the lowest price.*

To prove, first note that $\Omega_B$ has a bigger denominator and a smaller numerator than $\Omega_C$ hence $\Omega_B < \Omega_C$. Also, we have

$$\Omega_A - \Omega_B = \frac{2(S_A - S_B)(S_B + S_C)}{(S_A + S_W)(S_B + S_W)} > 0,$$

which completes the proof of the proposition. Proposition 1.1 indicates that the representative transportation firm in country B, the country with medium adjusted size, handles all world trade except for those between country A and country C. This is the special case of the first result from the simulation presented in Figure 1.1.

With only three countries, we determine the second lowest TCI as

$$\Omega'_A = \Omega'_C = \frac{S_A - S_C}{S_A + S_C}.$$

Due to the nature of bilateral trade, prices offered by the transportation firms of country A and country C are identical. Without loss of generosity, we pick country A's transportation firm to be the one that operates. We find that $\Omega_B < \Omega'_A$ since both values have the same numerator but $\Omega_B$ has a bigger denominator. From equations (1.2b) and (1.4), we derive the total value of trade from country *j* to country *i* as

$$V_{ji} = \left(\frac{\sigma T_{ji}}{\sigma - 1}\right)^{1-\sigma} S_i \tilde{\varphi}^{\sigma-1}. \tag{1.10}$$

Based on the assumption that $S_A > S_B > S_C$ and that $T_{ji}$ is positively related to $\Omega_{ji}$, we have

$$V_{AB} = V_{CB};\ V_{BA} > V_{AB};\ V_{CB} > V_{BC}; \tag{1.11a}$$

$$V_{CA} > V_{AC}; \tag{1.11b}$$

$$V_{BA} > V_{CA};\ V_{BC} > V_{AC}. \tag{1.11c}$$

In (1.11a), all $V_{ji}$ have the same $T_B$, the transportation costs, since all route connected to country B using transportation firm in B. As a result, the differences of $V_{ji}$'s only owe to $S_i$. Because $V_{ji}$ is an increasing function of $S_i$ we hence get (1.11a) given that $S_A > S_B > S_C$. Similarly, all $V_{ji}$ in (1.11b) have the same $T_A$. In (1.11c), $V_{ji}$ of the LHS of the inequality signs has a lower $T$ and a higher $S_i$, with $V_{ji}$ being an decreasing function of $T$. Summarizing all these relationships, we reach

$$V_{AC} < V_{BC} < V_{AB} = V_{CB} < V_{BA}. \tag{1.12}$$

Equations (1.11) and (1.12) permit us to establish the following proposition:

**PROPOSITION 1.2.** *In a three country world with transportation costs resulting from trade imbalance, after adjusting country size for cost-of-living, the largest country has net trade deficit (imports exceed exports) whereas the smallest country has net trade surplus (exports exceed imports).*

Proposition 1.2 is the special case of the result that trade surplus/deficit is negatively related to ACS presented in Figure 1.1. One possible reason for the existence of trade deficit of large countries is because they tend to consume more, both domestically and internationally, and export less. Trade imbalance further raises the transportation costs and worsens trade imbalance for these large countries. When cost-of-living is not so different everywhere around the world, the size of country can be approximated by real GDP of a country. This explains why United States has trade deficit in most of the 20th century and continues so after passing the millennium and, at the same time, Ecuador has trade surplus.

For the medium country, we calculate its trade balance, defined as exports minus imports, using equation (1.10) and get

$$\left(V_{BA} - V_{AB}\right) + \left(V_{BC} - V_{CB}\right) = \left(S_A + S_C - 2S_B\right)\left(\frac{\sigma T_B}{\sigma - 1}\right)^{1-\sigma} S_i \tilde{\varphi}^{\sigma-1}. \tag{1.13}$$

We thus have the next proposition:

**PROPOSITION 1.3.** *In a three country world with transportation costs resulting from trade imbalance, the country with medium adjusted size can either has a trade surplus or trade deficit depending on the size of the three countries.*

The RHS of equation (1.13) should not be taken quantitatively although it shows that if the adjusted size of the medium country is greater than the average of the adjusted size of the other two countries, it would have trade deficit, and vice versa. The more general case of

Proposition 1.3 was presented in the third result followed Figure 1.1. An application of this result is to note that the status of the medium country's trade account can evolve over time.

## 4 Empirical Model

To empirically test the theory, ideally one can follow the literature on demand system analysis to use the Almost Ideal Demand System developed by Deaton and Muellbauer (1980) or its variations. This strand of literature provides insights about the relationship between price and quantity demanded. But for internationally trading commodities, quantity measures could differ for the same product traded. On the other hand, even with value and quantity data in hand, the calculated prices using value-divide-quantity is often unreliable. First, one has to be cautious about whether the calculated price is the price that the exporter sold to the importer, or that the importer sold to consumers. Second, when this exercise is performed on the data described by Feenstra et al (2005), the price variation can be dramatic on the same product for the same exporters and importers in consecutive years.

We hence follow the tradition in the international trade literature by using trading values as the dependent variable. Note that when specialized transportation firms are handling shipments, they can combine shipments from different industries. As a result, we can focus on total value traded instead of values by industry. As in Anderson (1979), Deardorff (1998), and Anderson and van Wincoop (2003), a gravity equation can be derived from a typical C.E.S. utility preference under general equilibrium. To save space and without confusion, we drop $\varphi$ and $\tilde{\varphi}$ in this section.

### *4.1 Gravity Equation*

From equation (1.1), one can derive

$$v_y = p_y^{1-\sigma} \left(P^i\right)^{\sigma-1} I_i ,$$

as the value spent on product *y* by the representative consumer of country *i*. The total value from country *j* to country *i* can thus be written as

$$V_{ji} = \left(T_{ji} p_j^d\right)^{1-\sigma} \left(P^i\right)^{\sigma-1} I_i . \tag{1.14}$$

where $p_j^d$ is the domestic price of product from country *j* that also sold internationally. Summing over subscript *j*, we get the total importing value of country *i* as

$$V_i^{im} = \left(P^i\right)^{\sigma-1} I_i \sum_j \left(T_{ji} p_j^d\right)^{1-\sigma}, \tag{1.15}$$

while summing over *i* and switching subscript gives the total exporting value of country *i* as

$$V_i^{ex} = \left(p_i^d\right)^{1-\sigma} \sum_j T_{ji}^{1-\sigma} \left(P^j\right)^{\sigma-1} I_j . \tag{1.16}$$

Note that by definition,

$$P^i = \left[\left(p_i^d\right)^{1-\sigma} + \sum_j \left(T_{ji} p_j^d\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}} .$$

Thus equation (1.15) can be rewritten as

$$V_i^{im} = I_i - \left(P^i\right)^{\sigma-1} \left(p_i^d\right)^{1-\sigma} I_i . \tag{1.17}$$

General equilibrium requires $V_i^{im} = V_i^{ex}$.[9] Using equations (1.16) and (1.17), we have

$$I_i - \left(P^i\right)^{\sigma-1} \left(p_i^d\right)^{1-\sigma} I_i = \left(p_i^d\right)^{1-\sigma} \sum_j T_{ji}^{1-\sigma} \left(P^j\right)^{\sigma-1} I_j . \tag{1.18}$$

Solving for $p_i^d$, we get

$$\left(p_i^d\right)^{1-\sigma} = \left[\left(P^i\right)^{\sigma-1} I_i + \sum_j T_{ji}^{1-\sigma} \left(P^j\right)^{\sigma-1} I_j\right]^{-1} I_i . \tag{1.19}$$

Rewrite equation (1.14) for the value from country *i* to country *j*, and substituting in equation (1.19), we get

$$V_{ij} = \frac{\left(T_{ij}\right)^{1-\sigma} \left(P^j\right)^{\sigma-1}}{\left(P^i\right)^{\sigma-1} I_i + \sum_j T_{ij}^{1-\sigma} \left(P^j\right)^{\sigma-1} I_j} I_i I_j . \tag{1.20}$$

---

[9] One might notice the difference between the partial equilibrium framework in the earlier section of this paper and the general equilibrium (GE) framework here. These two frameworks can be reconciled by assuming the existence of foreign direct investment (FDI) and financial assets demanded by representative consumers in each country. Specifically, conditions under GE might imply all countries have the same size (in terms of GDP), but this is not necessary the case with FDI. On the other hand, GE requires no country has trade imbalance at the aggregate level. Under general equilibrium, the existed trade imbalance will be even out by financial assets.

Equation (1.20) is the gravity equation used for estimation later. It shows that trading values between any two countries are positively related to the size of the two countries ($I_i$ and $I_j$), and negatively related to transportation costs ($T_{ij}$). The denominator of the fraction term in equation (1.20) can be considered as either multilateral resistance as in Anderson and van Wincoop (2003), Eaton and Kortum (2001, 2002), and Waugh (2010), or a measure of the remoteness of country *i* similar to that of Chaney (2008).

### *4.2 Estimation*

From here, we assume $P^i = 1$ for all *i*. This assumption is consistent with Observation 3 reported in Waugh (2010, pp.2101) which states that "aggregate tradable goods prices are similar between rich and poor countries." Such simplified assumption allows me to use GDP as the proxy of the adjusted country size to construct the transportation cost index (TCI). It also makes it convenient to estimate the model using equation (1.20).

Making use of the assumption that $P^i = 1$, we can divide both numerator and denominator of the RHS of equation (1.20) by $(\sigma/\sigma - 1)^{1-\sigma}$ and obtain

$$V_{ij} = \exp\left\{\begin{array}{l}(1-\sigma)\ln(1+\theta\times\omega_{ij}) + \ln I_i + \ln I_j \\ -\ln\left[\left(\frac{\sigma-1}{\sigma}\right)^{1-\sigma} I_i + \sum_j I_j (1+\theta\times\omega_{ij})^{1-\sigma}\right]\end{array}\right\}, \tag{1.21}$$

where $\omega_{ij}$ is the $N \times N$ TCI matrix derived in Section 2. Note that we drop time dimension here and after whenever there is no confusion. Follow Santos Silva and Tenreyro (2006), we use Poisson Pseudo Maximum Likelihood (PPML) to estimate the model in equation (1.21). As described in Santos Silva and Tenreyro (2006), there are at least two reasons to use PPML estimator. First, given the presence of heteroskedasticity in international trade data, NLS estimator on equation (1.21) is inconsistent and inefficient. Second, the PPML estimator can handle zero values of trade flows, which appear frequently in international trade data, without relying on further assumptions. Although the Poisson model is generally being applied in count data, it can also be thought as a type of nonlinear regression model with heteroskedasticity.

Rewrite the curly bracket term as $X_n\beta$, where $X_n$ is a vector of independent variables of the *n*th observation, and $\beta$ a vector of parameters to be estimated. Also, rewrite $V_n$ as the dependent variable associated with $X_n$. The log-likelihood function of the PPML estimator, as shown by Gourierous, Morfort, and Trognon (1984), is:

$$L(\beta)=\sum_{n=1}^{N}V_nX_n\beta-\sum_{n=1}^{N}\exp(X_n\beta).$$

The final estimation specification of the model is given by

$$V_{ij}=\exp\left\{\begin{array}{l}(1-\beta_1)\ln(1+\beta_2\times\omega_{ij})+\beta_3\ln GDP_i+\beta_4\ln GDP_j \\ +\beta_5\ln\left[\left(\dfrac{\beta_1-1}{\beta_1}\right)^{1-\beta_1}GDP_i+\sum_j GDP_j(1+\beta_2\times\omega_{ij})^{1-\beta_1}\right]\end{array}\right\}. \quad (1.22)$$

In this specification, country *i* is the exporting country and country *j* is the importing country. $V_{ij}$ is the total value of trade from country *i* to country *j*. $\beta_1-\beta_5$ are parameters to be estimated. We expect all of them to be positive except for $\beta_5$. Also, by definition, $\beta_1$ should be greater than 1 which makes $1-\beta_1$ a negative value.

Bilateral trade data is from IMF Direction of Trade (DOT) statistics for 74 countries from 1993 to 2009. These are exporting values reported in f.o.b. A list of countries is in Table A.1 of the Appendix A, along with the percentage of world exports and imports to and from the sample countries (Table A.2). GDP data is from World Bank, in which 2009 is the latest year of non-estimated data available for all 74 countries at this point. The constructed $\omega_{ij}$ matrix is available upon request.

We first run the regression based on equation (1.20) in which bilateral trade cost, $T_{ij}$, is augmented and approximated by

$$T_{ij}=\alpha_0+\alpha_1Dist_{ij}+\alpha_2\Omega_{ij}.$$

In this augmented specification, $Dist_{ij}$ is distance between country *i* and *j*, while $\Omega_{ij}$ is given in equation (1.9). This takes into account the fact that bilateral trade costs might be affected by both distance and trade imbalance between two trading countries. We expect $\alpha_1>0$,

$\alpha_2 > 0$, while the sign of $\alpha_0$ is arbitrary. Estimation result is presented in the second column of Table 1.2. All parameters have expected signs and are statistically significant from zero except for $\alpha_0$ and $\alpha_1$. This estimation with augmented bilateral trade costs provides positive evidence for my approach of estimating equation (1.22).

**Table 1.2 PPML Estimation Results**

| Dependent Variable | Augmented $V_{ij}$ | TCI $V_{ij}$ | Distance $V_{ij}$ |
|---|---|---|---|
| Constant Elasticity of Substitution ($\beta_1$) | 5.8186** | 8.6134** | 1.4781** |
| | (1.2338) | (1.7156) | (0.1684) |
| Marginal Inefficiency of Imbalance ($\beta_2$) | 0.4812** | 0.6693** | - |
| | (0.2141) | (0.1052) | |
| Log Exporter's GDP ($\beta_3$) | 0.6196** | 0.9339** | 1.8590** |
| | (0.1716) | (0.2261) | (0.7654) |
| Log Importer's GDP ($\beta_4$) | 0.2945** | 0.3549** | 0.4650* |
| | (0.0698) | (0.0720) | (0.2249) |
| Multilateral Resistance ($\beta_5$) | -0.4954** | -0.8001** | -1.8519** |
| | (0.1502) | (0.2045) | (0.7111) |
| $\alpha_0$ | 0.1703 | - | - |
| | (0.2282) | | |
| $\alpha_1$ | 1.3042e-5 | - | - |
| | (0.8114e-5) | | |
| $\alpha_2$ | 1.0622** | - | - |
| | (0.2031) | | |
| Negative Log Likelihood | 0.9253e+8 | 1.1120e+8 | 1.7769e+8 |
| Number of Observations | 90146 | 90146 | 90146 |

Bootstrap standard errors in parentheses. The bootstrap procedure takes 1000 observations to resample in every iteration and iterates for 1000 times.
** indicates significance at 1%; * indicates significance at 5%.

In the estimation with only TCI, which is reported in third column of Table 1.2, all parameters have the expected signs and value ranges, and all are significant at 1% level. Specifically, the value of $\beta_1$ is significantly greater than 1, which is consistent with the theoretical model that a larger TCI is associated with a greater bilateral trade cost ($1-\beta_1$ is negative). The positive parameters for GDP of the two countries demonstrate the suitability of the gravity equation. Last, a negative $\beta_5$ is consistent with the idea of multilateral resistance of international trade.

In the fourth column of Table 1.2, we report the estimates when approximating $T_{ij}$ in equation (1.20) using distance between the two trading countries. In such case, we do not have $\beta_2$. All estimates have the expected signs but significantly different in magnitudes compared to the model using TCI. Moreover, the negative log likelihood value is significantly larger in the case of using distance. Using the non-nested likelihood ratio test proposed by Vuong (1989), we find that $LR' = 267.6951$ under the null hypothesis that the model using distance is as good as the one using TCI. The directional value of $LR'$ rejects the null and indicates the model with TCI is the favorable one.

### *4.3 Elasticity and Trade Costs*

The estimates of $\beta_3$ and $\beta_4$ in the third column of Table 1.2 are not values of elasticity. To calculate the elasticity of trade when there are changes in GDP of exporters and importers, we have from equation (1.20)

$$\varepsilon_{EX} \equiv \frac{\partial \ln V_{ij}}{\partial \ln GDP_i} = \beta_3 + \frac{GDP_i \times \beta_5 \left(\frac{\beta_1 - 1}{\beta_1}\right)^{1-\beta_1}}{\left[\left(\frac{\beta_1 - 1}{\beta_1}\right)^{1-\beta_1} GDP_i + \sum_j GDP_j \left(1 + \beta_2 \times \omega_{ij}\right)^{1-\beta_1}\right]};$$

$$\varepsilon_{IM} \equiv \frac{\partial \ln V_{ij}}{\partial \ln GDP_j} = \beta_4 + \frac{GDP_j \times \beta_5 \left(1 + \beta_2 \times \omega_{ij}\right)^{1-\beta_1}}{\left[\left(\frac{\beta_1 - 1}{\beta_1}\right)^{1-\beta_1} GDP_i + \sum_j GDP_j \left(1 + \beta_2 \times \omega_{ij}\right)^{1-\beta_1}\right]}.$$

The calculated value of average (averaging over all counties in all years) elasticity of trade volumes with respect to GDP of exporters and importers are

$\varepsilon_{EX} = .7475$; $\varepsilon_{IM} = .3463$.

These values indicate that the impacts of country sizes on trade volumes are asymmetric. Other things being equal, 1% change in GDP of a country is associated with 0.4012% ($0.7475 - 0.3463$) change in net export. Put alternatively, when China’s GDP grows at 10%

annually while US grows at 2.6%, it is predicted from the model that US trade deficit with China increases at an annual rate of 2.97% (0.4012×7.4%). However, the actual trade deficit from 1993 to 2009 increased at an average of 21.2% annually. This reflects that there are other factors restraining international trade. Details are reported in Table A.3 in Appendix A.

The elasticity of trade when there is change in TCI can be calculated according to

$$\varepsilon_{TCI} \equiv \frac{\partial \ln V_{ij}}{\partial \ln \omega_{ij}} = \frac{(1-\beta_1)\beta_2 \times \omega_{ij}}{1+\beta_2 \times \omega_{ij}} \left( 1 - \frac{GDP_j \times \left(1+\beta_2 \times \omega_{ij}\right)^{1-\beta_1}}{\left[ \left(\frac{\beta_1 - 1}{\beta_1}\right)^{1-\beta_1} GDP_i + \sum_j GDP_j \left(1+\beta_2 \times \omega_{ij}\right)^{1-\beta_1} \right]} \right).$$

The result, after taking average from all countries in all years, is

$$\varepsilon_{TCI} = -3.6763. \tag{1.23}$$

Equation (1.23) has a very interesting explanation. Other things being equal, the value of $\omega_{ij}$ is governed by the trade imbalance of the country (between *i* and *j*) that handles shipments. When the exporter is the shipment handler, my model and estimation results predict that a 1% increase in trade imbalance is equivalent to 4.92 % decrease in the exporter's GDP, or 10.61% decrease in the importer's GDP. There are large and significant welfare loss due to trade costs based on trade imbalance.

