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Insecure Resources, Bilateral Trade, and Endogenous Predation: A Game-Theoretic Analysis of Conflict and Trade

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This article analyzes how interstate conflict over resources affects the incentives to trade and how greater trade openness affects the endogenous decisions of arming by enemy countries. We identify conditions under which there is trade between two adversary countries and show that each adversary's arming affects domestic welfare in three different ways. The first is an export-revenue effect, which increases welfare because arming causes export revenue to go up (i.e., there is an arming-induced terms-of-trade improvement). The second is a resource-predation effect, which increases welfare because arming increases the appropriation of a rival country's resource input to produce a consumption good. The third is an output-distortion effect, which reduces welfare because arming lowers the domestic production of civilian goods. Based on these effects, we show circumstances in which greater trade openness reduces the intensity of arming. We also discuss the implications of resource security asymmetry for conflict and trade.

JEL Classification: D74, F10, F51, F52

1. Introduction

Conflicts and wars over natural resources (oil, minerals, natural gas, territories rich in marine resources, or other unique intermediate inputs) recur throughout human history.[1] Among the challenging questions posed to social scientists and policymakers are the following: How does security concern over resources (i.e., resource predation possibilities) affect a country's optimal decision on military buildup when engaging in trade with its threatening rival? What are conditions under which the classical liberal proposition of "trading with the enemy" constitute an effective mechanism in reducing armed conflict and hence promoting peace? There are resource-constrained problems in

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[1] See Findlay and O'Rourke (2010) who analyze issues on natural resources, conflict, and trade from the historical perspective. As defined by the World Bank, natural resources are those "materials that occur in nature and are essential or useful to humans, such as water, air, land, forests, fish and wildlife, topsoil, and minerals." See http://www.worldbank.org/depweb/english/modules/glossary.html. In a recent contribution by Garfinkel, Skaperdas, and Syropoulos (2015, p. 100), the authors present an interesting review on current events related to trade and resource insecurity. These events include the first Gulf war resulting from Iraq's invasion of Kuwait in the earlier 1990s, the Kashmir dispute between India and Pakistan, and the territorial dispute between China and Vietnam (or that between China and Philippine) "as part of a larger ongoing dispute over islets in the South China Sea that involves numerous other countries (including Taiwan, Brunei, Indonesia, and Malaysia)." For other contributions that analyze resource-based disputes and wars see, for example, Klare (2001) and Acemoglu et al. (2012).

many, if not all, parts of the world. In recent decades, considerable attention has focused on two related issues, which are of particular importance to global economic development and stability. One question concerns how interstate disputes over valuable resources affect economic activities and trade between contending nations. The other question concerns whether greater trade openness has a positive effect on reducing conflict intensity (as measured by aggregating the arming allocations of the adversaries).

Recognizing that resource disputes and international trade intertwine intrinsically with each other, we develop a conflict-theoretic model of trade and resource insecurity to shed light on the issues stated above. Specifically, we consider a two-country model wherein each country is endowed with a unique resource input exclusively used in the production of a country-specific consumption good. But part of a country's unique resource endowment is subject to predation by its rival. We wish to identify conditions under which resource-conflict countries may or may not engage in trade while making their optimal arming decisions. We attempt to characterize explicitly the nature of equilibrium in conflict-related arming allocations by two enemy countries owing to resource insecurity, on the one hand, and examine their incentives for trade under the shadow of resource predation, on the other. Our analysis puts particular emphasis on the relationship between the intensities of arming and the volumes of trade.

In pure conflict without trade, we find that increases in arming by two adversary countries raise the autarky price ratios of exportable goods, which negatively affect incentives to trade. In the presence of trade and resource predation possibilities, we show that the impact of a country's arming on domestic welfare contains three different effects. The first is an export-revenue effect, which increases welfare because arming causes export prices and revenues to go up (i.e., arming induces a terms-of-trade improvement). The second is a resource-predation effect, which increases welfare because arming increases the appropriation of a rival country's unique input for producing another consumption good. These two welfare-increasing effects constitute the marginal revenue (MR) of arming. The third is an output-distortion effect, which decreases welfare because allocating more resources to arming causes the domestic production of civilian goods to decline. This welfare-reducing welfare effect is the marginal cost (MC) of arming. We show that these three effects (and hence the MR and MC of arming) simultaneously interact in determining how resource-based conflict affects the volumes of trade, as well as how trade costs and different degrees of resource security/insecurity affect optimal arming allocations.

We summarize the key findings and implications of the article as follows. (i) With resource predation possibilities, whether two enemy countries will engage in trade depends on factors such as the proportion that a country's resource endowment is secure (which is referred to as resource security level), trade costs, the total amount of resource endowment, and their arming allocations. (ii) Under symmetry in all aspects, there is a positive relationship between trade costs and resource security. The higher (lower) the resource security level, the higher (lower) the likelihood that there is a bilateral trade. Other things being equal, arming under trade is *lower* arming under autarky. Moreover, greater trade openness resulting from lower trade costs reduces arming. This finding confirms the validity of the liberal peace proposition that trade reduces conflict. (iii) Under asymmetry in resource security, a higher degree of trade openness induces the more-secure country to cut back on its arming. Nevertheless, the less-secure country may increase arming when decreases in trade costs cause the MC of arming to be less than the MR. As a consequence, trade may or may not reduce conflict intensity when there is resource security asymmetry.

The present study is motivated by a growing body of the theoretical and empirical literature on whether the economic forces of globalization or greater trade openness will effectively reduce or end interstate conflicts.[2] One widely accepted argument in the literature is that nations prefer peace over armed confrontations to enjoy the benefits of trade. The rationale behind the argument is that open conflict affects bilateral trade negatively. Polachek (1980) is the first to show a negative correlation between trade and conflict empirically. This finding lends strong support to the long-debating liberal peace hypothesis that trade reduces conflict and hence promotes peace. The liberal view contends that economic interdependence through trade has a positive effect on lowering interstate disputes. Following Polachek's (1980) seminal work, numerous researchers have turned their attention to investigating the general validity of the liberal peace proposition. The results appear to have been somewhat mixed, however. For example, Oneal and Russett (1999), who align with Polachek (1980), contend that strengthening the extent of trade openness between enemy countries can reduce conflicts in terms of overall armament expenditures. Nevertheless, other studies either show that the pacifying effect of greater trade openness is neutral (see, e.g., Kim and Rousseau 2015) or find that trade may even foster conflict (see, e.g., Barbieri 1996).[3]

On the theoretical front, Skaperdas and Syropoulos (1996) examine what effects insecure property rights may have when there is a productive resource that no country possesses securely. The authors show that such resource conflict can have two possible outcomes: violent as military power determines the distribution of the disputed resource, or non-violent when the distribution of the resource is through political means. Skaperdas and Syropoulos (2001) further incorporate endogenous conflict into an exchange model with two small open economies having disputes over a valuable resource that is indispensable for producing tradable goods. The authors show that trade does not guarantee to be superior to no trade or autarky in softening the conflict-related arming. For the case wherein the international price of the contested resource exceeds a country's autarkic price, the opportunity cost of arming decreases such that trade hastens the intensity of competition for the disputed resource, increases arming, and reduces welfare relative to autarky. Garfinkel, Skaperdas, and Syropoulos (2015) develop a variant of the Heckscher–Ohlin model to analyze interstate disputes over resources. They find that if trade promotes adversarial countries to export goods that are intensive in disputed resource, it may intensify conflict so much that autarky is preferable to free trade—a finding that is rhyming with Skaperdas and Syropoulos (2001). In investigating the trade causes of war, Martin, Mayer, and Thoenig (2008) find that enlarging the number of member countries within a trade bloc reduces the economic dependency between any pair of adversaries, which, in turn, makes war between them more likely.[4]

The present article complements the contribution of Garfinkel, Syropoulos, and Yotov (2020) that analyzes trade between two resource-conflict countries. The connections and differences between the two studies deserve further addresses. Both studies stress trade between two large open economies in which the equilibrium prices of tradable goods are affected by their arming choices.