Last, we calculate the implied average total trade cost from the theoretical model. This trade cost is equivalent to prices charged by transportation firms and is given by $T-1$. The average total trade cost, that is, an average over all countries in all years, is ad-valorem tax equivalent of 76.24 percent. This number lies within the range reported in Anderson and van Wincoop (2004).

### *4.4 Robustness Checks*

In this section, we perform two robustness checks on the constructed TCI. First, since the theoretical model predicted that, with TCI, higher GDP is associated with higher trade deficit, we run the regression

$$\ln\left(\frac{\text{export}_{it}}{\text{import}_{it}}\right) = \eta_1 \times \ln\left(GDP_{it}\right) + \eta_2 \times \ln\left(\Omega_{it}\right) + \varepsilon_{it}, \tag{1.24}$$

where

$$\Omega_{it} \equiv \frac{\sum_j abs\left(S_{it} - S_{jt}\right)}{NS_{it} + \sum_j S_{jt}}$$

is calculated according to equation (1.9), $\eta_1$ and $\eta_2$ are parameters to be estimated, and we expect both of them to be negative. With 74 countries in my sample, $\Omega_i$ of each year is a 73-by-1 vector. Hence the country with the largest value of $\Omega_i$ (from US) is dropped. In addition, we drop observations when total import or export of a country is zero. As a result, there are 1236 observations in the sample of this regression. The regression result of equation (1.24) show that $\eta_1 = -0.076$ and $\eta_2 = -1.651$, both at 1% significance level. This hence confirms that when using the constructed TCI to explain trade volumes, larger GDP would be correlated with greater trade deficit.

As a second robustness check on the constructed TCI, we follow Limao and Venables (2001) and Waugh (2010) to use the fraction of reported c.i.f. values (from the import statistics of the IMF DOT) and f.o.b. values as a measure of true trade cost. Specifically, we run the regression:

$$t_{ij} = \mu_0 + \mu_1 \times \left[\frac{\sigma}{\sigma - 1}\left(1 + \theta \times \omega_{ij}\right)\right] + \varepsilon_{ij}, \tag{1.25}$$

where $t_{ij} \equiv cif_{ij} / fob_{ij}$ is the measure of trade cost from the IMF DOT, the bracket term is the implied trade cost from equation (1.8), and $\mu_0$ and $\mu_1$ are parameters to be estimated. We expect $\mu_1$ to be positive. Follow Waugh (2010), we drop values of $t_{ij}$ less than 1, which would imply negative transportation cost, and 1.1, which was used by IMF to calculate missing values. In addition, we drop values greater than 10, as a transportation cost 9 times as large as the values of the good is very likely to be a measurement error. This leaves 39030 observations in the sample. The correlation between the implied trade cost of the model and $t_{ij}$ is 0.082. Estimation result of equation (1.25) shows a value of $\mu_1 = 1.680$ at 1% significance level. The regression result provides positive evidence that the implied trade costs based on my theory and the constructed TCI is a very good approximation of real trade costs.

## 5 Concluding Remarks

In this paper, we have developed a model of international trade in which transportation costs are endogenously determined by trade imbalance of a country. The concept of transportation costs resulting from trade imbalance implicitly builds the connection between export and import flows. Based on the theoretical model, we derived and constructed a transportation cost index (TCI) to capture bilateral trade costs of country partners. This index is related trade imbalance and is time-variant.

We used simulation and a simplified three country model to show how transportation costs resulting from trade imbalance affect exports and imports. Simulation and analytical results show that representative transportation firm in a country with medium adjusted size offers the lowest transportation price and hence handles all trade to and from its home country. As a result, larger countries tend to incur a trade deficit. A possible reason for this result is that larger countries tend to consume more final goods, both domestically and internationally, but at the same time do not have the comparative advantage in becoming the handler of international shipments to lower its transportation costs. For the country with the lowest TCI, it escaped from the general trend that trade surplus/deficit is negatively related to adjusted country size.

Within a general equilibrium framework, we derived the gravity equation to estimate the proposed theory. The estimation results are consistent with the theoretical predictions. Specifically, a higher value of transportation cost index as well as a greater multilateral trade barriers lower the volume of international trade, while GDP of the exporter and importer have positive but asymmetric relationships with trading volumes.

One of the caveats of the constructed transportation cost index might be the fact that it does not take into account distance, which is often used as bilateral trade barriers in existing empirical literature. Although anecdotal evidences suggest that distance might not be an adequate approximation for bilateral trade costs, it might still be a good idea if one can theoretically and empirically take into account both distance and transportation costs resulting from trade imbalance. Another possible direction for future research is to model the competition between production firms and transportation firms and see how that would affect the outcome of international trade.

# Chapter 2 - Tax Policies, Regional Trade Agreements, and FDI: A Welfare Analysis

## 1 Introduction

The last half-century has brought unprecedented growth in the trade in goods and cross-border capital flows despite the numerous obstacles involved in moving both goods and capital across international borders. Great advances in communications and transportation have combined with an ever-expanding array of international agreements to reduce the frictions associated with these international transactions. While regional trade agreements (RTAs) have reduced the burden of tariffs on traded goods, agreements have also been established to promote cross-border FDI flows. Recent international agreements such as the North American Free Trade Agreement (NAFTA) have addressed both trade and investment.[10] Likewise, bilateral investment treaties (BITs) and double taxation treaties (DTTs) have been established to promote foreign direct investment (FDI). While the influences of both FDI and trade agreements are extensively explored as separate concepts in the literature, the joint impact has received much less attention despite the fact that a growing number of RTAs address investment. The primary focus of this paper is the examination of the joint impact of FDI and trade agreements on social welfare and firm behavior in an environment with potential double taxation.

Firms seeking to extend its market overseas may choose to enter foreign markets through exporting or, alternatively, by way of horizontal FDI. Many factors can affect this mode of entry into foreign markets. For example, Brainard's (1997) proximity-concentration trade-off suggests that firms will take into account transportation costs and market size when choosing between exporting and overseas production. Similarly, Helpman, et al. (2004) show that firms of the highest productivity levels will enter foreign markets by way of horizontal FDI, whereas relatively less productive firms are more likely to serve foreign markets by exporting. Alternatively, Yeaple (2003) finds that U.S. FDI flows are driven by a complex interaction of labor endowments and the skill intensity of the industry. He notes that his results suggest that

[10] In particular, Chapter 11 of NAFTA concerns cross-border investment and the settlement of investor disputes. Adams, et al. (2003) and Dee and Gali (2005) note that such agreements represent a "third wave" of RTAs that include substantial non-trade components.

outgoing U.S. FDI likely occurs due to both this endowment-based "comparative advantage motive" as well as the "market access motive" of horizontal FDI. Such endowment-based investment may provide final or intermediate goods to both the firm's home country and a third market, the latter of which might be classified by the literature as export-platform FDI (Ekholm, et al., 2007). As a whole, these prior works suggest that exports and FDI are inherently linked, which indicates the existence of a complex relationship between FDI and trade agreements.

FDI under a regional trade agreement may result in firm behavior and welfare outcomes that differ from those that occur without such an agreement. For example, Raff (2004) theoretically models tax competition for FDI under regional trade agreements and shows that free trade agreements may either induce or deter FDI, with the outcome largely dependent on the production costs within the region relative to the rest of the world. Ethier (1998a, 1998b) argues that RTAs may promote FDI flows to the smaller countries in a region that are driven by market access motives. Similarly, Collie's (2011) theoretical model suggests that RTAs lead to an increase in both FDI and trade, which occurs due to the export-platform nature of the FDI that is induced in such an environment.

While these prior works provide a theoretical foundation for the link between FDI and RTAs, several recent empirical studies examine this relationship as well. MacDermott (2007) uses a gravity model to examine the impact of NAFTA on FDI flows into NAFTA members from OECD countries. He shows positive, country-specific relationships influences of NAFTA on FDI inflows, but also suggests that these FDI flows originate outside of the region. Likewise, Medvedev's (2012) recent study suggests that regional trade agreements encourage FDI flows and this effect is driven largely by the subsample of time that includes the 1990s and 2000s. Medvedev notes that the RTAs in this subsample are often integrated agreements that include investment components that may lead to significant increases in FDI flows. While investor protections afforded by BITs and integrated agreements may not fully restrict FDI, such protection eliminates a large disincentive for firms to engage in FDI. It is precisely this concept of a trade agreement that coexists with the potential for FDI that we examine later in the paper.

Our objective is to expand the previous theoretical literature concerning FDI and trade agreements to address the issue of double taxation, which presents an additional obstacle to foreign investment. When profits are earned by foreign subsidiaries they are taxable by the foreign government and a repatriation tax imposed by the home government when the firm repatriates its profits. Double taxation may be welfare-deteriorating due to the distortion of the cross-border post-tax return to capital. The potential distortions from double taxation prompted the OECD to introduce a model tax treaty that restricts member countries to use either credits or exemptions in the calculation of taxes on repatriated profits.[11] The theoretical and empirical evidence regarding the influence of double taxation treaties on FDI is mixed,[12] which suggests that additional influences beyond changes in double-taxation policy may play a role in determining FDI flows. We posit that one such influence is the establishment of regional trade agreements. As noted earlier trade agreements that include investment provisions are increasingly common. Likewise, the share of RTAs that are signed with prior BIT and DTT agreements in place is growing over time. Columns 1 through 3 of table 1 shows bilateral country pairs that have signed an RTA agreement with prior DTT or BIT agreements already in place as a share of all bilateral country pairs entering into an RTA.[13] Likewise, the signing of an RTA may also result in additional negotiations concerning investment and double taxation which may be signed before or after the RTA, but are largely part of the same negotiation effort. Columns 4 and 5 of table 1 shows the share of countries with both an RTA and DTT or BIT that signed these two types of agreements within five years of each other. In both cases, a fairly substantial portion of countries with a combination of these agreements signs both agreements within five years of each other and this trend is growing over time. These statistics suggest that policymakers view the issues concerning foreign direct investment and RTAs as interrelated, which is precisely the focus of our paper.

Our model expands on the work of Haufler and Wooten (2006), Raff (2004), and Collie (2011) and examines the location decision and welfare implications of the interaction between FDI and a regional trade agreement (RTA) while also addressing the impact of double taxation.

[11] A credit reduces the home-country taxes on repatriated profits by the amount of foreign-country taxes. Exemptions eliminate home-country taxes on overseas profits. A deduction, which is not permitted under the OECD model treaty, simply reduces the taxable income used to calculate the home-country tax.

[12] Davies (2003) uses a theoretical model to examine the OECD model treaty and finds that the use credits result in welfare improvements under symmetric countries, but such treaties will not necessarily result in welfare improvements in the case of asymmetric countries. For mixed empirical studies, see Blonigen and Davies (2004), Egger et al. (2006), Coupé, et al. (2009), Barthel, et al. (2010) and Neumayer (2007).

[13] RTAs often include more than two countries, whereas BITs and DTTs do not. Therefore, we compare bilateral relationships across treaty types. For example, a three country RTA would include three bilateral country pairs that could be contrasted with prior BITs and DTTs, which are bilateral in nature.

We contribute to the literature by examining how FDI alongside an RTA impacts behavior of firms, government revenue, and welfare. We develop an asymmetric three-country model where firms are headquartered and owned by households in the two countries that are considering an RTA. The firms produce their entire output in one country, but serve the other two countries through exporting. Wage asymmetry across the two countries in the potential RTA further enhances the model by creating a potential for comparative advantage-based FDI and export-platform FDI. In the first stage of our model, the first country chooses the rate at which it will tax repatriated profit. In the second stage all countries simultaneously set their tariff rates. In the third stage, the firm will optimally choose to locate production in one of the three countries, which is a decision driven by the after-tax profit implications of the location decision as well as tariff rates and the cost of production in each country. In the final stage, the firms compete via Cournot competition. We analyze welfare under six cases, which include *(i)* trade without FDI and without an RTA, *(ii)* trade with an RTA and without FDI, *(iii)* trade with FDI, but no RTA, *(iv)* trade when an RTA is established at the same time that ability to engage in FDI is opened, *(v)* trade when FDI occurs after an RTA is already established, and *(vi)* trade when FDI has occurred before an RTA is established. We then extend our analysis to examine the critical values of a repatriation tax that induce a firm to engage in FDI when an RTA is and is not established.

**Table 2.1 Agreements Prior to the Signing of an RTA**

| | Agreements prior to RTA signing as a share of RTAs established | | | Share of RTAs signed within 5 years of other agreement | |
|---|---|---|---|---|---|
| Decade | DTT Only | BIT Only | Both BIT and DTT | DTT | BIT |
| | (1) | (2) | (3) | (4) | (5) |
| 1960s | 0.28% | 1.70% | 0.00% | 8.59% | 23.68% |
| 1970s | 3.83% | 0.45% | 0.11% | 17.07% | 7.14% |
| 1980s | 1.90% | 0.38% | 0.08% | 7.45% | 16.67% |
| 1990s | 10.99% | 8.40% | 11.15% | 39.37% | 78.68% |
| 2000s | 7.57% | 9.56% | 9.79% | 33.56% | 49.85% |

Data Sources: UNCTAD DTT and BIT Databases, WTO RTA Database.

Notes: RTAs often include more than two countries, whereas BITs and DTTs do not. Therefore, we compare bilateral relationships across treaty types. For example, a three country RTA would include three bilateral country pairs that could be contrasted with prior BITs and DTTs, which are bilateral in nature. RTAs are categorized by the year of entry into force, not the date of WTO notification. DTTs and BITs are dated accordingly to the date of signature.

The remainder of the paper is organized as follows: Section 2 lays out the analytical framework of the paper and presents the firms' optimal production decision under Cournot competition. Section 3 analyzes the social welfare consequences under each case noted above. Section 4 then analyzes how firm's investment decision is affected by policy, focusing on the government's decision of a repatriation tax rate. The last section concludes.

## 2 The Model

### *2.1 The Basic Assumptions*

We consider a simple three-country model in which two countries, A and B, are located in the same region, while a third country, C, lies outside the region.[14] Countries A and B will potentially form a regional trade agreement, permit firms headquartered in their country to engage in FDI, or both.

In both country A and country B, there is a local firm owned by the households of each country. Although each firm is headquartered inside its own country, its production plant (denoted as country name A or B) can be located in any of the three countries.

We assume a simple demand structure which is functionally identical across countries A and B, but varies with the market size of country C:

$$Q_A = 1 - p_A;\ Q_B = 1 - p_B;\ Q_C = n(1 - p_C); \tag{2.1}$$

where $Q_i$ and $p_i$ are, respectively, the consumption and price of final good in country $i(=\text{A, B, C})$, $n$ represents the relative size of the market in country C. As in Haufler and Wooton (2006), we set $n \in [1,2]$.

Labor is the only input in the production of the final good and technology is the same across countries. Specifically, one unit of labor is used to make one unit of the final good. Denote $w_j$ as the competitive wage rate in country $j(=A, B, C)$, and $\tau_{ji}$ as a specific tariff (or subsidy) that country $i$ imposes on imports from country $j$ when $i \neq j$. Both firms are able to

[14] Country C can also represent the rest of the world.

segment markets such that when plant $k(=A,B)$ is located in country $j$, the pre-tax profit from servicing country $i$ is:

$$\pi_{ji}^{k} = (p_i - c_{ji})x_i^k, \tag{2.2}$$

where $p_i$ is the market price of final good in country $i$, $x_i^k$ is the quantity sold in country $i$ by firm $k$, and $c_{ji} = w_j + \tau_{ji}$. Note that $\tau_{ii} = 0$ when a firm is located its own country and we refer to "taxes" as profit and repatriation taxes, but not tariffs.

To allow for input cost asymmetry, we assume that the wage rate is higher in country A than in country B. Also, we assume that wage rate in country C is critically high. That is, $w_A > w_B$ and $w_C \gg w_A$. Other things being equal, this assumption eliminates the following possibilities: (i) plant B will locate in country A and (ii) both plants A and B will locate in country C.

In this one-period game, we consider that all post-tax profits of a firm are repatriated if it decides to undertake foreign direct investment (FDI) in another country. As such, country A can choose to tax the repatriation of profits if the production plant of its firm is located country B. Let this repatriation tax rate be denoted as $t^r$.

Following Haufler and Wooten (2006), we treat profit tax rates in countries A and B as predetermined. But unlike their analysis, we assume that each of the three countries optimally sets tariff rate $\tau_{ji}$ on its final good import to maximize its social welfare. To make the analysis simple, we assume that transportation costs are zero. As in the trade literature, social welfare in each country is taken to be the sum of consumer surplus, producer surplus (post-tax profit), and government revenue (tax plus tariff).

The timeline of the game is described as follows. There is a four-stage game. In the first stage, country A chooses a repatriation tax rate $t^r$ when its firm undertakes FDI by locating its production plant abroad. In the second stage, countries that import final goods produced in other countries set their tariff rates, $\tau_{ji}$, for goods produced in country *j* and exported to country *i*. In the third stage, taking into account the afore-mentioned conditions, each firm decides where to locate its plant. In the last stage of the game, the two firms adopt a Cournot strategy and compete in each market.

### *2.2 Production Decisions of the Firms*

In the last stage of the game, firms A and B independently and simultaneously determine the quantities of their outputs in each market $i(=A,B,C)$. Given the demand and profit equations (2.1) and (2.2) and taking into account the fact that plant B locates in its own country due to a relatively lower wage rate there, we calculate the equilibrium quantities, $x_i^j$, when plant A locates in country $j(=A,B)$ and sells to markets $i(=A,B,C)$ as

$$x_i^A = \frac{1}{3}(1-2w_j-2\tau_{ji}+w_B+\tau_{Bi}) \text{ and } x_i^B = \frac{1}{3}(1+w_j+\tau_{ji}-2w_B-2\tau_{Bi}) \qquad (2.3)$$

for $i = A,B,C$. For the market in country C, the quantities exported by plant A located in country $j(=A,B)$ are

$$x_C^A = \frac{n}{3}(1-2w_j-2\tau_{jC}+w_B+\tau_{BC}) \text{ and } x_C^B = \frac{n}{3}(1+w_j+\tau_{jC}-2w_B-2\tau_{BC}). \qquad (2.4)$$

## 3 Welfare Analysis

We use the (i) pre-RTA regime as the benchmark to evaluate alternative regimes when (ii) the two regional countries A and B form an RTA, (iii) firm A undertakes FDI, or (iv) both. We also analyze two additional scenarios: (v) firm A undertakes FDI when an RTA is already in place, or the two countries consider forming an RTA when the location decisions of FDI have been done. For each scenario we calculate the resulting prices, tariff rates, and social welfare. While trade and tax policies are set by governments, FDI decisions are made by firms. Thus, given trade and tax policies a firm will choose whether or not to engage in FDI. We specifically examine this relationship in section 4.

### *3.1 Benchmark Scenario Welfare*

In this and the following cases, we only report optimal tariff rates, prices of final goods in the three markets, and social welfare (SW) of each country. Without lost of generality, we assume $w_B = 0$ and interpret $w_A$ as the wage differential between the two regional countries. For the three-country trade without the formation of a regional trade agreement between countries A and B (i.e., the pre-RTA regime), we have

$$\tau_{BA} = \frac{1}{3};\ \tau_{AB} = \frac{1}{10}(1-5w_A);\ \tau_{AC} = \frac{1}{35}(5-13w_A);\ \tau_{BC} = \frac{1}{35}(5+8w_A); \tag{2.5a}$$

$$p_A = \frac{1}{9}(4+3w_A);\ p_B = \frac{2}{5};\ p_C = \frac{1}{7}(3+2w_A); \tag{2.5b}$$

$$SW_A^A = \frac{4}{49}n - \frac{38}{45}w_A - \frac{48}{245}nw_A + \frac{11}{18}w_A^2 + \frac{144}{1225}nw_A^2 + \frac{23}{50}; \tag{2.5c}$$

$$SW_A^B = \frac{4}{49}n + \frac{7}{54}w_A + \frac{8}{245}nw_A + \frac{7}{18}w_A^2 + \frac{4}{1225}nw_A^2 + \frac{1337}{4050}; \tag{2.5d}$$

where $SW_j^k$ denotes country $k$'s social welfare when plant A is located in country $j$.

We consider the situations that tariff rates set by the three countries are all positive and that the final good prices exceed their marginal/average costs under imperfect competition. Based on the analytical framework, we note that as long as $\tau_{AB}$ is positive under the pre-RTA regime, the equilibrium values of the model are all positive. It follows from equation (2.5a) that the regional wage differential should satisfy the following condition: $w_A < 1/5$. Throughout the analysis, we assume that this wage differential condition holds.

### *3.2 Welfare Effect of an RTA without FDI*

For the case in which countries A and B sign an RTA to promote free trade but this RTA does not affect the decisions of the international producers on FDI, we have the following solutions:

$$\tau_{AC} = \frac{1}{35}(5-13w_A);\ \tau_{BC} = \frac{1}{35}(5+8w_A); \tag{2.6a}$$

$$p_A = p_B = \frac{1}{3}(1+w_A);\ p_C = \frac{1}{7}(3+2w_A); \tag{2.6b}$$

$$\overline{SW}_A^A = \frac{4}{49}n - \frac{10}{9}w_A - \frac{48}{245}nw_A + \frac{17}{18}w_A^2 + \frac{144}{1225}nw_A^2 + \frac{4}{9}; \tag{2.6c}$$

$$\overline{SW}_{A}^{B} = \frac{4}{49}n + \frac{2}{9}w_A + \frac{8}{245}nw_A + \frac{5}{18}w_A^2 + \frac{4}{1225}nw_A^2 + \frac{4}{9}. \qquad (2.6d)$$

Under the assumption that the regional wage differential falls within the range of $w_A < 1/5$, it is easy to verify from (2.5a) and (2.6a) that external tariff rates are lower after the formation of an RTA. It is also easy to see the final good prices in the regional countries are lower under the RTA, implying that consumers there are better off.

Next, we compare social welfare between the pre-RTA regime and the RTA regime without affecting FDI. It follows from equations (2.5c), (2.5d), (2.6c), and (2.6d) that

$$\overline{SW}_{A}^{A} < SW_A^A; \qquad (2.6e)$$

$$\overline{SW}_{A}^{B} > SW_A^B; \ \overline{SW}_{A}^{A} + \overline{SW}_{A}^{B} > SW_A^A + SW_A^B. \qquad (2.6f)$$

The findings in equations (2.6e) and (2.6f) permits us to establish

**PROPOSITION 2.1.** *When two regional countries with wage cost asymmetry form an RTA without affecting any relocation of their production plants, the RTA is welfare-improving for the low-wage country and the region, but is welfare-deteriorating for the high-wage country.*

The formation of an RTA makes consumers in the regional countries better off. The opening of free trade in the region leads to increased competition in the final good markets, causing their prices to decrease. But there is a greater fall in final good price in the high-wage country. An immediate result of the lower price is smaller output by both firms. Firm profits decrease in the high-wage country, but increase in the low-wage country. As a result, forming an RTA makes the high-wage country worse off but the low-wage country better-off.

### *3.3 Welfare Effect of FDI without an RTA*

In this section we examine welfare implications when firm A locates its plant in country B (that is, firm A decides to undertake its FDI in country B). In this case, there is no RTA between the two counties. We calculate tariff rates, final good prices, and social welfare for this case as follows: [15]

[15] It is important to note that the repatriation tax is welfare neutral for country A assuming that firm A locates its plant in country B; the tax simply transfers and reallocates firm A's post-tax profit to country's A government

$$\tau_{BA} = \frac{2-t_B}{5-t_B}\,;\ \tau_{BC} = \frac{1}{4}\,; \tag{2.7a}$$

$$p_A = \frac{3-t_B}{5-t_B};\ p_B = \frac{1}{3};\ p_C = \frac{1}{2}; \tag{2.7b}$$

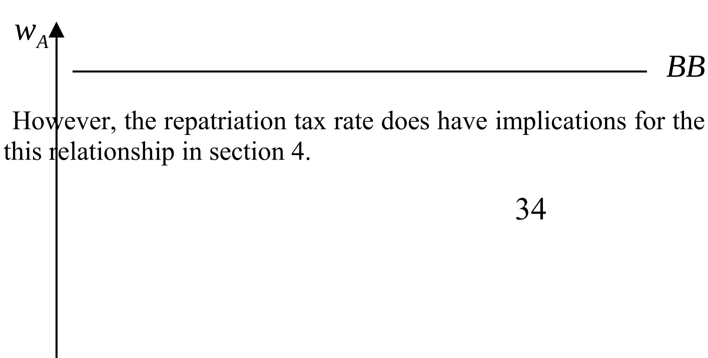
$$SW_B^A = (1-t_B)\left[\frac{1}{(5-t_B)^2} + \frac{n}{16} + \frac{1}{9}\right] + \frac{6-2t_B}{(5-t_B)^2} \tag{2.7c}$$

$$SW_B^B = (1+t_B)\left[\frac{1}{(5-t_B)^2} + \frac{n}{16} + \frac{1}{9}\right] + \frac{2}{9}. \tag{2.7d}$$

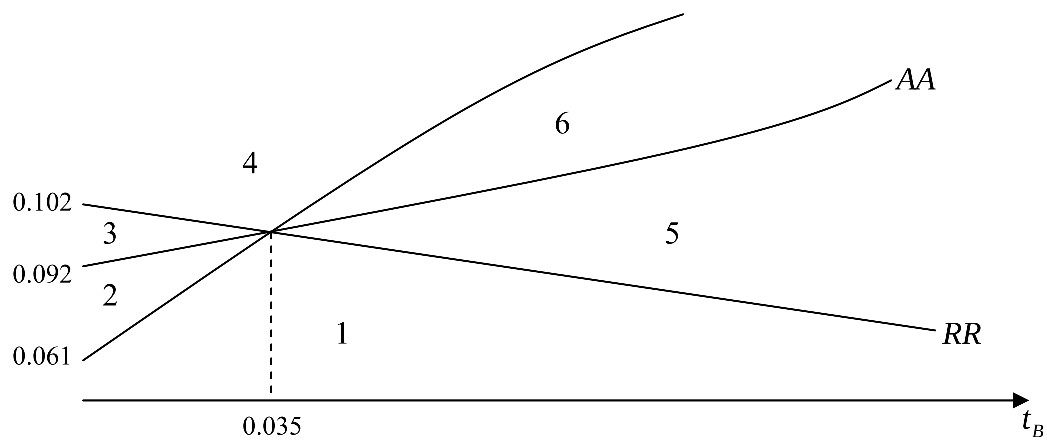
It is instructive to use graphs to illustrate the relationships between these two sets of social welfares. Graphical analysis shows that the change of $n$ has no qualitative effect on the welfare comparison. In Figure 2.2, we set $n = 1.6$ and plot $w_A$ against $t_B$. In Areas 1 to 3, where the wage differential is relatively small, there is welfare deterioration for the regional countries when the production plant is relocated to country B. In Area 4, it is welfare-improving for the region and country A when there is an FDI in country B. Under this circumstance, country A has an incentive to enact policies that induce FDI. In Area 5, while it is welfare-improving for the region and country B when there is an FDI there, it is welfare-deteriorating for country A. In Area 6, if firm A locates its plant in country B, then welfare will be improved in each signatory country and, hence, the region.

**PROPOSITION 2.2.** *Given the rate of profit tax on FDI set by a host country, FDI through a relocation of production plant from a high-wage country to a low-wage country is welfare-deteriorating for the two-country region when their wage cost asymmetry is critically small. However, if the wage cost asymmetry is significantly large, the FDI is welfare-improving for at least one of the two countries (Area 4 for the high-wage country and Area 5 for the low-wage country) or both (Area 6), depending on the degree of wage cost asymmetry and the profit tax rate in the low-wage country.*

**Figure 2.1 Comparing Welfare of FDI without an RTA**




revenue. However, the repatriation tax rate does have implications for the firm's location decision. We specifically examine this relationship in section 4.




When there is FDI, all production of the final good for domestic consumption and exporting takes places in the low-wage country. In this case, there is no tariff revenue for the country. However, the low-wage country is able collect revenues from taxing the profits of firm A, which sells final goods to all three markets. Consumers in the low-wage country are better off because of a lower price for their consumption of final goods produced by the two firms. Consumers in the high-wage country are worse off due to the following two reasons: one is tariffs imposed by its own country on the final good imports, the other is profit taxes imposed by the government of the low-wage country. Profits of the firms are affected negatively due to increased competition, except when the tax rate in the low-wage country is low.

### *3.4 Welfare Effect of FDI with an RTA*

The next case of interest is when FDI occurs at the same time as the formation of an RTA. We calculate the equilibrium tariff, final good prices, and social welfare in an RTA when firm A chooses to locate its production plant in country B.

$$\tau_{BC} = \frac{1}{4};\ p_A = p_B = \frac{1}{3};\ p_C = \frac{1}{2}; \tag{2.8a}$$

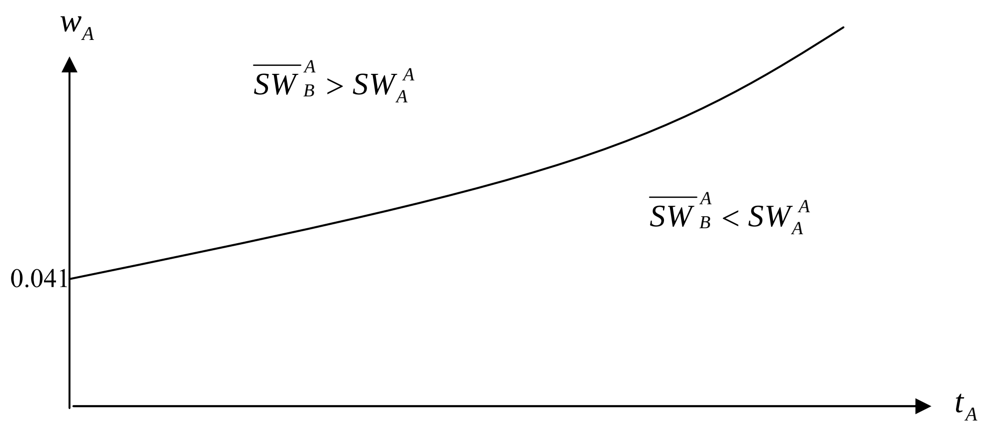
$$\overline{SW}_B^A = \frac{2}{9} + (\frac{2}{9} + \frac{n}{16})(1 - t_B);\ \overline{SW}_B^B = \frac{4}{9} + \frac{n}{16} + (\frac{2}{9} + \frac{n}{16})t_B. \tag{2.8b}$$

It is easy to verify from equations (2.5c), (2.5d), and (2.8b) that

$$\overline{SW}_B^B > SW_A^B;\ \overline{SW}_B^A + \overline{SW}_B^B > SW_A^A + SW_A^B. \tag{2.8c}$$

In terms of social welfare for country A, we find that the effect cannot be determined unambiguously. Setting $n = 1.6$, we use Figure 2.3 to illustrate a cut-off line above which $\overline{SW}_B^A > SW_A^A$.

**Figure 2.2 Comparing Welfare of the High-wage Country of FDI with an RTA**




This analysis leads to

**PROPOSITION 2.3.** *Forming an RTA between two regional countries with wage cost asymmetry alongside the relocation of production plant from the high-wage country to the low-wage country, is welfare-improving for the latter as well as for the region, but is welfare-deteriorating for the high-wage country if the wage differential is small or profit tax of the low-wage country is high.*

As in the case of the RTA without the relocation of Plant A, the existence of the RTA increases consumer surplus of both regional countries. For the low-wage country, the increase of consumer surplus together with the extra tax revenue from FDI and extra profit of firm 2 from sales in country A, are enough to compensate the losses of firm profits in other markets and tariff revenue due to RTA, with the result that there is a net increase in social welfare. For the high-wage country, however, the increase in consumer surplus cannot compensate other losses and result in a decrease in total SW.

### *3.5 FDI under the presence of a previously established RTA*

If the ability to locate overseas is made possible after the establishment of an RTA, firm A has a stronger incentive to move overseas since the only thing at stake is wage differential. We model this as two separate decisions and not a sequential game. To access the welfare implication, we analyze social welfare by comparing the following pairs of social welfares:

$$\overline{SW}_A^A \text{ and } \overline{SW}_B^A; \tag{2.9a}$$

$$\overline{SW}_A^B \text{ and } \overline{SW}_B^B; \tag{2.9b}$$

$$\overline{SW}_A^A + \overline{SW}_A^B \text{ and } \overline{SW}_B^A + \overline{SW}_B^B. \tag{2.9c}$$

It can be verified that the following inequality holds:

$$\overline{SW}_B^B < \overline{SW}_A^B. \tag{2.9d}$$

For comparing social welfare for country A as well as the two-country region, we present the graphical results in Figure 2.4. For the four regimes, we have

$$\text{Area 1: } \overline{SW}_B^A > \overline{SW}_A^A,\ \overline{SW}_B^A + \overline{SW}_B^B > \overline{SW}_A^A + \overline{SW}_A^B; \tag{2.10a}$$

$$\text{Area 2: } \overline{SW}_B^A < \overline{SW}_A^A,\ \overline{SW}_B^A + \overline{SW}_B^B < \overline{SW}_A^A + \overline{SW}_A^B; \tag{2.10b}$$

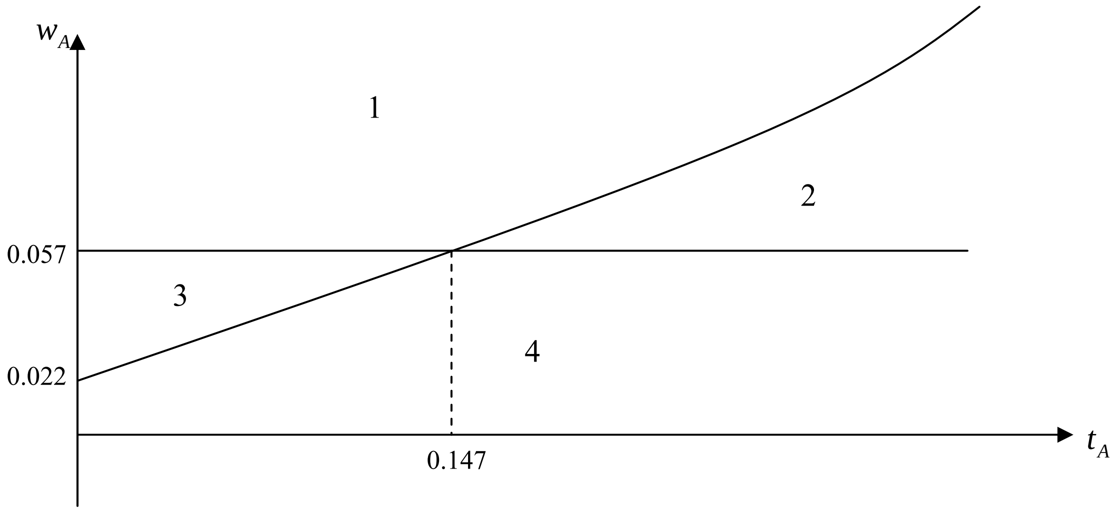
$$\text{Area 3: } \overline{SW}_B^A > \overline{SW}_A^A,\ \overline{SW}_B^A + \overline{SW}_B^B < \overline{SW}_A^A + \overline{SW}_A^B; \tag{2.10c}$$

$$\text{Area4: } \overline{SW}_B^A < \overline{SW}_A^A,\ \overline{SW}_B^A + \overline{SW}_B^B < \overline{SW}_A^A + \overline{SW}_A^B. \tag{2.10d}$$

When $n = 1.6$, the critical value for $\overline{SW}_B^A + \overline{SW}_B^B > \overline{SW}_A^A + \overline{SW}_A^B$ to hold is $w_A > 0.057$. These results lead to

**PROPOSITION 2.4.** *In the presence of a previously established RTA between a high-wage country and a low-wage country, FDI is welfare-deteriorating for the latter. When the wage differential is critically small, this additional FDI is welfare-deteriorating for the high-wage country and the region too (areas 2 and 4). When the wage differential is sufficiently but not critically large, this additional FDI is welfare-improving for the high-wage country but not for the region (area 3). Only when wage differential is critically high this additional FDI is welfare-improving for the high-wage country and the region (area 1).*

**Figure 2.3 Comparing Welfare of the High-wage Country and Region of the Additional FDI**




As in any other case with new FDI (sections 3.3 and 3.4), the presence of FDI increases competition in all markets, causing the profit of firm B to decline. A decrease in consumer surplus has a negative effect on country B's welfare, but this negative effect is offset by a collection of profit tax from plant A. On the other hand, the regional wage differential must be sufficiently high to make the relocation of plant A to be profitable.