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[2] Issues concerning the role that international trade plays in conflict resolution have been a long-standing debate in political science. See, for example, Barbieri and Schneider (1999), for a systematic survey on the issues explored by both the theoretical and empirical researchers.

[3] For studies on issues related to the association between trade and conflict see, for example, Anderton and Carter (2001), Barbieri and Levy (1999), Barbieri and Schneider (1999), Glick and Taylor (2010), Levy and Barbieri (2004), Polachek, Robst, and Chang (1999), and Polachek and Seiglie (2007).

[4] There is also a sizable theoretical literature that examines the effects of trade and its economic implications related to resourced-based predation, but from different respects. For example, some scholars have analyzed the interactive relationship among expropriation of traded goods (piracy), likelihood of free trade, and civil war (see, e.g., Anderson and Marcoullier 2005; Anderson and Bandiera 2006; Garfinkel, Skaperdas, and Syropoulos 2008; Stefanadis 2010; and Garfinkel, Syropoulos, and Yotov 2020). Other researchers analyze various development issues associated with military conflicts (see, e.g., Gartzke and Rohner 2011).

Based on a Ricardian-type framework of international trade, Garfinkel, Syropoulos, and Yotov (2020) consider the case that two countries have disputes over the unsecured portion of capital resources and that secure labor and capital endowments produce the guns. In the present study, we incorporate resource predation into a stylized framework of competing exporters *à la* Bagwell and Staiger (1997, 1999) to identify conditions under which two adversaries may engage in trade while making their arming decisions. In our analysis, each country's endowment of its unique resource input is subject to predation by its rival, and countries make guns from their secure endowments.

Garfinkel, Syropoulos, and Yotov (2020) further examine the case of asymmetry wherein one country has a higher capital-to-labor ratio in endowment and hence a lower level of arming under autarky than its rival. The rival's arming is higher under both autarky and trade, but the rival's arming is lower under trade than under autarky. The authors show that trade could intensify conflict under asymmetry in factor endowments. In our study, following the classical notion of Wolfers (1952) in the political science literature that "different nations may face different levels of security," we examine the scenario with resource security asymmetry. There are thus significant differences regarding the analytical framework and methodological approach between the present article and the work by Garfinkel, Syropoulos, and Yotov (2020). Nevertheless, these two studies reach similar implications: (i) Trade constitutes an effective mechanism for reducing conflict when two resource-conflict countries are symmetric in all dimensions; (ii) Trade may not reduce conflict when there are asymmetries in such vital aspects as differences in factor endowments or differences in the levels of resource security.

It is necessary to mention that our analysis deals with similar issues as the study by Bandyopadhyay, Sandler, and Younas (2019), albeit in a different context. The authors analyze the interaction of trade and terrorism externalities under free trade between a developed country that exports manufactured products to and imports primary commodities from a developing nation. Using a Heckscher–Ohlin-type general equilibrium model, Bandyopadhyay, Sandler, and Younas (2019) show that greater counterterror effort raises the relative price of manufactured products and may encourage excessive counterterror effort by the product's exporters while presenting opposing terms-of-trade incentives to the importers of primary commodities. In our analysis of welfare decomposition, arming induces a terms-of-trade improvement in that it causes export prices and revenues to go up. This incentivizes a further increase in arming. Our result parallels the positive effect that greater counterterror effort has on the relative price of manufactured goods (i.e., a terms-of-trade externality), which may cause counterterror effort to be excessive.

We organize the remainder of the article as follows. In section 2, we present a game-theoretic model of resource conflict between two enemy countries and analyze their arming decisions under autarky. Section 3 examines resource conflict and arming choices when bilateral trade is possible. In section 4, we investigate the nexus of conflict and trade under resource security asymmetry. Section 5 concludes.

2. Resource Conflict in the Absence of International Trade

We wish to investigate how insecure property rights of valuable inputs affect the appropriative and productive decisions by two contending countries, as well as their incentives to engage in trade under the threat of resource predation. Notably, we attempt to examine how resource-based conflict affects trade volumes (imports and exports of consumption goods) and the optimal arming allocations of the adversaries, as compared to the case without trade. To do so, we consider the simple framework of a two-country world in which property rights of valuable inputs are not well defined or enforced.

Insecure Country-Specific Resources and Technology of Conflict

For two enemy countries (A and B) having disputes over valuable resources, we assume that each country possesses a unique resource input in its country's name. Country A has R_A units of a unique input A, among which σ_A portion is inalienable, but the remaining portion $(1 - \sigma_A)$ is unsecured. The amount of input A subject to predation is $(1 - \sigma_A)R_A$, where $0 < \sigma_A \leq 1$. Similarly, country B has R_B units of a specific input B, among which σ_B portion is inalienable, but the remaining portion $(1 - \sigma_B)$ is unsecured. The amount of input B subject to predation is $(1 - \sigma_B)R_B$, where $0 < \sigma_B \leq 1$.[5] The parameter σ_i represents the level of resource security for country i ($i = A, B$).

In the absence of international property rights law and effective enforcement, arming decisions of the adversary countries affect the equilibrium amounts of the insecure inputs, as well as their production decisions on final goods for consumption and exportation. Due to concerns over insecure resources, the two adversaries may choose to arm. Denote $G_i(\geq 0)$ as the level of arming by country i to protect its input i and to appropriate input j from its rival, where $i, j = A, B$ and $i \neq j$. In the event of predation, each country can retrain a fraction Φ_i of its unsecured resource, $[(1 - \sigma_i)R_i]$. We use a canonical "contest success function" (CSF) to reflect that fraction Φ_i which defines the technology of conflict (see, e.g., Tullock 1980; Hirshleifer 1989; Skaperdas 1996). That is, we have

$$\Phi_i = \frac{G_i}{G_A + G_B} \text{ for } G_A + G_B > 0; \Phi_i = \frac{1}{2} \text{ for } G_A + G_B = 0. \tag{1}$$

For analytical simplicity, we assume one unit of a country-specific input produces one unit of weapons. We also consider the condition that each country's arming is no greater than its inalienable resource: $0 \leq G_i \leq \sigma_i R_i$ for $i = A, B$. Given the CSFs as specified in Equation 1, the amount of input i being appropriated by country j is

$$\frac{G_j}{G_A + G_B}[(1 - \sigma_i)R_i] = \Phi_j[(1 - \sigma_i)R_i] \text{ for } i, j = A, B \text{ and } i \neq j. \tag{2}$$

In the analysis, insecurity or threat arises from resource appropriation possibilities.

Production, Consumption, and the Social Welfare Maximization of Arming

The next step of the analysis is to determine the production and consumption of final goods in each of the enemy countries, as well as their optimal arming allocations.[6]

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[5] The setting with a proportion of inalienable resource in conflict analysis is borrowed from Garfinkel, Skaperdas, and Syropoulos (2015).

[6] To examine resource predation possibilities, we abstract our analysis from the case of one country transferring money to the other country to avoid fighting. For this interesting issue on money transfer for peace agreements, see Beviá and Corchón (2010).

Country A (resp. B), which possesses the specific input A (resp. B), uses its input to produce a country-specific final good X (resp. Y) for domestic consumption and exportation (if there is a trade). For each country, we adopt the simple production technology that one unit of a specific input is required to produce one unit of a consumption good.[7] Also recall that, under open conflict, country i allocates the amount of its specific resource to arming for protection and predation. As a result, the quantities of the final goods X and Y that country A produces are

$$Q_A^X = \sigma_A R_A + \Phi_A[(1-\sigma_A)R_A] - G_A \text{ and } Q_A^Y = \Phi_A[(1-\sigma_B)R_B], \tag{3.a}$$

and those of the two final goods that country B produces are

$$Q_B^X = \Phi_B[(1-\sigma_A)R_A] \text{ and } Q_B^Y = \sigma_B R_B + \Phi_B[(1-\sigma_B)R_B] - G_B. \tag{3.b}$$