### *3.6 Welfare effect of an RTA when FDI has already occurred*

Similar to the analysis in Section 3.5, we assume that RTA and FDI are two separate decisions and that firm A has already located its plant in country B before the establishment of the RTA. In this case, we conduct a welfare comparison for the following pairs:

$SW_B^A$ and $\overline{SW}_B^A$; (2.11a)

$SW_B^B$ and $\overline{SW}_B^B$; (2.11b)

$SW_B^A + SW_B^B$ and $\overline{SW}_B^A + \overline{SW}_B^B$. (2.11c)

It can be verified that, under the assumption of $w_A < 1/5$, the following relationships hold:

$\overline{SW}_B^B > SW_B^B$; (2.11d)

$$\overline{SW}_B^A + \overline{SW}_B^B > SW_B^A + SW_B^B . \quad (2.11e)$$

For the welfare of country A, there exists a critical value of $t_B \approx 0.576$ below which $\overline{SW}_B^A > SW_B^A$. We present the economic implications of these findings in the following proposition:

**PROPOSITION 2.5.** *When FDI through a relocation of the production plant from a high-wage country to a low-wage country is in existence despite import tariffs set by their respective governments, forming an RTA is a welfare-improving option for the low-wage country and the region. If profit tax set by the low-wage country is not critically high, the RTA formation is also welfare-improving for the high-wage country.*

This case is similar to the one that involves the trade regime change from pre-RTA to RTA. Eliminations of import tariffs by the two regional governments allow firm B in the low-wage country to make higher profits. The difference between this case and the case discussed in Section 3.1 (Welfare Effect of an RTA without FDI) is that firm A's profits earned in country B are subject to the profit tax policy there.

## 4 Determining the Critical Value of Repatriation Tax Rate

In this section, we analyze economic effects of repatriation taxes. Repatriation taxes constitute an important issue in the taxation of multinational firms in the literature. In our analysis, we look at how a repatriation tax set by the high-wage country affects the profits of its firm in undertaking FDI in the low-wage country. Accordingly, the use of a repatriation tax, $t^r$, is to influence the location decision of a firm's production plant.

We solve for the critical value of a repatriation tax for two cases. The critical repatriation tax rate makes firm A indifferent between locating its production plant at home or in country B. The first case is when an RTA does not exist (and FDI is assumed to be allowed). The second case is when both countries A and B engage in trade under an RTA (and FDI is assumed to be allowed).

*Case I:*

This critical value of $t^r$ for the case without an RTA (but with FDI) satisfies the following condition:

$$(1-t_A)\sum_{i=A,B,C}\pi_{Ai}^A = (1-t^r)(1-t_B)\sum_{i=A,B,C}\pi_{Bi}^A \,, \tag{2.12}$$

where the term on the LHS is firm A's post-tax profit when its plant is located within its own country, and the term on the RHS is firm A's post-tax profit when its plant is located in country B. Solving for the critical value of $t^r$ when there is no regional trade agreement between countries A and B yields

$$\hat{t}^r = 1 - \frac{\left[(\frac{4}{3}-2w_A)^2 + (\frac{4}{5}-w_A)^2 + n(\frac{6}{7}-\frac{36}{35}w_A)^2\right](1-t_A)}{9\left[\frac{1}{(5-t_B)^2}+\frac{1}{9}+\frac{n}{16}\right](1-t_B)}\,. \tag{2.13}$$

From equation (2.13), we have the following comparative statics derivatives:

$$\frac{\partial \hat{t}^r}{\partial t_A} > 0\,;\; \frac{\partial \hat{t}^r}{\partial t_B} < 0\,;\; \frac{\partial \hat{t}^r}{\partial n} > 0\,; \tag{2.14a}$$

$$\frac{\partial \hat{t}^r}{\partial w_A} > 0 \text{ if } w_A < \frac{324n+1274}{3888n+18375}, \text{ and } \leq 0 \text{ otherwise.} \tag{2.14b}$$

Note that the sufficient condition in equation (2.14b) is increasing with $n$ and the minimum value of the fraction is equal to 0.2028. This implies that $\partial\hat{t}^r/\partial w_A > 0$ always holds for $w_A < 0.2028$. We thus have the following proposition:

**PROPOSITION 2.6.** *When there is no RTA, the critical value of repatriation tax rate, above which the high-wage regional country is able to induce its firm to produce domestically, is positively related to its profit tax rate and the relative size of the market outside the region, but is negatively related to the profit tax rate set by the low-wage regional country. There is no unambiguous relationship between the critical repatriation tax rate and the wage cost asymmetry. Only when the wage cost asymmetry is sufficiently small will the critical repatriation tax rate be positively related to the wage cost asymmetry.*

<u>*Case II*</u>:

Next, we define $\bar{t}^r$ as the critical value of the repatriation tax rate for the case with both FTA and FDI between the two regional countries. Making use of equation (2.12) and considering the presence of an RTA, we solve for $\bar{t}^r$ as follows:

$$\bar{t}^r = 1 - \frac{\left[2(1-2w_A)^2 + n(\frac{6}{7} - \frac{36}{35}w_A)^2\right](1-t_A)}{(2+\frac{9n}{16})(1-t_B)}. \tag{2.15}$$

From equation (2.15), we have the following comparative statics derivatives:

$$\frac{\partial \bar{t}^r}{\partial t_A} > 0;\ \frac{\partial \bar{t}^r}{\partial t_B} < 0;\ \frac{\partial \bar{t}^r}{\partial n} < 0;\ \frac{\partial \bar{t}^r}{\partial w_A} > 0. \tag{2.16}$$

This naturally leads to

**PROPOSITION 2.7.** *In the presence of an RTA between two regional countries, the critical value of the repatriation tax rate is positively related to the profit tax rate set by the high-wage country and the degree of wage cost asymmetry, but is negatively related to the profit tax rate set by the low-wage country and the relative size of the market outside the region.*

For both $\hat{t}^r$ and $\bar{t}^r$, the effect of wage differential and profit tax rates is intuitive. When the profit tax rate of the home country is relatively high (higher $t_A$ or lower $t_B$), the firm has a higher incentive to locate its plant in country B. This implies that a higher profit tax rate $t^r$ is required to keep the firm within its home country. The same logic applies when the wage differential is large. The economic effect associated with the market size of the outside country is somewhat surprising, however. The reason is that when there is no RTA between the two regional countries, the tariff rate is higher for the final good from country B to A as compared to that from country B to C (see $\tau_{BA}$ and $\tau_{BC}$ in Section 3.2). Thus, firm A has a higher incentive to locate its production plant in country B and export more of the final good to country C. On the other hand, when there is an RTA between the two regional countries, which means zero tariff on final good from country B to A, the size of country C. This is because the increase in sales due to the larger demand is more than offset by tariff costs.

It is instructive to compare the critical repatriation tax rates as derived above for the two different cases. It follows from equations (2.13) and (2.15) that

$\overline{t}^r < \hat{t}^r$.

**PROPOSITION 2.8.** *The critical value of the repatriation tax rate that induces the firm of the high-wage country to locate its plant in the high-wage country is higher when there is no RTA than when there is an RTA.*

The relationship between these critical repatriation tax rates and welfare can be interpreted as follows. Without an RTA, it is in the interest of the high-wage country to set a high repatriation tax rate to encourage its firm to produce domestically. The high-wage country will choose such a repatriation tax rate if locating the production plant abroad is welfare-deteriorating as indicated by the results in Proposition 2.2. For the case with an RTA, however, only a mild repatriation tax rate is required to keep the plant within the country because zero tariffs lower the costs of exports to member countries. The relationship between the two repatriation tax rates implies that the signing of an RTA would not induce FDI unless the high-wage country also lowers its repatriation tax rate. As shown in Proposition 2.3, the high-wage country would benefit from the signing of the RTA and a decrease in the repatriation tax rate if the wage differential is sufficiently large or if the profit tax of the low-wage country is sufficiently small. For the case in which the repatriation tax rate is low and the firm finds it profitable to locate its plant in the low-wage country with the presence of an RTA, the elimination of the RTA would not affect the firm's location decision.

## 5 Concluding Remarks

In this paper, we derive economic conditions under which regional countries have incentives to create FDI-enabling policies, with or without forming a regional trade agreement. Using a stylized three-country model, we express these conditions in terms of profit tax rates, wage cost asymmetry, and the market size outside of the region.

We show that the formation of an RTA between two regional countries with wage cost asymmetry makes the low-wage country and the region better off, but can be welfare-deteriorating for the high-wage country. Other things being equal, FDI through a relocation of production plant from the high-wage country to the low-wage country can be welfare-improving or welfare-deteriorating, depending on the degree of wage cost asymmetry between the countries. When wage cost asymmetry is significantly large, FDI is welfare-improving for at least one of the two countries or both. When FDI through the relocation of the production plant from a high-wage country to a low-wage country exists despite import tariffs set by their respective governments, RTA formation is a welfare-improving option for the high-wage country and the region. If the profit tax set by the low-wage country is not critically high, forming the RTA is also a welfare-improving option for the low-wage country.

The analysis in this paper is able to reconcile several observations and prior findings with theory. Our results support the findings of Adams, et al. (2003), who note the increasing tendency of RTAs with investment provisions and their corresponding positive influence on FDI flows. If a high-wage country is to enter into an RTA with a low-wage country, then policies that positively influence FDI, such as investment provisions within the RTA or BITs that were signed prior to the RTA, will likely improve the welfare outcome of the high-wage country. The inclusion of such investment provisions, or the signing of additional agreements as shown in our descriptive statistics, would likely result in the positive FDI flows identified by Medvedev (2012). We further discuss issues on repatriation taxes under different trade regimes. Our results suggest that the signing of an RTA is not, by itself, influential in inducing FDI from the high-wage country to the low wage country in an environment with double taxation. However, the critical threshold of the repatriation tax that makes a firm indifferent in terms of its location decision varies across trade regimes, which suggests the impact of double taxation treaties on FDI flows may be largely influenced by the trade regime. We expect that further attention to trade agreements in future empirical work will help to reconcile the different findings currently found in the literature concerning double taxation treaties and their impact on FDI.

# Chapter 3 - War's Inefficiency Puzzle: An Economic Theory of Bargaining and Fighting with Endogenous Destruction

## 1 Introduction

Wars and fighting recur throughout human history and their causes are complex.[16] Among the challenging and puzzling questions posed to social scientists are as follows. Why do nations, political factions, interest groups or individuals (e.g., workers and capitalists, family members, etc.) choose to fight despite the fact that fighting is costly and in many cases highly destructive? What determines the conditions under which conflictual parties have incentives for engaging in negotiations to resolve their disputes and to avoid costly fighting? Conventional thinking holds that costly fighting is inferior to settlement through bargaining. The works of Fearon (1995) and Powell (1999, 2002, 2004) are among the influential contributions that popularize the "war's inefficiency puzzle." In particular, Fearon (1995) states that

> [N]one of the principal rationalist arguments advanced in the literature holds up as an explanation because none addresses or adequately resolves the central puzzle, namely, that war is costly and risky, so rational states should have incentives to locate negotiated settlements that all would prefer to the gamble of war. (p. 380)

Powell (2004) further indicates that

> Civil wars, revolutions, litigation, strikes, economic sanctions, international conflict, and the use of power in general pose *an inefficiency puzzle* (italics added). Suppose that a group of actors is bargaining about how to resolve an issue or, more abstractly, about how to divide a "pie." One or more of them can affect the outcome and possibly even impose a division through the use of some form of power—be it military, economic, legal, or more broadly political. The exercise of power, however, consumes resources, and, consequently, the pie to be divided among the bargainers before anyone tries to impose a settlement is larger than it will be afterward. As a result, there usually are divisions of the larger pie that would have given each bargainer more than it will obtain from an imposed settlement. The use of power, in other words, leads to Pareto

[16] The influential works in the economic literature include the earlier studies by Haavelmo (1954), Schelling (1957, 1960), and Boulding (1962). See also the contributions by Brito and Intriligator (1985), Hirshleifer (1988, 1989, 1991, 1995, 2000), Fearon (1995), Grossman (1991, 1995), Grossman and Kim (1995, 1996), Alesina and Spolaore (1997), Powell (1999, 2004, 2006), Acemoglu and Robinson (2000), Alesina, Spolaore and Wacziarg (2000), Garfinkel and Skaperdas (2000), Grossman and Mendoza (2001), Skaperdas (2006), Leventoğlu and Slantchev (2007), Baliga and Sjöström (2008), Besley and Persson (2008, 2009, 2010), and Chassang and Padro i Miquel (2010), to name a few. Garfinkel and Skaperdas (2007) present a systematic review of interesting studies on the economics of conflict.

inefficient outcomes. Why, then, do the bargainers sometimes fail to reach a Pareto superior agreement prior to the explicit use of power? (p. 231)

In the present paper, we tackle this fundamental question about wars and fighting within the rational-choice framework of economic decision-making without incomplete information or misconceptions. Specifically, we develop a general equilibrium model of production and appropriation, attempting to present an economic analysis to resolving the long-standing puzzle of war's inefficiency in the theoretical conflict literature. We consider the scenario that two conflictual parties engage in unbiased negotiations to avoid war when fighting or armed confrontation is costly and destructive. In the positive analysis with complete information, we assume that fighting's destructiveness is endogenously increasing in armaments or combative inputs. Quite contrary to the conventional wisdom that bargaining is Pareto superior over fighting, we show conditions under which fighting constitutes a Nash equilibrium choice and is a Pareto improvement relative to bargaining. We find that, under the shadow of conflict, locating a settlement through bargaining is costly. Fighting may actually be a preferred choice, despite that it is second-best as compared to the Pareto ideal outcome of "total peace" without armaments.

In modeling the optimal choice between bargaining and fighting, we pay particular attention to differences between direct costs (e.g., arms buildups) and indirect costs (e.g., destruction to productive resources) of conflict. In military conflict, for instance, fighting involves both arms costs and the resulting destruction costs in terms of consumable resources destroyed. Our model shows that, under the shadow of conflict, contending parties unambiguously allocate more resources to armaments for guarding a settlement through bargaining than for fighting. The equilibrium amount of the non-military, consumable good produced is then relatively lower in settlement bargaining than in the event of fighting. Bargaining is thus more costly than fighting in terms of the consumable good forgone. This implies that there are "gains from fighting" in terms of the consumable good produced. These gains provide strong incentives for the adversaries to fight. When the resulting destruction costs of fighting are lower than its gains, fighting dominates bargaining as the dominant strategy. In equilibrium, war costs (i.e., arms costs plus destruction costs) are shown to be less than settlement costs (i.e., the costs of resources allocated to guarding the bargaining settlement), causing each party's expected payoff to be relatively higher under war. The condition that facilitates fighting depends not only on arming, but also on the endogeneity of fighting's destructiveness. Given that bargaining is costly under the shadow of conflict, the argument that war is costly does not imply that bargaining is always preferable to fighting. Our theoretical findings may help explain the general causes of wars, strikes, international conflict without incomplete information or misperceptions.

But when the endogenous destruction costs are higher than gains from fighting, each party's expected payoff becomes relatively higher in the bargaining settlement. In equilibrium, war costs exceed settlement costs. That is, arms costs plus destruction costs are greater than the costs of resources allocated to arming for protecting the settlement. Consequently, bargaining is a Pareto-improving choice and the relatively higher level of arming under settlement (than that under war) is efficient in generating an effective deterrence. This result has an important implication for the economics of "armed peace." Within the framework of conflict with endogenously increasing destruction, allocating more resources to arming is not inconsistent with bargaining for a mutually acceptable settlement. This suggests that, for launching a peace talk between adversaries, arms reductions are perceived as Pareto-suboptimal to the parties and hence will generally not be accepted on a voluntary basis. These results stand in stark contrast to the conventional wisdom on arms reductions for the purpose of promoting peace.[17]

In the general equilibrium analysis, we explicitly characterize the simultaneous interaction of conflict technology, production technology, and "destruction technology" (in terms of fighting's destructiveness) in determining the optimal allocations of resources to productive and combative activities by the contending parties, as well as their choices between fighting and bargaining. We do not impose any specific functional forms on conflict and production technologies in the analysis. We consider different modes of military technology to capture the endogeneity of increasing destruction, an important element of armed confrontation not adequately analyzed in the theoretical conflict literature. Our simple model indicates that the availability of unbiased negotiations for resolving disputes between adversaries does not guarantee that fighting will not break out. Preparing relatively fewer armaments under settlement in the shadow of conflict may only jeopardize the parties' capabilities in guarding a

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[17] See Baliga and Sjöström (2004) for an analysis of arms race and peace deals. They show, among other things, the conditions under which arms race always occurs and a cheap talk can resolve such dilemma.

bargaining settlement once fighting breaks out. This is especially true when property rights are imperfectly specified or when there exists no enforceable mechanism for achieving the "ideal" or first-best outcome of total peace (with low or no resources allocated to arming).

This paper makes no intention to address issues concerning the actual causes of specific wars in history. The primary objective of the game-theoretic analysis is to resolve the inefficiency puzzle of war, the central issue that underlines academic debates about the general causes of fighting. From the positive economic perspective, we show that conflictual parties may perceive it beneficial to initiate a war, without the presumptions of incomplete information, misperceptions, commitment problems, indivisibilities, or negotiation failures as suggested by Fearon (1995) and Powell (1999, 2004, 2006). These underlying conditions are undeniably the possible causes of wars and may explain many facets of historical conflicts. Nevertheless, these conditions do not adequately resolve the central puzzle concerning why bargaining settlements are not preferred to costly wars (see the quotations). In contrast to the argument that war is more costly than settlement, we find that bargaining under the threat of conflict can be more costly than fighting (in terms of resources allocated to armaments or combative inputs). Not surprisingly, bettering the bargaining position or guarding a mutually acceptable settlement is highly costly. The likelihood of achieving a negotiated settlement or not thus depends crucially on the endogeneity of fighting's destructiveness. Our analysis presents an answer to the puzzling question raised by Powell (2004) concerning "why the bargainers sometimes fail to reach a Pareto superior agreement prior to the explicit use of power." We further analyze the robustness of our primary findings by investigating alternative types of destruction technology.