As for the preferences over final goods in consumption, we assume for analytical simplicity and model tractability that market demands for goods X and Y in country i are

$$C_i^X = \alpha - \beta P_i^X \text{ and } C_i^Y = \alpha - \beta P_i^Y, \tag{4}$$

where P_i^X and P_i^Y are, respectively, the domestic prices of goods X and Y, the parameter α is a measure of market size, and the parameter β is positive. We assume that $\alpha > R_i$. Corresponding to the demands in Equation 4, consumer surplus (CS) for country$i$ is[8]

$$\text{CS}_i = \frac{1}{2\beta}\left[\left(\alpha - \beta P_i^X\right)^2 + \left(\alpha - \beta P_i^Y\right)^2\right] \text{ for } i = A, B. \tag{5}$$

Each country's producer surplus (PS) is the total value of its final good productions: $\text{PS}_i = P_i^X Q_i^X + P_i^Y Q_i^Y$, where Q_i^X and Q_i^Y are quantities of goods X and Y that country i produces. That is,

$$\text{PS}_i = \begin{cases} P_A^X\left[\sigma_A R_A + \dfrac{G_A}{G_A+G_B}(1-\sigma_A)R_A - G_A\right] + P_B^Y\left[\dfrac{G_A}{G_A+G_B}(1-\sigma_B)R_B\right] & \text{for } i = A, \\ P_B^X\left[\dfrac{G_B}{G_A+G_B}(1-\sigma_A)R_A\right] + P_B^Y\left[\sigma_B R_B + \dfrac{G_B}{G_A+G_B}(1-\sigma_B)R_B - G_B\right] & \text{for } i = B. \end{cases} \tag{6}$$

As in the economics literature, we specify the social welfare (SW) of country i as

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[7] We can introduce labor by assuming that production technology for each country-specific consumption is a Leontief type: one unit of output requires (i) one unit of resource input and (ii) one unit of labor. In this case, the labor market clearing conditions are: $L_i^X + L_i^Y = \bar{L}_i$, where $\bar{L}_i$ is labor endowment of country i(=A, B). Note that this assumption makes the framework more complete without affecting the main findings of the analysis.

[8] As in the competing exporters framework of Bagwell and Staiger (1997, 1999), we assume away income effects in demand for each good as well as substitutability between traded goods. It should be mentioned that there is implicitly a freely traded numeraire good that leads to the derivation of linear demands. The assumption of linear demands makes the present analysis tractable in terms of deriving optimal arming allocations under symmetry. We make no attempt to present a general analysis due to its complexity. In characterizing the trade equilibrium under resource predation possibilities in section 3, we follow an anonymous referee's suggestions to introduce a traded numeraire good and verify that the trade balance conditions will not qualitatively alter the central results of this article. That is, our partial equilibrium analysis can be closed by a traded numeraire good. We present this proof in Appendix A.4.

$$\mathrm{SW}_i = \mathrm{CS}_i + \mathrm{PS}_i, \tag{7}$$

where CS_i and PS_i are given in Equations 5 and 6. The objective of country i is to maximize its domestic welfare SW_i in Equation 7 by determining an optimal arming, G_i. We consider a simultaneous-move game in which A and B independently determine G_A and G_B, respectively. In the next section, we examine the case of symmetry in endowed resources ($R_A = R_B = R$), resource security($\sigma_A = \sigma_B = \sigma$), and trade costs (if there is a departure from autarky to trade).