The remainder of the paper is organized as follows. Section 2 lays out the general equilibrium model of bargaining and fighting between conflictual parties under complete information. In this section, we first discuss assumptions on conflict technology, production technology, and destruction technology. We then derive and compare the fighting equilibrium and the bargaining equilibrium in terms of combative inputs and expected payoffs under symmetry. Section 3 extends the analysis to allow for conflict with alternative settings of destruction. Section 4 concludes.

## 2 The Baseline Model

### *2.1 Basic Assumptions and the Endogeneity of Destruction*

To show the tradeoff between production and appropriation and to analyze the general causes of war, we consider a simple general equilibrium model of fighting and bargaining between two conflictual parties, denoted as 1 and 2. The two parties are rational and risk-neutral in seeking control over resources or gaining political dominance. Each party is endowed with a fixed amount of an inalienable resource *R*, which can be transformed into a non-combative (productive) input, *x*, and a combative (appropriative) input, *y*.[18] The resource constraint facing each party is $R = x_i + y_i$.

Departing from the conflict models of Garfinkel and Skaperdas (2000) and Skaperdas (2006) that adopt the solution concept of subgame-perfect equilibrium, we assume that the conflictual parties play a simultaneous Nash non-cooperative game. Specifically, under complete information, the two parties choose between fighting and bargaining and, at the same time, determine their optimal allocations of resources to non-combative and combative inputs, $\{x_i, y_i\}$. This assumption rules out the commitment problem or failure as discussed in Fearon (1995). For example, when party 1 chooses to fight, it concurrently determine its optimal values of $\{x_1, y_1\}$ for fighting a war under the belief that party 2 will do the same under complete information and symmetry. The same logic applies to the case of settlement bargaining (but under the shadow of conflict) and when party 2 makes its decision. We further assume that war breaks out when either party chooses to fight.

Following Hirshleifer (1992) and Skaperdas (1992), we hypothesize that party 1 and party 2 jointly produce a consumable good using their productive inputs $x_1$ and $x_2$. The assumption of joint production parallels the notion of the *integrative* system as developed by Boulding (1962, 1963). In explaining a socio-economic system in which production and appropriation co-exist, Boulding (1963) remarks that the system is fundamentally governed by three subsystems: the threat system, the exchange system, and the integrative system. Boulding (1963) further stresses the importance of the integrative system in that it "establishes community

[18] The combative inputs can broadly be defined as guns, weapons, armaments, and soldiers in military conflict, efforts in rent-seeking activities, or monetary expenditures in litigation.

between the threatener and the threatened and produces common values and common interest" (p. 430). For example, countries in the global community engage in exchange of commodities based on the comparative advantage principle, but they may also engage in inter-state conflicts. The notion of the integrative system also applies to nation as a community where factions or interest groups devote their resources to producing goods and services for exchange (i.e., production), but they may also engage in intra-state conflicts or civil wars (i.e., appropriation). We thus assume that the technology of producing a consumable good is summarized by

**ASSUMPTION 3.1 (Production Technology).** *The technology of producing a consumable good takes the general form:* $Q = f(x_1, x_2)$, *which is concave in productive inputs. That is,*

$$f_{x_i} = \frac{\partial f}{\partial x_i} > 0, \quad f_{x_i x_i} = \frac{\partial^2 f}{\partial x_i^2} \leq 0, \text{ and } f_{x_i x_i} f_{x_j x_j} - (f_{x_i x_j})^2 \geq 0 \text{ for } i, j = 1, 2, \text{ and } i \neq j. \quad (3.1)$$

*Given that* $x_i = R_i - y_i$, *the production function is* $Q = f(R_1 - y_1, R_2 - y_2)$.

When property rights are imperfectly defined or enforced, the consumable good produced constitutes the overall contestable or negotiable resource for the two parties. This consumable good can be disposed either (i) through fighting with uncertain outcome or (ii) through bargaining with a mutually agreeable outcome but under the shadow of conflict. If the two parties decide to resolve their disputes over the distribution of the consumable good by fighting, the equilibrium shares of the good are determined by a conflict technology. If the two parties choose to settle disputes through bargaining, their equilibrium outcome is determined by a mutually acceptable sharing rule or norm that will be discussed later.

Let the technology of conflict be such that party 1's winning probability is $p(y_1, y_2)$ and party 2's winning probability is $1 - p(y_1, y_2)$. Note that these probabilities depend on the parties' allocations of resources to their combative inputs. Following Dixit (1987) and Skaperdas (1992), the conflict technology or the contest success function (expressed in terms of $p(y_1, y_2)$) satisfies some standard properties as summarized in[19]

[19] Skaperdas (1996) is the first to present an axiomatic approach to different classes of CSFs. In analyzing inter- or intra-group conflicts, an additive form of CSF is widely used (see. e.g., Hirshleifer (1997), Gershenson and Grossman (2000), Garfinkel and Skaperdas (2000, 2007), and Chang, Potter, and Sanders (2007a) ). Konrad (2007) presents a systematic review of studies on contest and conflict that employ different forms of CSFs.

**ASSUMPTION 3.2 (Conflict Technology).** *Defining the first- and second-order derivatives of the contest success function* $p(y_1, y_2)$ *as*

$$p_{y_i} = \frac{\partial p(y_1, y_2)}{\partial y_i}, \; p_{y_i y_i} = \frac{\partial^2 p(y_1, y_2)}{\partial y_i^2}, \textit{ and } p_{y_i y_j} = p_{y_j y_i} = \frac{\partial^2 p(y_1, y_2)}{\partial y_i \partial y_j} \textit{ for } i, j = 1, 2, \textit{ and } i \neq j,$$

*we assume that they satisfy the following conditions:*

$$0 < p_{y_1} < \infty, \; -\infty < p_{y_2} < 0, \; p_{y_1 y_1} \leq 0, \; p_{y_2 y_2} \geq 0, \tag{3.2}$$

$$\textit{and } p_{y_1 y_2} = p_{y_2 y_1} \begin{cases} \geq 0 \textit{ as } y_1 \geq y_2, \\ < 0 \textit{ as } y_1 < y_2. \end{cases}$$

Next, we introduce into the conflict analysis the endogeneity of fighting's destructiveness associated with combative inputs. Besides the *direct* costs of conflict as measured by resources allocated to the combative inputs (e.g., arms buildups), there are *indirect* costs of conflict in terms of consumable resources destroyed. For the purpose of our theoretical model, we adopt the plausible assumption that total destruction, $D$, is endogenously determined by the combative input allocations of the conflicting parties, i.e., $D = D(y_1, y_2)$. This total destruction function satisfies certain properties as described in

**ASSUMPTION 3.3 (Destruction Technology).** *Destruction technology is depicted by an endogenous and increasing damage to the consumable good in the event of fighting. Further, total destruction is a convex function of the combative inputs* $y_1$ *and* $y_2$ *such that for* $i, j = 1, 2,$ $i \neq j,$

$$D_{y_i} = \frac{\partial D(y_1, y_2)}{\partial y_i} > 0, \; D_{y_i y_i} = \frac{\partial^2 D(y_1, y_2)}{\partial y_i^2} > 0, \; D_{y_i y_j} = D_{y_j y_i} = \frac{\partial^2 D(y_1, y_2)}{\partial y_i \partial y_j} \geq 0, \tag{3.3}$$

$$\textit{and } D_{y_i y_i} D_{y_j y_j} - (D_{y_i y_j})^2 > 0.$$

Assumption 3.3 indicates that, when two parties choose to fight, the resulting destructiveness is a monotonically increasing and convex function of their combative input allocations. An increase in $y_i$ increases the amount of the consumable good destroyed when war breaks out. Marginal destruction, defined as $D_{y_i} = \partial D(y_1, y_2)/\partial y_i$, is strictly positive. Also, marginal destruction of a party's combative input $y_i$ is non-decreasing in its rival's combative input $y_j$. That is, $\partial D_{y_i}(y_1, y_2)\big/\partial y_j \geq 0.$

We proceed to analyze the equilibrium outcomes of fighting and bargaining, and the optimal allocations of resources to the productive and combative activities under the alternative decisions. We then compare their equilibrium expected payoffs. Last, when there is an exogenous change in the destructiveness multiplier, we examine the change in equilibrium allocations and outcomes. Unless otherwise noted, detailed proofs and the deviations of model results are to be found in the Appendix B.

### *2.2 Nash Equilibrium in the Event of Fighting*

We begin our analysis with the scenario where the two parties choose to resolve their disputes by means of fighting. Denote $V_i^W$ as the expected payoff that party *i* receives from fighting. The two parties' expected payoffs are:

$$V_1^W = p(y_1, y_2)\left[f(R - y_1, R - y_2) - \lambda D(y_1, y_2)\right], \tag{3.4a}$$

$$V_2^W = \left[1 - p(y_1, y_2)\right]\left[f(R - y_1, R - y_2) - \lambda D(y_1, y_2)\right]. \tag{3.4b}$$

This specification recognizes that each party's payoff is determined by the conflict technology, $p(y_1, y_2)$, the pre-fighting production of the consumable good, $Q = f(R - y_1, R - y_2)$, as well as the destruction technology, $D(y_1, y_2)$. The parameter $\lambda(> 0)$ converts total destruction into each party's payoff and is treated as a "destructiveness multiplier." An increase in $\lambda$ (*ceteris paribus*) can be treated as an exogenous advancement in the destruction technology of weapons.

The first-order conditions (FOCs) for the two conflicting parties are:

$$\frac{\partial V_1^W}{\partial y_1} = p_{y_1}(Q - \lambda D) - p(f_{x_1} + \lambda D_{y_1}) = 0, \tag{3.5a}$$

$$\frac{\partial V_2^W}{\partial y_2} = -p_{y_2}(Q - \lambda D) - (1 - p)(f_{x_2} + \lambda D_{y_2}) = 0. \tag{3.5b}$$

Denote $\{y_1^W, y_2^W\}$ as the optimal combative input allocations in the fighting equilibrium that satisfy the FOCs in (3.5). We show in Appendix B.2 that the second-order conditions (SOCs) for the expected payoff maximization problems are satisfied. These conditions ensure the strict concavity of $V_i^W$ in $y_i^W$. We also show that the Jacobian determinant of the FOCs for the two parties at the event of fighting is strictly positive. This indicates that there is an interior solution for the fighting equilibrium, $\{y_1^W, y_2^W\}$.

### *2.3 Nash Equilibrium under Settlement (but in the Shadow of Conflict)*

We proceed to discuss the second scenario where the adversaries choose to negotiate and resolve their disputes through a bargaining settlement (but under the threat of conflict due to imperfect enforcement in property rights). In modeling bargaining, there are different rules that may be employed by the parties. We assume that the two parties agree to use the Nash bargaining rule. It should be noted that, in our analytical framework, the Nash bargaining is equivalent to the split-the-surplus rule.[20]

Denote $\gamma$ as the share that party 1 receives when both parties settle their disputes by negotiations. It follows that the share for party 2 is $(1-\gamma)$. Letting $V_i^S$ represent party *i*'s payoff under settlement, we have

$$V_1^S = \gamma Q \text{ and } V_2^S = (1-\gamma)Q, \tag{3.6}$$

where $Q = f(R - y_1, R - y_2)$. Under the Nash bargaining rule, the two parties negotiate mutually acceptable shares, denoted as $\{\gamma, 1-\gamma\}$, such that

$$\gamma = \arg\max(V_1^S - V_1^W)(V_2^S - V_2^W).$$

The expected payoffs $V_i^W$ and $V_i^S$ are respectively given by equations (3.4) and (3.6). We show in Appendix B.1 that the optimal shares mutually agreeable to both parties are:

$$\gamma = p - \frac{(2p-1)\lambda D}{2Q} \text{ and } 1-\gamma = 1 - p - \frac{(2p-1)\lambda D}{2Q}. \tag{3.7}$$

Substituting $\{\gamma, 1-\gamma\}$ from equations (3.7) into the expected payoff functions in (3.6) yields the following:

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[20] We show in the Appendix the equivalence in the mutually acceptable shares between Nash bargaining and the split-the-surplus rule, a sharing rule under settlement as discussed in Garfinkel and Skaperdas (2000).

$$V_1^S = p(y_1, y_2)\left[ f(R - y_1, R - y_2) - \lambda D(y_1, y_2)\right] + \frac{\lambda D(y_1, y_2)}{2}, \tag{3.8a}$$

$$V_2^S = \left[1 - p(y_1, y_2)\right]\left[ f(R - y_1, R - y_2) - \lambda D(y_1, y_2)\right] + \frac{\lambda D(y_1, y_2)}{2}. \tag{3.8b}$$

Despite the bargaining settlement, imperfect enforcement of the "contract" requires the two parties to allocate resources to combative inputs for protecting their negotiated shares of the consumable good. Under the shadow of conflict, the FOCs for the two parties in bargaining are:

$$\frac{\partial V_1^S}{\partial y_1} = p_{y_1}(Q - \lambda D) - p(f_{x_1} + \lambda D_{y_1}) + \frac{\lambda D_1}{2} = 0, \tag{3.9a}$$

$$\frac{\partial V_2^S}{\partial y_2} = -p_{y_2}(Q - \lambda D) - (1 - p)(f_{x_2} + \lambda D_{y_2}) + \frac{\lambda D_2}{2} = 0. \tag{3.9b}$$

Denote $\{y_1^S, y_2^S\}$ as the optimal combative input allocations in the bargaining equilibrium that satisfy the FOCs in (3.9). We show in Appendix B.2 that the SOCs for the expected payoff maximization problems are satisfied. These conditions ensure the strict concavity of $V_i^S$ in $y_i^S$. We also show that the Jacobian determinant of the FOCs for the two parties in settlement bargaining is strictly positive. This indicates that there is an interior solution for the bargaining equilibrium, $\{y_1^S, y_2^S\}$.

### *2.4 Comparison between Fighting and Bargaining*

We are now in a position to analyze and compare whether the two conflictual parties will allocate more or less amounts of their resources to combative inputs between the two alternative decisions. To do so, we adopt the comparison methodology by evaluating the first-order derivatives $\partial V_1^S / \partial y_1$ and $\partial V_2^S / \partial y_2$ in equations (3.9) at $\{y_1^W, y_2^W\}$, taking into account the FOCs for the fighting equilibrium in equations (3.5a) and (3.5b). After re-arranging terms, we have

$$\left.\frac{\partial V_i^S}{\partial y_i}\right|_{(y_i^W, y_2^W)} = \frac{\lambda D_{y_i}(y_1^W, y_2^W)}{2} > 0 \text{ for } i = 1, 2. \tag{3.10}$$

The derivatives in (3.10) are unambiguously positive because $D_i$ ($i=1,2$) is strictly positive according to Assumption 3.3. Given that each party's expected payoff function $V_i^S$ is strictly concave in $y_i$, we infer that

$$y_i^S > y_i^W. \tag{3.11a}$$

Equation (3.11a) indicates that each party's optimal combative input is relatively greater in the bargaining equilibrium than in the fighting equilibrium.

The intuition behind the result in (3.11a) is as follows. When the conflictual parties anticipate destruction to be avoided through bargaining, they have a strong incentive to allocate relatively more resources to gun allocations for guarding the settlement. Given that $Q^S = f(R-y_1^S, R-y_2^S)$ and $Q^W = f(R-y_1^W, R-y_2^W)$ according to the production technology in Assumption 3.1, the finding that $y_i^S > y_i^W$ implies

$$Q^S < Q^W. \tag{3.11b}$$

Equation (3.11b) indicates that, relative to the settlement bargaining, there are "gains from fighting" in terms of the consumable good produced, $Q^W - Q^S$. We thus have

**PROPOSITION 3.1 (Bargaining is costly)**. *For conflict between two parties in which the overall destruction to the consumable good is endogenously increasing in their combative inputs, each party allocates more resources to combative inputs for guarding their settlement through bargaining than in the event of fighting. As a result, the aggregate production of the consumable good is relatively lower in the bargaining equilibrium. In terms of the consumable good produced which is contestable, there are gains from fighting.*

Proposition 3.1 has an interesting implication for conflictual parties. In terms of consumable resources forgone, settlement bargaining is costly under the threat of conflict. Preparing a lower level of arming under settlement (relative to the case of fighting) turns out to be "inefficient" and will only risk one's capability in guarding a negotiated settlement.

Two questions of interest naturally arise. With the relatively higher levels of armaments, will the settlement bargaining constitute the dominant outcome in situations where property rights are imperfectly defined or enforced? Will the conflictual parties ever choose to fight? To answer the questions, we employ the plausible assumption that each party's choice between fighting and bargaining depends on the level of its expected payoff. This is consistent with the rational choice theory of international relations that contending parties start a war intending to win. Winning a war increases a party's power and wealth which are captured by its expected payoff in our setting.

The next step of the analysis is to compare their equilibrium expected payoffs between fighting and bargaining. Before doing so, we discuss the following Lemma:

**LEMMA 3.1.** *Denote* $p^S(y_1^S, y_2^S)$ *as party 1's winning probability when the two parties negotiate for mutually acceptable shares (see equations (3.7a) and (3.7b)). Denote* $p^W(y_1^W, y_2^W)$ *as party 1's winning probability in the event of fighting without negotiations. The assumption of symmetry in all aspects implies that* $p^S = p^W = \gamma = 1/2$.

Applying Lemma 3.1 to $V_i^W$ in equation (3.4) and $V_i^S$ in equation (3.6), we have

$$V_i^S - V_i^W = \frac{1}{2}\left[\lambda D(y_1^W, y_2^W) - (Q^W - Q^S)\right]. \tag{3.12a}$$

Note that $\lambda D(y_1^W, y_2^W)$ is the indirect cost of fighting for party *i*, measured by the scale $\lambda$ times the destruction to the consumable good. Since gains from fighting, $Q^W - Q^S$, are strictly positive (see equations (3.11b)), we are able to compare the expected payoffs between bargaining and fighting as follows:

$$V_i^S > V_i^W \text{ if and only if } \lambda D(y_1^W, y_2^W) > Q^W - Q^S, \tag{3.12b}$$

$$V_i^W > V_i^S \text{ if and only if } \lambda D(y_1^W, y_2^W) < Q^W - Q^S. \tag{3.12c}$$

Based on the necessary and sufficient conditions in (3.12), we have

**PROPOSITION 3.2 (To fight or not to fight)**. *Other things being equal, settlement through bargaining is a Pareto-improving choice if, and only if, the total destructiveness of fighting,* $\lambda D$, *is higher than its gains,* $Q^W - Q^S$. *Nevertheless, fighting is a Pareto-improving choice if, and only if, the total destructiveness of fighting is less than its gains. In the later case, the perceived payoffs from fighting are strictly higher than those in settlement bargaining.*

Proposition 3.2 indicates that when gains from fighting exceed total destruction such that $(Q^W - Q^S) > \lambda D$, the conflictual parties find it beneficial to go to war. Figures 3.1 and 3.2 are graphical interpretations of the findings in the above two propositions. Figure 3.1 contains three panels *A*, *B*, and *C* for the case in which bargaining dominates fighting. In panel *A*, each party's expected payoff curve under settlement ($V_i^S$) is lying to the right of its expected payoff curve in the event of fighting ($V_i^W$) according to equations (3.10) and (3.11a). The slope of $V_i^S$, when evaluated at $y_i^W$, is strictly positive as shown by point *E*. The positivity of the slope is consistent with the finding that $y_i^S > y_i^W$. Panel *B* shows the total destruction function of fighting, $\lambda D$, which is convex in the combative inputs, $y_i^W$. Panel *C* shows the product curve of the consumable good, which is strictly concave in the productive inputs, $x_i (= R - y_i)$.

Given each party's endowment constraint, the result that $y_i^S > y_i^W$ implies that $x_i^S < x_i^W$. This in turn implies that gains from fighting are positive ($Q^W - Q^S > 0$). It follows from panels *B* and *C* that fighting is more costly than bargaining since $\lambda D > Q^W - Q^S$. This explains why bargaining is the preferred choice ($V_i^S > V_i^W$).

Figure 3.2 shows the case in which fighting dominates bargaining, i.e., $V_i^W > V_i^S$. This is because total destructiveness of fighting is lower than its gains, $\lambda D < Q^W - Q^S$. As a result, fighting is the preferred choice ($V_i^W > V_i^S$).

Propositions 3.1 and 3.2 indicate that there is a positive relationship between combative inputs (arms buildups) and "armed peace." In terms of resources allocated to combative inputs for appropriation, our model shows that it is always more costly to maintain a negotiated settlement (under the shadow of conflict) than in the event of fighting. Despite the availability of an unbiased settlement for conflictual parties to resolve their disputes, there is no guarantee that fighting will not emerge. The prospect of weapons' destructiveness plays an important role in affecting the expected payoffs of the parties and their choices between fighting and bargaining. Allocating relatively small amounts of resources to arming unambiguously lower the capacities of the parties to guard their negotiated settlement once fighting breaks out. This situation becomes more serious when the destructiveness of weapons becomes greater.

**Figure 3.1 Bargaining Dominates**

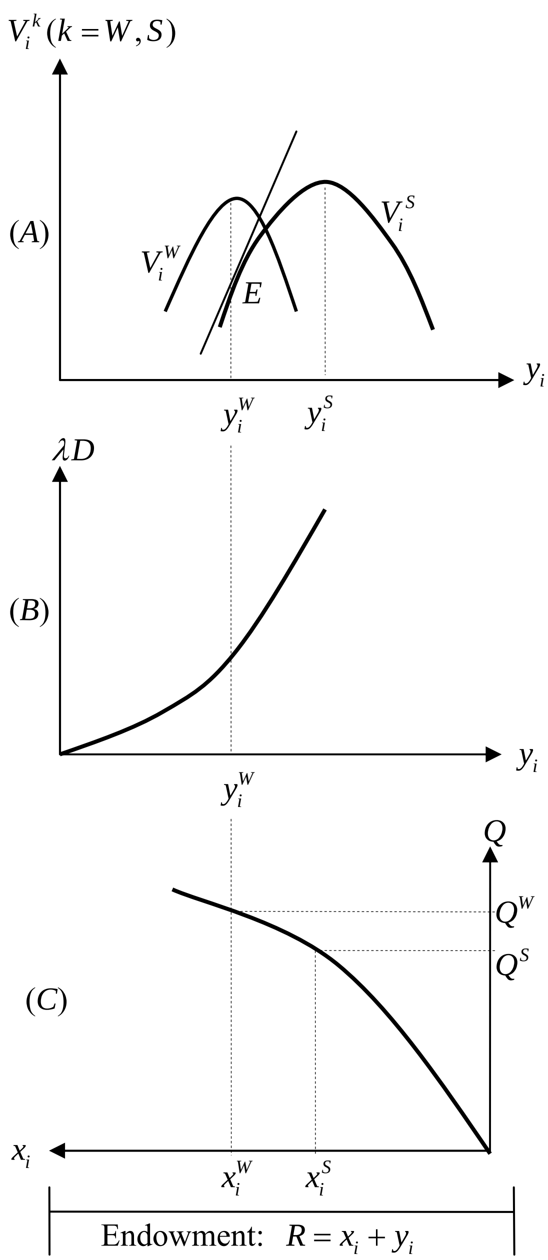
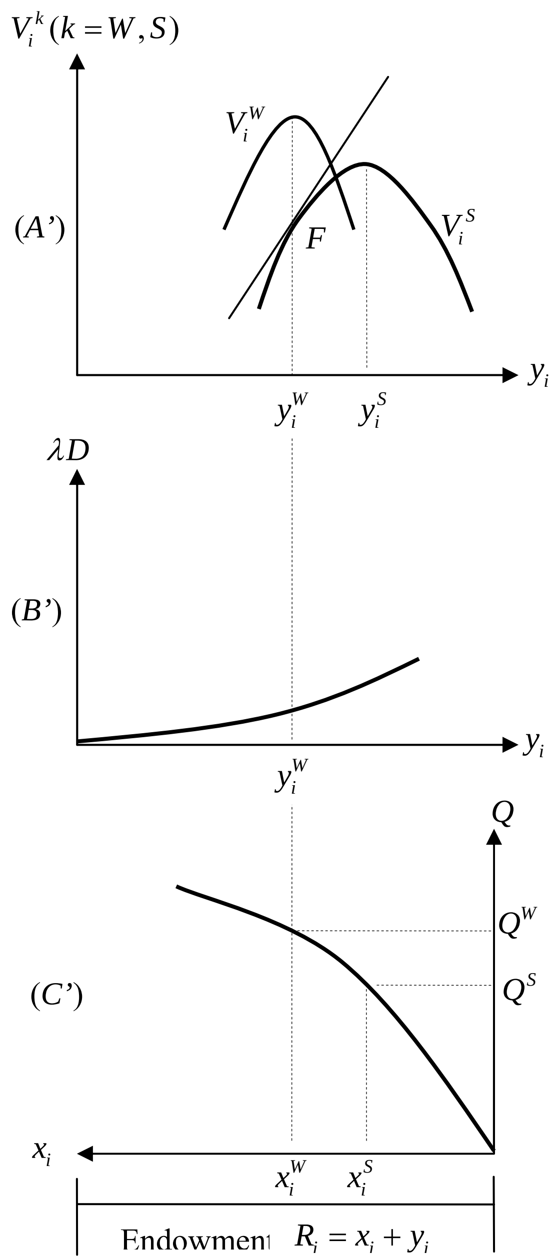



**Figure 3.2 Fighting Dominates**




In the context of military conflicts, it is important to identify the roles that weapons of mass destruction (WMD) might play in affecting the decisions of contending parties between fighting and bargaining. This is especially true when the scale of fighting's destructiveness is endogenously increasing in resources allocated to the production of WMD. The inequality conditions in equation (3.12b) can be used to reflect Schelling's (1960) notion of mutually assured destruction (MAD). In his now classic work, Schelling contends that for effectively achieving mutual cooperation rather than mutual defection, it is necessary to introduce MAD. The underlying rationale is that each party has the capability to destroy the other in the event of war. In the present analysis of conflict under endogenous and increasing destruction, we are able to show a case where the MAD size is optimally determined by adversaries to generate effective deterrence. For the destructiveness of weapons such that $D(y_1^W, y_2^W) > (Q^W - Q^S)/\lambda$, we have $V_i^S > V_i^W$, implying that fighting is a Pareto-inferior or inefficient choice. Schelling (2005), in explaining why "[w]e have enjoyed sixty years without nuclear weapons exploded in anger," clearly notes the following: "What nuclear weapons have been used for, effectively, successfully, for sixty years has not been on the battlefield nor on population targets: they have been used for influence." Our model of endogenous destruction and armed peace is consistent with Schelling's idea of *influence*.

Social researchers have devoted considerable effort to analyzing the causes of wars. Possible explanations of why war occurs include incomplete information, over-optimism, miscalculations, biased negotiations, bargaining failures, commitment problems, irrationality, or a long-term strategy of gaining dominance over one's opponent. This list of underlying conditions explains well many facets of open conflicts or armed confrontations. From a different perspective, our findings in Propositions 3.1 and 3.2 offer a solution to the fundamental question about the general causes of wars, without relying on these conditions. Costly war, international conflict, or fighting in general may emerge as a dominant choice over bargaining even under complete information without misperceptions. The positive analysis suggests that the use of power does not necessarily lead to an outcome inferior to settlement through bargaining. Moreover, higher levels of armaments may not actually make the world more unsafe, depending on weapons' destructiveness relative to the gun allocation differentials between bargaining and fighting.

### *2.5 Effects of an (Exogenous) Advancement in Destruction Technology*

One question of interest concerns how the equilibrium choice between fighting and bargaining is affected by a technical progress in destruction technology. This is a complicated issue and should be examined in a more general framework. Nevertheless, the simple model presented in this paper may offer a preliminary exploration for the question. We consider the case of an exogenous advancement in destruction technology which generates a larger scale of destructiveness, other things being equal. This allows us to conduct the comparative statics of the destructiveness multiplier, $\lambda$.

Based on the analyses of fighting and bargaining discussed earlier, we show in appendix B.3 the following comparative-static derivatives with respect to $\lambda$:

$$\frac{\partial y_i^W}{\partial \lambda} < 0,\ \frac{\partial V_i^W}{\partial \lambda} > 0,\ \frac{\partial y_i^S}{\partial \lambda} < 0, \text{ and } \frac{\partial V_i^S}{\partial \lambda} > 0.$$

Further, applying the Envelope Theorem to equation (3.12a) yields

$$\frac{\partial (V_i^S - V_i^W)}{\partial \lambda} > 0.$$

Thus, when there is an exogenous increase in $\lambda$, the increase in each party's expected payoff is higher in bargaining settlement than in the event of fighting.

Suppose that initially fighting dominates bargaining such that $V_i^W > V_i^S$. Advancement in destruction technology as captured by an increase in $\lambda$ will make the expected payoff differentials, defined as $(V_i^W - V_i^S)$, to become smaller. When $\lambda$ increases up to the level beyond which $(V_i^W - V_i^S)$ becomes negative, we have $V_i^S < V_i^W$. Consequently, bargaining settlement dominates fighting. The likelihood that bargaining dominates fighting is positively related to the exogenous advancement in destruction technology. These results permit us to construct the following proposition:

**PROPOSITION 3.3 (How a war ends)**. *When there is an exogenous increase in the scale of destructiveness, both contending parties allocate relatively less resources to the combative inputs whether they choose to fight or not to fight. In equilibrium, each party's expected payoff becomes larger for either decision. Other things being equal, an exogenous advancement in destruction technology (in terms of fighting's destructiveness) lowers the likelihood that two parties choose fight.*

The logic underlying the result is as follows. An increase in the destructiveness of weapons unambiguously reduces the perceived payoffs in the event of armed confrontation. Accordingly, each party has a lower incentive to fight.

Figures 3.1 and 3.2 can now be used to illustrate the case of "how a war ends" in response to a change in destruction technology that leads to an increase in the scale of destructiveness to valuable resources.[21] In such case, Figure 3.2 is associated with a low level of destructiveness such that fighting dominates bargaining. When $\lambda$ increases, that is, from panel *B'* to panel *B*, bargaining becomes the dominant strategy. This implies that costly fighting is no longer the preferred choice and the adversaries find it better off to end their war.

### *2.6 An Illustrative Example*

It is instructive to use numerical examples to analyze and compare the equilibrium outcomes between fighting and bargaining. As discussed in the previous sections, we are particularly interested in the coexistence of $y_i^S > y_i^W$ and $V_i^W > V_i^S$, which suggest that fighting is a preferred choice over bargaining.

For the simplicity of calculations, we use the additive form of the CSF and an exponential destruction function:

$$p(y_1, y_2) = \frac{y_1}{y_1 + y_2} \text{ and } \lambda D(y_1, y_2) = \lambda \delta^{y_1 + y_2},$$

where $\delta$ is a positive constant. Under symmetry in endowments, we assume that the production function takes the simple form as: $Q = f(R - y_1, R - y_2) = 2R - y_1 - y_2$. Based on the conflict technology, destruction technology, and production technology assumed above, equations (3.4) and (3.8) of the baseline model imply that each party's expected payoffs from fighting and bargaining are:

$$V_i^W = \frac{y_i}{y_1 + y_2}(2R - y_1 - y_2 - \lambda \delta^{y_1 + y_2}),$$

$$V_i^S = \frac{y_i}{y_1 + y_2}(2R - y_1 - y_2 - \lambda \delta^{y_1 + y_2}) + \frac{\lambda \delta^{y_1 + y_2}}{2}.$$

These specifications are consistent with Assumptions 3.1 to 3.3.

[21] The use of nuclear weapons in WWII resulting from advancement in destruction technology may serve as an example.

Assuming that $R = 50$, $\delta = 1.1$, and $\lambda = 1$, we solve numerically for the equilibrium combative inputs, quantities of the consumable good produced, and destruction to be

$$y_1^W = y_2^W = 13.445,\ \ y_1^S = y_2^S = 17.701,\ Q^W - Q^S = 8.512, \text{ and } \lambda D = 12.973.$$

It follows that $y_i^S > y_i^W$ and $\lambda D > Q^W - Q^S$. The expected payoffs of the parties are calculated to be $V_1^W = V_2^W = 30.069$ and $V_1^S = V_2^S = 32.299$, which imply that $V_i^S > V_i^W$. These results are consistent with the findings in equations (3.11b) and (3.12b). Two parties allocate relatively more resources to combative inputs in settlement bargaining than in the event of fighting. Because the destructiveness of fighting is higher than its gains, bargaining turns out to be the preferred choice (see Proposition 3.2).

Next, we assume that $R$ and $\delta$ remain unchanged but the scale of destructiveness becomes as small as $\lambda = 0.01$. We solve for the equilibrium solutions to be

$$y_1^W = y_2^W = 23.728,\ y_1^S = y_2^S = 24.722,\ \ Q^W - Q^S = 1.988, \text{ and } \lambda D = 0.92115.$$

It follows that $y_i^S > y_i^W$ and $\lambda D < Q^W - Q^S$. The expected payoffs of the parties are calculated to be $V_1^W = V_2^W = 25.811$ and $V_1^S = V_2^S = 25.278$, which imply that $V_i^W > V_i^S$. These results are consistent with the findings in equations (3.11a) and (3.12a). Two parties continue to allocate more resources to combative inputs in settlement bargaining than in the event of fighting. Because the gains from fighting are greater than its destructiveness, fighting turns out to be the preferred choice (see Proposition 3.2).

The above numerical examples show that both $y_i^W$ and $y_i^S$ decrease with $\lambda$, other things being equal. Interestingly, we can use the examples to illustrate how a war ends when the scale of destructiveness changes from $\lambda = 0.01$ to $\lambda = 1$ (say, due to an exogenous advancement in military weapons and their destruction technology). These results are consistent with the implications as shown in Figures 3.1 and 3.2, as well as the findings in Proposition 3.3.

## 3 Alternative Models of Conflict with Endogenous Destruction

To further demonstrate the robustness of the model results in Section 2, we examine three different settings in terms of fighting's destructiveness. The first setting is when the proportion of valuable resources destroyed by war is proportional to the amounts of combative inputs allocated by conflictual parties. The second setting is when the amounts of destructions to the parties differ even though their combative inputs are equally effective in fighting. The third setting is when destructions are party-specific but combative inputs have both the offensive effect of inflicting damage on a rival party and the defensive effect of reducing damage caused by fighting. In each mode of the destruction technology, we wish to examine whether the parties' combative input allocations are greater in settlement bargaining than in the event of fighting. Moreover, we wish to analyze and compare their expected payoffs between fighting and bargaining.

### *3.1 Proportional Destruction*

Denote $\phi(y_1, y_2)$ as the proportion of the consumable good that remains after fighting, where $0 \le \phi \le 1$. The proportion of the consumable good caused by fighting is then equal to $(1-\phi)$. The expected payoff functions of the parties in the event of fighting are:

$$\bar{V}_1^W = p(y_1, y_2) f(R - y_1, R - y_2)\phi(y_1, y_2), \tag{3.13a}$$

$$\bar{V}_2^W = \left[1 - p(y_1, y_2)\right] f(R - y_1, R - y_2)\phi(y_1, y_2). \tag{3.13b}$$

Following Chang and Luo (2012), we assume that the proportional function $\phi(y_1, y_2)$ has the properties according to

**ASSUMPTION 3.3.1.** *The portion of the consumable good that remains after fighting is a strictly concave function of combative input allocations such that for* $i, j = 1, 2$, $i \neq j$,

$$\phi_{y_i} = \frac{\partial \phi(y_1, y_2)}{\partial y_i} < 0,\ \phi_{y_i y_i} = \frac{\partial^2 (y_1, y_2)}{\partial y_i^2} < 0,\ \phi_{y_i y_j} = \phi_{y_j y_i} = \frac{\partial^2 \phi(y_1, y_2)}{\partial y_1 \partial y_2} < 0, \tag{3.14}$$

*and* $\phi_{y_i y_i}\phi_{y_j y_j} - (\phi_{y_i y_j})^2 > 0$. *In addition, we have* $\phi(0,0) = 1$.

This assumption extends the models of conflict and settlement in Garfinkel and Skaperdas (2000) where the proportion of valuable resources that remain after war is assumed to be exogenously fixed.

Based on the expected payoff functions in (3.13) and Assumption 3.3.1, the FOCs of the two parties are:

$$\frac{\partial \overline{V}_1^W}{\partial y_1} = p_{y_1} Q\phi - pf_{x_1}\phi + pQ\phi_{y_1} = 0 \text{ and } \frac{\partial \overline{V}_2^W}{\partial y_2} = -p_{y_2} Q\phi - (1-p) f_{x_2}\phi + (1-p)Q\phi_{y_2} = 0. \qquad (3.15)$$

Denote $\{\overline{y}_1^W, \overline{y}_2^W\}$ as the optimal combative input allocations in the fighting equilibrium where the proportional function satisfies the FOCs in (3.15). We show in Appendix B.4 that the SOCs are satisfied which ensure the strict concavity of $\overline{V}_i^W$ in $\overline{y}_i^W$.