Pure Conflict, Resource Security, and Optimal Arming under Autarky

We first discuss the optimizing behavior of interstate resource predation without trade. In pure conflict, there are no cross-bordered transactions in final goods. For country A, the production of final good X, Q_A^X, net of secure resource allocated to arming, G_A, is equal to its consumption of the good, C_A^X. On the other hand, country A appropriates input B to produce good Y, Q_A^Y, which defines its consumption of the different good, C_A^Y. It follows from Equations 3.a and 4 that, under symmetry, the market equilibrium conditions for the two goods in country A are

$$\sigma R + \frac{G_A}{G_A + G_B}[(1-\sigma)R] - G_A = \alpha - \beta P_A^X \text{ and } \frac{G_A}{G_A + G_B}[(1-\sigma)R] = \alpha - \beta P_A^Y.$$

Solving for the prices of the two goods in country A yields

$$P_A^X = \frac{(G_A + \alpha - R)\left(\frac{G_A}{G_B}\right) + \left[\left(\frac{G_A}{G_B}\right) + \alpha - \sigma R\right]}{\beta\left(\frac{G_A}{G_B} + 1\right)} \text{ and } P_A^Y = \frac{[\alpha - (1-\sigma)R]\left(\frac{G_A}{G_B}\right) + \alpha}{\beta\left(\frac{G_A}{G_B} + 1\right)}. \tag{8.a}$$

Similarly, market equilibrium conditions for country B are

$$\sigma R + \frac{G_B}{G_A + G_B}[(1-\sigma)R] - G_B = \alpha - \beta P_B^Y \text{ and } \frac{G_B}{G_A + G_B}[(1-\sigma)R] = \alpha - \beta P_B^X,$$

which determine the domestic prices of the two goods to be

$$P_B^X = \frac{\alpha\left(\frac{G_A}{G_B}\right) + [\alpha - (1-\sigma)R]}{\beta\left(\frac{G_A}{G_B} + 1\right)} \text{ and } P_B^Y = \frac{(G_B + \alpha - \sigma R)\left(\frac{G_A}{G_B}\right) + (G_B + \alpha - R)}{\beta\left(\frac{G_A}{G_B} + 1\right)}. \tag{8.b}$$

According to Equations 8.a and 8.b, the quantities of the goods consumed in the two countries are

$$C_A^X = \frac{(R - G_A)\left(\frac{G_A}{G_B}\right) + (\sigma R - G_A)}{\frac{G_A}{G_B} + 1}, \quad C_A^Y = \frac{(1-\sigma)R\left(\frac{G_A}{G_B}\right)}{\frac{G_A}{G_B} + 1}, \tag{8.c}$$

$$C_B^X = \frac{(1-\sigma)R\left(\frac{G_A}{G_B}\right)}{\frac{G_A}{G_B}+1}, C_B^Y = \frac{(\sigma R - G_B)\left(\frac{G_A}{G_B}\right)+(R-G_B)}{\frac{G_A}{G_B}+1}. \tag{8.d}$$

Making use of Equations 5, 6, and 8.a–8.d, we further calculate CS and PS for the two countries:

$$\mathrm{CS}_i = \frac{1}{2\beta}\left[\frac{(R-G_i)G_i+(\sigma R-G_i)G_j}{G_A+G_B}\right]^2 + \frac{1}{2\beta}\left[\frac{(1-\sigma)G_iR}{G_A+G_B}\right]^2, \tag{8.e}$$

$$\begin{aligned}\mathrm{PS}_i = &\left(\frac{(G_i+\alpha-R)G_i+(G_i+\alpha-\sigma R)G_j}{\beta(G_A+G_B)}\right)\left[\left(\sigma R+\frac{G_i}{G_A+G_B}(1-\sigma)R-G_i\right)\right]\\ &+\left(\frac{[\alpha-(1-\sigma)R]G_i+\alpha G_j}{\beta(G_A+G_B)}\right)\left[\frac{G_i}{G_A+G_B}(1-\sigma)R\right],\end{aligned} \tag{8.f}$$

where $i, j = A, B, i \neq j$.