For the bargaining equilibrium, it is easy to verify that the Nash Bargaining shares denoted as $\{\overline{\gamma}, 1-\overline{\gamma}\}$, of the consumable good for the two parties are:

$$\overline{\gamma} = p\phi + \frac{1}{2}(1-\phi) \text{ and } 1-\overline{\gamma} = (1-p)\phi + \frac{1}{2}(1-\phi).$$

In settlement bargaining under the shadow of conflict (due to the absence of enforcement), the two parties' expected payoffs are:

$$\overline{V}_1^S = p(y_1, y_2) f(R-y_1, R-y_2)\phi(y_1, y_2) + \frac{1}{2} f(R-y_1, R-y_2)\left[1-\phi(y_1, y_2)\right], \qquad (3.16a)$$

$$\overline{V}_2^S = \left[1-p(y_1, y_2)\right] f(R-y_1, R-y_2)\phi(y_1, y_2) + \frac{1}{2} f(R-y_1, R-y_2)\left[1-\phi(y_1, y_2)\right]. \qquad (3.16b)$$

The FOCs of the parties with respect to $y_1$ and $y_2$ are:

$$\frac{\partial \overline{V}_1^S}{\partial y_1} = p_{y_1} Q\phi - pf_{x_1}\phi + pQ\phi_{y_1} + \frac{1}{2}(f_{x_1}\phi - f_{x_1} - Q\phi_{y_1}) = 0, \qquad (3.17a)$$

$$\frac{\partial \overline{V}_2^S}{\partial y_2} = -p_{y_2} Q\phi - (1-p) f_{x_2}\phi + (1-p)Q\phi_{y_2} + \frac{1}{2}(f_{x_2}\phi - f_{x_2} - Q\phi_{y_2}) = 0. \qquad (3.17b)$$

Denote $\{\overline{y}_1^S, \overline{y}_2^S\}$ as the optimal combative input allocations in the bargaining equilibrium with the proportional function that satisfies the FOCs in (3.17). We show in Appendix B.4 that the SOCs are satisfied which ensure the strict concavity of $\overline{V}_i^S$ in $\overline{y}_i^S$.

Next, given that $\overline{V}_i^W$ and $\overline{V}_i^S$ are strictly concave, we evaluate the derivatives of $\overline{V}_i^S$ with respective to $y_i$ at the war equilibrium gun allocations, $\{\overline{y}_1^W, \overline{y}_2^W\}$. Making use of equations (3.15) and (3.17), we have

$$\left.\frac{\partial \bar{V}_i^S}{\partial y_i}\right|_{\{\bar{y}_1^W, \bar{y}_2^W\}} = \frac{1}{2}(f_{x_i}\phi - f_{x_i} - Q\phi_{y_i})\Big|_{\{\bar{y}_1^W, \bar{y}_2^W\}} \text{ for } i = 1, 2. \tag{3.18}$$

Define $\varepsilon_{f,y_i} \equiv \frac{\partial Q}{\partial \bar{y}_i^W} \frac{\bar{y}_i^W}{Q}$ and $\varepsilon_{1-\phi,y_i} = \frac{\partial(1-\phi)}{\partial \bar{y}_i^W} \frac{\bar{y}_i^W}{1-\phi}$ as elasticities of production and destruction with respect to combative inputs. It follows from equation (3.18) that

$$\left.\frac{\partial \bar{V}_i^S}{\partial y_i}\right|_{\{\bar{y}_1^W, \bar{y}_2^W\}} > 0 \text{ if and only if } \varepsilon_{f,y_i} < \varepsilon_{1-\phi,y_i}. \tag{3.19}$$

For a one percent change in each party's combative input, if the percentage change in destruction proportion is greater than the percentage change in production, we have $(f_{x_i}\phi - f_{x_i} - Q\phi_{y_i}) > 0$ such that the derivative in equation (3.18) is positive. The strict concavity of $\bar{V}_i^S$ in $\bar{y}_i^S$ then implies that

$$\bar{y}_i^S > \bar{y}_i^W. \tag{3.20}$$

If follows from equation (3.20) and the production that $\bar{Q}^W - \bar{Q}^S > 0$. This difference in the amounts of the consumable good produced measures gains from fighting.

Under symmetry, we use equations (3.14) and (3.16) to compare the expected payoffs between fighting and bargaining. We have

$$\bar{V}_i^W - \bar{V}_i^S = \frac{1}{2}\bar{Q}^W\phi - \frac{1}{2}\bar{Q}^S,$$

which is strictly positive if, and only if,

$$\bar{Q}^W - \bar{Q}^S > \bar{Q}^W(1-\phi). \tag{3.21}$$

Note that the right-hand side of equation (3.21) is the total destruction cost resulting from fighting. This result is consistent with the finding as shown in equation (3.12b) of the baseline model. We thus have

**PROPOSITION 3.4**. *Consider conflict between two symmetric parties where total destruction caused by fighting is proportional to their resources allocated combative inputs. The parties allocate more resources to combative inputs in the bargaining equilibrium than in the fighting* *equilibrium if, and only if, the use of combative inputs increases the proportional destruction more effective than the use of productive inputs in producing the consumable good. In addition, fighting is a Pareto-improving choice over bargaining if, and only if, gains from fighting are greater than its total destruction.*

### *3.2 Party-Specific Destruction*

Next, we examine the setting where total destructions to the conflictual parties differ in amounts. Specifically, the expected payoffs with party-specific destructions are given as

$$\tilde{V}_1^W = p(y_1, y_2)\, f(R-y_1, R-y_2) - \lambda D^1(y_1, y_2); \tag{3.22a}$$

$$\tilde{V}_2^W = \left[1 - p(y_1, y_2)\right] f(R-y_1, R-y_2) - \lambda D^2(y_1, y_2); \tag{3.22b}$$

where $D^i(y_1, y_2)$ measures destruction specific to party $i$ and $\lambda$, as defined earlier, is a destructiveness multiplier. Similar to Assumption 3.3, we assume that $D^i$ satisfies certain conditions as outlined in

**ASSUMPTION 3.3.2.** *Total destruction to a party is a convex and increasing function of the combative inputs* $y_1$ *and* $y_2$ *such that for* $i, j = 1, 2$ , $i \neq j$ ,

$$D_{y_i}^i = \frac{\partial D^i(y_1, y_2)}{\partial y_i} > 0,\ D_{y_i y_i}^i = \frac{\partial^2 D^i(y_1, y_2)}{\partial y_i^2} > 0,\ D_{y_i y_j}^i = D_{y_j y_i}^i = \frac{\partial^2 D^i(y_1, y_2)}{\partial y_i \partial y_j} \geq 0, \tag{3.23}$$

*and* $D_{y_i y_i}^i D_{y_j y_j}^j - D_{y_i y_j}^i D_{y_j y_i}^j > 0.$

Applying Assumption 3.3.2 to the expected payoff functions in (3.22), the FOCs of the two parties are:

$$\frac{\partial \tilde{V}_1^W}{\partial y_1} = p_{y_1} Q - p f_{x_1} - \lambda D_{y_1}^1 = 0 \text{ and } \frac{\partial \tilde{V}_2^W}{\partial y_2} = -p_{y_2} Q - (1-p) f_{x_2} - \lambda D_{y_2}^2 = 0. \tag{3.24}$$

Denote $\{\tilde{y}_1^W, \tilde{y}_2^W\}$ as the optimal combative input allocations in the fighting equilibrium that satisfy the FOCs in (3.24). We show in Appendix B.5 that the SOCs are satisfied which ensure the strict concavity of $\tilde{V}_i^W$ in $\tilde{y}_i^W$.

It can easily be verified that when the two parties negotiate a settlement through bargaining, the shares of the consumables, denoted as $\{\tilde{\gamma}, 1-\tilde{\gamma}\}$ are:

$$\gamma = p + \frac{\lambda(D^2 - D^1)}{2Q} \text{ and } 1 - \gamma = 1 - p + \frac{\lambda(D^1 - D^2)}{2Q}. \tag{3.25}$$

In settlement bargaining, the two parties' expected payoffs are:

$$\tilde{V}_1^S = p(y_1, y_2) f(R - y_1, R - y_2) - \lambda D^1(y_1, y_2) + \frac{\lambda[D^1(y_1, y_2) + D^2(y_1, y_2)]}{2}, \tag{3.26a}$$

$$\tilde{V}_2^S = [1 - p(y_1, y_2)] f(R - y_1, R - y_2) - \lambda D^2(y_1, y_2) + \frac{\lambda[D^1(y_1, y_2) + D^2(y_1, y_2)]}{2}. \tag{3.26b}$$

It follows from equations (3.26) that the FOCs are:

$$\frac{\partial \tilde{V}_1^S}{\partial y_1} = p_{y_1} Q - p f_{x_1} - \lambda D_{y_1}^1 + \frac{\lambda(D_{y_1}^1 + D_{y_1}^2)}{2} = 0, \tag{3.27a}$$

$$\frac{\partial \tilde{V}_2^S}{\partial y_2} = -p_{y_2} Q - (1 - p) f_{x_2} - \lambda D_{y_2}^2 + \frac{\lambda(D_{y_2}^1 + D_{y_2}^2)}{2} = 0. \tag{3.27b}$$

Denote $\{\tilde{y}_1^S, \tilde{y}_2^S\}$ as the optimal combative input allocations in the bargaining equilibrium that satisfy the FOCs in (3.27). We show in Appendix B.5 that the SOCs are satisfied which ensure the strict concavity of $\tilde{V}_i^S$ in $\tilde{y}_i^S$.

Next, evaluating the first-order derivatives of $\tilde{V}_i^S$ with respect to $y_i$ in equations (3.27) at the war equilibrium combative input allocations $\{\tilde{y}_1^W, \tilde{y}_2^W\}$, yields

$$\left.\frac{\partial \tilde{V}_i^S}{\partial \tilde{y}_i}\right|_{(\tilde{y}_1^W, \tilde{y}_2^W)} = \left.\frac{\lambda(D_{y_i}^i + D_{y_i}^j)}{2}\right|_{(\tilde{y}_1^W, \tilde{y}_2^W)} > 0 \text{ for } i, j = 1, 2 \text{ and } i \neq j. \tag{3.28}$$

The positive sign in equation (3.28) is due to the strict concavity of $\tilde{V}_i^W$ and $\tilde{V}_i^S$, as well as the plausible assumptions that marginal destructions ($D_i^i$ and $D_i^j$) are positive. Given that each party's expected payoff function $\tilde{V}_i^S$ is strictly concave in $\tilde{y}_i$, we infer that

$$\tilde{y}_i^S > \tilde{y}_i^W. \tag{3.29a}$$

This further implies that

$$\tilde{Q}^W > \tilde{Q}^S. \tag{3.29b}$$

From equations (3.22) and (3.26), we find differences in expected payoffs between fighting and bargaining to be

$$\tilde{V}_1^W - \tilde{V}_1^S = p\tilde{Q}^W - \gamma \tilde{Q}^S - \lambda D^1(\tilde{y}_1^W, \tilde{y}_2^W); \tag{3.30a}$$

$$\tilde{V}_2^W - \tilde{V}_2^S = (1 - p)\tilde{Q}^W - (1 - \gamma)\tilde{Q}^S - \lambda D^2(\tilde{y}_1^W, \tilde{y}_2^W). \tag{3.30b}$$

We show in the Appendix B.6 that equations (3.30) imply that

$$\tilde{V}_i^W - \tilde{V}_i^S > 0 \text{ if, and only if, } Q^W - Q^S > \lambda D^1(\tilde{y}_1^W, \tilde{y}_2^W) + \lambda D^2(\tilde{y}_1^W, \tilde{y}_2^W). \quad (3.31)$$

Note that the term on the right-hand side of equation (3.31) is total destruction caused by fighting. We therefore have

**PROPOSITION 3.5**. *For the circumstances in which the destructiveness of fighting is party-specific, the findings of the baseline model continue to hold. Both parties allocate more resource to combative inputs in settlement bargaining than in the event of fighting. Fighting (bargaining) is a Pareto-improving choice if, and only if, the destruction costs are less (greater) than gains from fighting.*

### *3.3 Preventive and Offensive Destructions*

Military weapons can fundamentally be classified into two broad categories: offensive and defensive. Offensive weapons such as missiles are used to inflict destructions to an enemy in warfare. Defensive weapons such as interceptor missiles are used for reducing damages by intercepting missiles from an enemy. Based on these observations, we consider the third setting in which resources allocated to combative inputs produce weapons that serve the dual purposes of an offensive attack and a defensive protection.

In the event of fighting, we assume that destructions have both the defensive and offensive components as summarized in

**ASSUMPTION 3.3.3.** *Destructions to party $i$ are decreasing in its combative input allocation but are increasing in the combative input allocation of its rival party own $j$ ($i, j = 1, 2$, $i \neq j$) such that the following conditions are satisfied:*

$$D_{y_i}^i = \frac{\partial D^i(y_1, y_2)}{\partial y_i} < 0, \; D_{y_j}^i = \frac{\partial D^i(y_1, y_2)}{\partial y_j} > 0, \; D_{y_i y_i}^i = \frac{\partial^2 D^i(y_1, y_2)}{\partial y_i^2} > 0, \quad (3.32)$$

$$D_{y_i y_j}^i = D_{y_j y_i}^i = \frac{\partial^2 D^i(y_1, y_2)}{\partial y_i \partial y_j} \leq 0, \; \textit{and} \; D_{y_i y_i}^i D_{y_j y_j}^j - D_{y_i y_j}^i D_{y_j y_i}^j > 0.$$

Assumption 3.3.3 indicates that in the event of fighting, each party's combative input is able to protect its own gains by lowering destruction and to inflict damages to its rival party. Furthermore, the marginal effect of a party's defensive and offensive combative input is subject to diminishing with its rival's combative input.

Given equations (3.32) and Assumptions 3.3.3 and 3.3.2, the implications as shown by equations (3.24) to (3.31) continue to be valid except that the sign for the derivative in equation (3.28) is no longer positive. Denote the optimal combative input allocation in the case of preventive and offensive destructions as $\{\hat{y}_1^k, \hat{y}_2^k\}$ for $k = W, S$. We have, for $i = 1, 2$ and $i \neq j$, that

$$\left.\frac{\partial \hat{V}_i^S}{\partial \hat{y}_i}\right|_{(\hat{y}_1^W, \hat{y}_2^W)} = \left.\frac{\lambda(D_{y_i}^i + D_{y_i}^j)}{2}\right|_{(\hat{y}_1^W, \hat{y}_2^W)} > 0 \text{ if and only if } D_{y_i}^j > \left|D_{y_i}^i\right|.$$

This indicates that $\hat{y}_1^S > \hat{y}_1^W$ if and only if combative inputs are more effective in attacking than in protecting. In other words, if combative inputs have more success in lowering rivalry's payoff as compared to keeping one's payoff not being lowered, each party allocates more combative inputs in guarding its bargaining position. We summarize the results in

**PROPOSITION 3.6**. *Consider the case where endogenous destructions resulting from fighting have the offensive and defensive components in that a party's combative input lowers its own damages but increases damages to its rival. The two parties allocate more resources to combative inputs in the event of fighting than in settlement bargaining if, and only if, their combative inputs are more effective offensively (in increasing destructions to their rivals) than defensively (in reducing destructions to their own). Under these circumstances, fighting is a Pareto-improving choice if, and only if, the destruction costs are less than gains from fighting. But if the destruction costs are greater than gains from fighting, bargaining is a Pareto-improving choice.*

## 4 Concluding Remarks

This paper contributes to the theoretical conflict literature by presenting a general equilibrium model that explicitly characterizes how conflict technology, production technology, and destruction technology interact in determining the equilibrium choice between fighting and bargaining. We make no attempts to explain real wars in history. Rather, our aim is to present an economic approach to examining the determinants of incentives for conflictual parties to engage in bargaining and settlement when they wish to avoid costly and destructive fighting. Under the shadow of conflict, bargaining is shown to be costly. We find that a party's decision to bargain or to fight depends crucially on the endogeneity of weapons' destructiveness, an important aspect that has not been adequately analyzed in the theoretical conflict literature. We show conditions under which fighting constitutes a Nash equilibrium choice and Pareto dominates bargaining, without the conditions of incomplete information, miscalculations, biased negotiations, or irrationality. This result stands in sharp contrast with the conventional wisdom that costly fighting is an inferior outcome than bargaining. The general equilibrium model of conflict with endogenously increasing destruction shows an economic approach to resolving the long-standing puzzle of war's inefficiency.

We find that, irrespective of the equilibrium outcome, resources allocated to combative inputs for guarding negotiated shares of a contested property are strictly greater in settlement bargaining than in the event of fighting. When the endogenously determined destruction costs exceed gains from fighting, each party's expected payoff under settlement is relatively higher. As a consequence, bargaining is a dominant choice over fighting. For achieving a mutually acceptable settlement, each party finds it optimal to better its bargaining position by increasing arming relative to that in the event of fighting. Ironically, potential benefits from avoiding the breakout of a war are higher the more severe the destructiveness of fighting, ceteris paribus. Under the shadow of conflict with endogenously increasing destruction, increasing armaments is not inconsistent with negotiating a settlement. The positive analysis of fighting and bargaining has an interesting implication for armed peace.[22] This result contrasts with the idealist perspective that an effective bargaining and settlement requires arms reductions. Quite to the contrary, mutually acceptable bargaining settlements may not be effectively maintained unless there are sufficient amounts of armaments.

Furthermore, the positive analysis with this paper offers an explanation of how a war ends. We find that if there is an advance in technology which makes combative inputs more destructive, conflictual parties find it optimal to allocate less resource to combative inputs for both fighting and bargaining. Each party's expected payoff becomes larger, but the payoff of bargaining increases faster than the payoff of fighting. These results imply that, all else being

[22] Chassang and Miquel (2010) present an interesting model of conflict to characterize the role that predatory and preemptive incentives play in determining the sustainability of peace. Under complete information, symmetric increases in weapons are shown to foster peace since expected payoffs from conflict diminish. But under incomplete information or strategic risk, symmetric increases in weapons may be destabilizing since contending parties may increase their preemptive incentives. Chassang and Miquel (2010) further show that very large stocks of weapons may facilitate peace under strategic risk and asymmetry in military strength.

unchanged, an exogenous increase in the scale of destructiveness associated with combative inputs reduces the likelihood that the adversaries choose to fight. Finally, the extensions of the baseline model to include other types of destruction function show the robustness of the aforementioned results.