Next, we examine how a country's arming affects its SW under autarky. For country A, we show in Appendix A.1 the following welfare decomposition:

$$\frac{\partial(\mathrm{SW}_A)^{\text{Autarky}}}{\partial G_A} = \underbrace{P_A^Y\frac{\partial Q_A^Y}{\partial G_A}}_{\substack{\text{Resource-predation effect}\\ \text{of arming under autarky}\\ (+)}} + \underbrace{P_A^X\frac{\partial Q_A^X}{\partial G_A}}_{\substack{\text{Output-distortion effect}\\ \text{of arming under autarky}\\ (-)}} = 0. \tag{9}$$

It is instructive to note that the positive resource-predation effect measures the MR of arming, and the negative output-distortion effect in absolute value measures the MC of arming. This analysis suggests that, under autarky, each country determines its equilibrium arming according to the MR = MC optimality condition.

The first-order conditions (FOCs) that determine the optimal arming levels for countries A and B are, respectively, given by $\frac{\partial \mathrm{SW}_i}{\partial G_i} = \frac{\partial \mathrm{CS}_i}{\partial G_i} + \frac{\partial \mathrm{PS}_i}{\partial G_i} = 0$, where CS_i and PS_i are derived from Equations 8.e and 8.f. Denote $\left\{G_A^{\text{Autarky}}, G_B^{\text{Autarky}}\right\}$ as the equilibrium arming levels under autarky. Under symmetry in all dimensions, we have $G_A^{\text{Autarky}} = G_B^{\text{Autarky}} = G^{\text{Autarky}}$. Solving for the optimal arming under autarky yields

$$G^{\text{Autarky}} = \frac{3R-4\alpha+\sigma R+\sqrt{R^2(\sigma^2+22\sigma-7)+8\alpha(2\alpha+R-5\sigma R)}}{8}. \tag{10}$$

Given that arming is no greater than the amount of the secure resource, we set G^{Autarky} in Equation 10 to be identical to σR and determine the critical level of resource security: $\hat{\sigma}^{\text{Autarky}} = 1/3$. It follows that each country's optimal arming equals σR when the security level is lower than $\hat{\sigma}^{\text{Autarky}}$. But the optimal arming equals G^{Autarky} when the security level exceeds $\hat{\sigma}^{\text{Autarky}}$. That is,

$$G^{\text{Autarky}} = \begin{cases} \sigma R & \text{if } 0 < \sigma \le \dfrac{1}{3}; \\ \dfrac{3R - 4\alpha + \sigma R + \sqrt{R^2(\sigma^2 + 22\sigma - 7) + 8\alpha(2\alpha + R - 5\sigma R)}}{8} & \text{if } \dfrac{1}{3} < \sigma < 1. \end{cases} \tag{11}$$

Figure 1 presents a graphical illustration of the results in Equation 11.

The reason why $G^{\text{Autarky}} = \sigma R$ for a low level of resource security ($0 < \sigma \le 1/3$) should be explained. A country's secure endowment (σR) serves dual purposes: it is an input for producing the domestic civilian good; it is also an input for making weapons to predate a rival country's resource in order to produce another consumption good. When resource security is critically low ($0 < \sigma \le 1/3$), the fraction of endowment subject to predation is significantly large. With the remaining fraction of the endowment being relatively small, a country finds it optimal to allocate *all* the already small amount of secure endowment to arming. Allocating the limited amount of the endowment to production will only jeopardize a country's capability in fighting for appropriation. This explains why $G^{\text{Autarky}} = \sigma R$ and arming is positively correlated with the resource security level, $\partial G^{\text{Autarky}}/\partial\sigma > 0$.

In contrast, when resource security is sufficiently high ($\sigma > 1/3$), the fraction of a country's endowment subject to predation is small. With a relatively more amount of secure endowment, each country engages in both appropriative and productive activities. One is to allocate some of the secure endowment to arming for resource predation, which increases the production of a different consumption good. The other is to use the remaining fraction of secure endowment for producing its civilian good. For $\sigma > 1/3$, diverting part of the endowment to domestic production leads to a negative correlation between arming and the security level because

$$\frac{\partial G^{\text{Autarky}}}{\partial\sigma} = -\frac{R\left(20\alpha - 11R - \sigma R - \sqrt{R^2(\sigma^2 + 22\sigma - 7) + 8\alpha(2\alpha + R - 5\sigma R)}\right)}{8\sqrt{R^2(\sigma^2 + 22\sigma - 7) + 8\alpha(2\alpha + R - 5\sigma R)}} < 0.$$