Some caveats about the analysis with this paper, and hence the potentially interesting extensions of the simple model, should be mentioned. First, we do not allow for the possibility of asymmetry in information structure. Although former researchers have shown that fighting or war is more likely to emerge under incomplete information, endogenous destruction may change the incentive structure of the adversaries in choosing between production and appropriation. Second, we do not examine the effect of third party interventions. Third-party interventions may or may not eliminate conflict between two rival parties.[23] It might be instructive to see how the endogeneity of weapons' destructiveness would affect an outside party's incentives to intervene, as well as the duration and outcome of the conflict. Third, a possible extension is to allow for continuous fighting and examine how conflict persistence affects the decisions of the parties on allocating resources to combative inputs in a dynamic setting. The present analysis also abstracts from the possibility that the contending parties may undertake military R&D to enhance their likelihoods of wining or to improve their bargaining positions. These issues may constitute interesting topics for future research.

[23] See, for example, Regan (1998, 2002), Rowlands and Carment (2006). Amegashie and Kutsoati (2007), Chang, Potter, and Sanders (2007b), Chang and Sanders (2009), and Chang, Sanders, and Walia (2010), and Chang and Luo (2011).

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# Appendix A - Appendix of Chapter 1

**Table A.1 List of Countries**

| | | | |
|---|---|---|---|
| Argentina | *El Salvador* | Malawi | Russian Federation |
| *Australia* | Estonia | Malaysia | Senegal |
| Austria | *Finland* | Malta | Singapore |
| Bangladesh | *France* | Mauritius | Slovenia |
| Belarus | *Germany* | Mexico | South Africa |
| Bolivia | Ghana | Moldova | *Spain* |
| Brazil | *Greece* | Morocco | *Sri Lanka* |
| Bulgaria | Guatemala | *Netherlands* | *Sweden* |
| *Cambodia* | Guyana | New Zealand | *Switzerland* |
| Cameroon | Hong Kong | Norway | Tunisia |
| Canada | India | P. R. China | Turkey |
| Chile | Indonesia | Pakistan | *United Kingdom* |
| Colombia | *Ireland* | Panama | United States |
| Costa Rica | Israel | Paraguay | Uruguay |
| Cyprus | *Italy* | Peru | Venezuela |
| Czech Republic | Japan | Philippines | Zambia |
| *Denmark* | Kenya | Poland | Zimbabwe |
| Dominica | Lithuania | Republic Of Korea | |
| Ecuador | Macedonia | Romania | |

**Table A.2 Percentage of World Trade with Sample Countries**

| Year | Imports | Exports | Year | Imports | Exports |
|---|---|---|---|---|---|
| 1993 | 85.24% | 85.55% | 2002 | 85.99% | 85.18% |
| 1994 | 85.60% | 86.10% | 2003 | 85.92% | 84.76% |
| 1995 | 85.48% | 86.17% | 2004 | 85.48% | 84.07% |
| 1996 | 85.52% | 85.85% | 2005 | 85.21% | 83.05% |
| 1997 | 85.92% | 85.89% | 2006 | 85.05% | 82.19% |
| 1998 | 86.23% | 86.98% | 2007 | 84.52% | 82.26% |
| 1999 | 86.89% | 86.71% | 2008 | 83.71% | 81.02% |
| 2000 | 86.97% | 85.20% | 2009 | 83.16% | 82.35% |
| 2001 | 86.50% | 85.04% | | | |

## Table A.3 Trade Deficit of US from Trade with China

| Year | Trade from China to US | Trade from US to China | Deficit | Difference | Growth Rate (%) |
|---|---|---|---|---|---|
| 1993 | 16976.5 | 8767.1 | 8209.4 | | |
| 1994 | 21421.4 | 9286.9 | 12134.5 | 3925.1 | 47.81 |
| 1995 | 24743.9 | 11748.5 | 12995.4 | 860.9 | 7.09 |
| 1996 | 26730.6 | 11977.9 | 14752.7 | 1757.3 | 13.52 |
| 1997 | 32743.9 | 12805.4 | 19938.5 | 5185.8 | 35.15 |
| 1998 | 38000.6 | 14258 | 23742.6 | 3804.1 | 19.08 |
| 1999 | 42003.1 | 12943.6 | 29059.5 | 5316.9 | 22.39 |
| 2000 | 52161.7 | 15963.7 | 36198 | 7138.5 | 24.57 |
| 2001 | 54395.1 | 19234.9 | 35160.2 | -1037.8 | -2.87 |
| 2002 | 70063.8 | 22052.7 | 48011.1 | 12850.9 | 36.55 |
| 2003 | 92633.2 | 28418.5 | 64214.7 | 16203.6 | 33.75 |
| 2004 | 125181 | 34721 | 90460 | 26245.3 | 40.87 |
| 2005 | 163348 | 41836.7 | 121511.3 | 31051.3 | 34.33 |
| 2006 | 203898 | 55224 | 148674 | 27162.7 | 22.35 |
| 2007 | 233181 | 65238.4 | 167942.6 | 19268.6 | 12.96 |
| 2008 | 252786 | 71457 | 181329 | 13386.4 | 7.97 |
| 2009 | 221384 | 69576 | 151808 | -29521 | -16.28 |
| Mean | | | | | 21.20 |

# Appendix B - Appendix of Chapter 3

## B.1 The equivalence of Nash bargaining and the split-the-surplus rule

To solve for $\gamma$, we take the first-order derivative of the Nash product $(V_1^S - V_1^W)(V_2^S - V_2^W)$, as defined in equations (3.4) and (3.6), with respect to $\gamma$ and set it to zero. This yields

$$Q\big[(1-\gamma)Q-(1-p)(Q-\lambda D)\big]-Q\big[\gamma Q-p(Q-\lambda D)\big]=0.$$

Canceling out $Q$ and solving for $\gamma$, we have

$$\gamma = p-\frac{(2p-1)\lambda D}{2Q}.$$

Next we consider the split-the-surplus rule (see, e.g., Garfinkel and Skaperdas (2000)). This rule guarantees that the equilibrium gains in payoffs (which may be referred to as "peace dividends") are equalized across the two parties when negotiating a settlement. That is,

$$V_1^S - V_1^W = V_2^S - V_2^W.$$

Substituting the expected payoffs from equations (3.4) and (3.6) into the above equality, we have

$$\gamma Q - p(Q-\lambda D) = (1-\gamma)Q-(1-p)(Q-\lambda D).$$

Solving for $\gamma$ yields

$$\gamma = p-\frac{(2p-1)\lambda D}{2Q}.$$

## B.2 SOCs and the Jacobian determinants of the baseline model

In the event of fighting, the SOCs of the expected payoff maximization problems for the two parties are strictly negative according to Assumptions 3.1 to 3.3:

$$\frac{\partial^2 V_1^W}{\partial y_1^2} = p_{y_1 y_1}(Q-\lambda D)-2p_{y_1}(f_{x_1}+\lambda D_{y_1})+p(f_{x_1 x_1}-\lambda D_{y_1 y_1})<0;$$

$$\frac{\partial^2 V_2^W}{\partial y_2^2} = -p_{y_2y_2}(Q-\lambda D) + 2p_{y_2y_2}(f_{x_2} + \lambda D_{y_2}) + (1-p)(f_{x_2x_2} - \lambda D_{y_2y_2}) < 0.$$

Under symmetry, the Jacobian determinant of the FOCs for the two parties in the fighting equilibrium is:

$$\left|J^W\right| = \left(\frac{\partial^2 V_1^W}{\partial y_1^2}\right)\left(\frac{\partial^2 V_2^W}{\partial y_2^2}\right) - \left(\frac{\partial^2 V_1^W}{\partial y_1 \partial y_2}\right)\left(\frac{\partial^2 V_2^W}{\partial y_2 \partial y_1}\right).$$

Making use of equations (3.5), we have

$$\left|J^W\right| = [p_{y_1y_1}(Q-\lambda D) - 2p_{y_1}(f_{x_1} + \lambda D_{y_1}) + \tfrac{1}{2}(f_{x_1x_1} - \lambda D_{y_1y_1})]^2 - [\tfrac{1}{2}(f_{x_1x_2} - \lambda D_{y_1y_2})]^2. \quad \text{(b.1)}$$

Rewriting (b.1) yields

$$\left|J^W\right| = \frac{p_{y_1y_1}(Q-\lambda D) - 2p_{y_1}(f_{x_1} + \lambda D_{y_1}) + \tfrac{1}{2}(f_{x_1x_1} - f_{x_1x_2} + \lambda D_{y_1y_2} - \lambda D_{y_1y_1})}{\left[p_{y_1y_1}(Q-\lambda D) - 2p_{y_1}(f_{x_1} + \lambda D_{y_1}) + \tfrac{1}{2}(f_{x_1x_1} + f_{x_1x_2} - \lambda D_{y_1y_1} - \lambda D_{y_1y_2})\right]^{-1}}. \quad \text{(b.2)}$$

According to Assumptions 3.1 to 3.3, both the numerator and the denominator of equation (b.2) are negative. This implies that $\left|J^W\right| > 0$.

In settlement bargaining, under symmetry, i.e., $y_1^S = y_2^S$ and $p = 1 - p = 1/2$, we have from equations (3.9) the SOCs of the two parties:

$$\frac{\partial^2 y_1^S}{\partial y_1^2} = p_{y_1y_1}(Q-\lambda D) - 2p_{y_1}(f_{x_1} + \lambda D_{y_1}) + \tfrac{1}{2} f_{x_1x_1} < 0;$$

$$\frac{\partial^2 y_2^S}{\partial y_2^2} = -p_{y_2y_2}(Q-\lambda D) - 2p_{y_2}(f_{x_2} + \lambda D_{y_2}) + \tfrac{1}{2} f_{x_2x_2} < 0.$$

They are strictly negative according to Assumptions 3.1 to 3.3. The Jacobian determinant of the FOCs for the two parties in the bargaining equilibrium is

$$\left|J^S\right| = \left(\frac{\partial^2 V_1^S}{\partial y_1^2}\right)\left(\frac{\partial^2 V_2^S}{\partial y_2^2}\right) - \left(\frac{\partial^2 V_1^S}{\partial y_1 \partial y_2}\right)\left(\frac{\partial^2 V_2^S}{\partial y_2 \partial y_1}\right).$$

Making use of equations (3.9) and (3.10), we have

$$\left|J^S\right| = \left[p_{y_1y_1}(Q-\lambda D) - 2p_{y_1}(f_{x_1} + \lambda D_{y_1}) + \tfrac{1}{2} f_{x_1x_1}\right]^2 - \left[\tfrac{1}{2} f_{x_1x_2} - p_{y_1}\lambda D_{y_2}\right]^2. \quad \text{(b.3a)}$$

Rewriting (b.3a) yields

$$\left|J^S\right| = \frac{p_{y_1y_1}(Q-\lambda D) - 2p_{y_1} f_{x_1} - p_{y_1}\lambda D_{y_1} + \tfrac{1}{2} f_{x_1x_1} - \tfrac{1}{2} f_{x_1x_2}}{\left[p_{y_1y_1}(Q-\lambda D) - 2p_{y_1} f_{x_1} - 3p_{y_1}\lambda D_{y_1} + \tfrac{1}{2} f_{x_1x_1} + \tfrac{1}{2} f_{x_1x_2}\right]^{-1}}. \qquad \text{(b.3b)}$$

According to Assumptions 3.1 to 3.3, both the numerator and the denominator of equation (b.3b) are negative. This implies that $\left|J^S\right| > 0$.

## B.3 Comparative statics of a change in destructiveness multiplier

Taking the total differentiation of the FOCs in (3.5) yields

$$\begin{bmatrix} \frac{\partial^2 V_1^W}{\partial y_1^2} & \frac{\partial^2 V_1^W}{\partial y_1 \partial y_2} \\ \frac{\partial^2 V_2^W}{\partial y_1 \partial y_2} & \frac{\partial^2 V_2^W}{\partial y_2^2} \end{bmatrix} \begin{bmatrix} dy_1^W \\ dy_2^W \end{bmatrix} = \begin{bmatrix} (p_{y_1} D + \tfrac{1}{2} D_{y_1}) d\lambda \\ (-p_{y_2} D + \tfrac{1}{2} D_{y_2}) d\lambda \end{bmatrix}.$$

Solving for $dy_1^W / d\lambda$, taking into account that $dy_1^W / d\lambda = dy_2^W / d\lambda$, we have

$$\frac{dy_1^W}{d\lambda} = \frac{p_{y_1} D + pD_{y_1}}{\left|H^W\right|} [p_{y_1y_1}(Q-\lambda D) - 2p_{y_1}(f_{x_1} + \lambda D_{y_1}) + \tfrac{1}{2}(f_{x_1x_1} - f_{x_1x_2} + \lambda D_{y_1y_2} - \lambda D_{y_1y_1})].$$

Based on Assumptions 3.1 to 3.3 and the fact that $\left|H^W\right| > 0$, we have $dy_i^W / d\lambda < 0$. This further implies that $dV_i^W / d\lambda > 0$.

Taking the total differentiation of the FOCs in (3.9) yields

$$\begin{bmatrix} \frac{\partial^2 V_1^S}{\partial y_1^2} & \frac{\partial^2 V_1^S}{\partial y_1 \partial y_2} \\ \frac{\partial^2 V_2^S}{\partial y_1 \partial y_2} & \frac{\partial^2 V_2^S}{\partial y_2^2} \end{bmatrix} \begin{bmatrix} dy_1^S \\ dy_2^S \end{bmatrix} = \begin{bmatrix} p_{y_1} D d\lambda \\ -p_{y_2} D d\lambda \end{bmatrix}.$$

Solving for $dy_1^S / d\lambda$, taking into account that $dy_1^S / d\lambda = dy_2^S / d\lambda$, we have

$$\frac{dy_1^S}{d\lambda} = \frac{p_{y_1} D}{\left|H^S\right|} [p_{y_1y_1}(Q-\lambda D) - 2p_{y_1} f_{x_1} - p_{y_1}\lambda D_{y_1} + \tfrac{1}{2}(f_{x_1x_1} - f_{x_1x_2})].$$

Based on Assumptions 3.1 to 3.3 and the fact that $\left|H^S\right| > 0$, we have $dy_i^S / d\lambda < 0$. As a result, $dV_i^S / d\lambda > 0$.

## B.4 SOCs of the proportional destruction model

In the event of fighting, the SOCs of the two parties for the case of proportional destruction are:

$$\frac{\partial^2 \overline{V}_1^W}{\partial \overline{y}_1^2} = p_{y_1 y_1} Q\phi + pf_{x_1 x_1}\phi + pQ\phi_{y_1 y_1} - 2p_{y_1} f_{x_1}\phi + 2p_{y_1} Q\phi_{y_1} - 2pf_{x_1}\phi_{y_1} < 0; \quad \text{(b.4)}$$

$$\frac{\partial^2 \overline{V}_2^W}{\partial \overline{y}_2^2} = -p_{y_2 y_2} Q\phi + (1-p) f_{x_2 x_2}\phi + (1-p)Q\phi_{y_2 y_2} + 2p_{y_2} f_{x_2}\phi - 2p_{y_2} Q\phi_{y_2} - 2pf_{x_2}\phi_{y_2} < 0. \quad \text{(b.5)}$$

Note that in (b.4), the last two terms can be written as $-2pQ\phi_{y_1}^2$ according to the FOCs in equation (3.16). The second-order derivatives in (b.4) and (b.5) are strictly negative according to Assumptions 3.1, 3.2, and 3.3.1.

In settlement bargaining, the SOCs of the two parties for the case of proportional destruction are:

$$\frac{\partial^2 \overline{V}_1^S}{\partial \overline{y}_1^2} = p_{y_1 y_1} Q\phi - p_{y_1} f_{x_1}\phi + p_{y_1} f\phi_{y_1} + \tfrac{1}{2} f_{x_1 x_1} < 0; \; \frac{\partial^2 \overline{V}_2^S}{\partial \overline{y}_2^2} = -p_{y_2 y_2} Q\phi + p_{y_2} f_{x_2}\phi - p_{y_2} Q\phi_{y_2} + \tfrac{1}{2} f_{x_2 x_2} < 0.$$

## B.5 SOCs of the model with destructions to specific parties

In the event of fighting, the SOCs of the two parties for the case of party-specific destructions are:

$$\frac{\partial^2 \tilde{V}_1^W}{\partial \tilde{y}_1^2} = p_{y_1 y_1} Q - 2p_{y_1} f_{x_1} + pf_{x_1 x_1} - \lambda D_{y_1 y_1}^1 < 0; \; \frac{\partial^2 \tilde{V}_1^W}{\partial \tilde{y}_1^2} = -p_{y_2 y_2} Q + 2p_{y_2} f_{x_2} + (1-p) f_{x_2 x_2} - \lambda D_{y_2 y_2}^2 < 0.$$

These second-order derivatives are strictly negative according to Assumptions 3.1, 3.2, and 3.3.2.

In settlement bargaining, the SOCs of the parties for the case of party-specific destructions are satisfied since

$$\frac{\partial^2 \tilde{V}_1^S}{\partial \tilde{y}_1^2} = p_{y_1 y_1} Q - 2 p_{y_1} f_{x_1} + p f_{x_1 x_1} < 0; \quad \frac{\partial^2 \tilde{V}_2^S}{\partial \tilde{y}_2^2} = -p_{y_2 y_2} Q - 2 p_{y_2} f_{x_1} + p f_{x_2 x_2} < 0.$$

## B.6 Necessary and sufficient conditions for the model with destructions to specific parties

It follows from equations (3.30) that

$\tilde{V}_1^W - \tilde{V}_1^S > 0$ if and only if $p\tilde{Q}^W - \gamma \tilde{Q}^S > \lambda D^1(\tilde{y}_1^W, \tilde{y}_2^W)$;

$\tilde{V}_2^W - \tilde{V}_2^S > 0$ if and only if $p\tilde{Q}^W - \gamma \tilde{Q}^S < Q^W - Q^S - \lambda D^2(\tilde{y}_1^W, \tilde{y}_2^W)$.

That is,

$\tilde{V}_i^W - \tilde{V}_i^S > 0$ if and only if $\lambda D^1(\tilde{y}_1^W, \tilde{y}_2^W) < p\tilde{Q}^W - \gamma \tilde{Q}^S < Q^W - Q^S - \lambda D^2(\tilde{y}_1^W, \tilde{y}_2^W)$.

After re-arranging terms, we have conditions in (3.31).