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

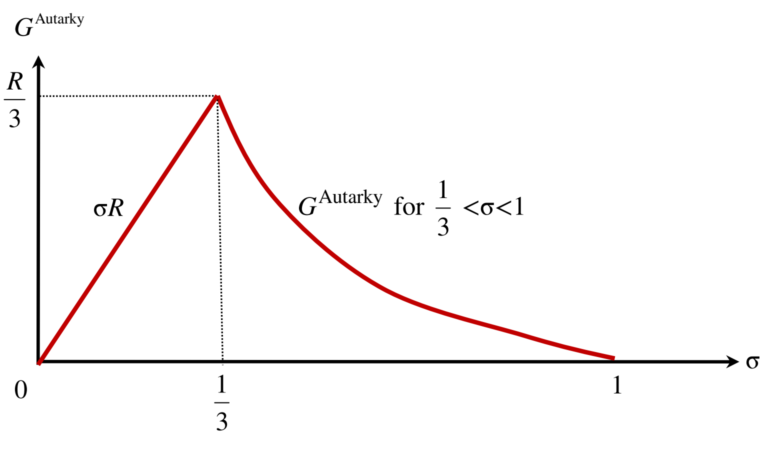

Figure 1. Optimal Arming Under Autarky May Increase or Decrease With Resource Security. [Color figure can be viewed at wileyonlinelibrary.com]

PROPOSITION 1. Considering the scenario where there is no trade between two resource-conflict countries, which are symmetric in all aspects, each country's arming decision depends crucially on its level of resource security. When security is sufficiently low ($\sigma \leq 1/3$), the equilibrium arming increases with the security level. However, when security is sufficiently high ($\sigma > 1/3$), the equilibrium arming decreases with security level due to the diversion of some secure resource to domestic production and consumption.

The implications of Proposition 1 are as follows. An increase in resource security level implies that the fraction of resource endowment subject to predation decreases, but the optimal arming level (or conflict intensity under symmetry) is *nonmonotonic* in σ. Only when resource security is at a level exceeding its threshold will arming be monotonically decreasing.

It is straightforward to verify that the derivative $\partial G^{\text{Autarky}}/\partial R$ is positive, regardless of the level of resource security. This result suggests that, with resource appropriation possibilities, a world composed of more-endowed countries is more "dangerous" than a world composed of less-endowed countries. The economic intuition is that conflict intensity is higher for the more-endowed world than for the less-endowed world. The model of conflict has implications for the issues related to the *resource curse* from a global perspective.[9] It suggests that if "trading with the enemy" constitutes an effective mechanism in reducing conflict intensity, trade may help reduce the global resource curse problems. This prompts us to investigate the circumstances under which trade emerges despite resource predation possibilities.

Before analyzing trade issues under resource conflict, we look at the autarkic prices of tradable or exportable goods in the adversary countries and see how these prices are affected by their arming decisions for a departure from autarky to trade.

Arming Reduces the Incentives to Depart from Autarky to Trade

Because country A (resp. B) possesses input A (resp. B), it is natural to consider that country A exports good X in exchange for good Y and country B exports good Y in exchange for good X once there is bilateral trade. Denote t_X (resp. t_Y) as trade cost for each unit of output that country A (resp. B) incurs when exporting good X (rep. Y) to country B (resp. A). To maintain the patterns of trade, we note the comparative advantage principle that a country exports a good whose autarkic price in its domestic market plus unit trade cost can never exceed the good's autarkic price in an importing country's market. Given the autarkic prices of the two goods in Equations 8.a and 8.b, we impose the following conditions for the emergence of trade in goods X and Y:

$$P_A^X + t_X < P_B^X \text{ and } P_B^Y + t_Y < P_A^Y. \tag{12.a}$$

Substituting the autarkic price equations from Equations 8.a to 8.b into Equation 12.a yields

$$t_X < P_B^X - P_A^X = \frac{\alpha G_A + [\alpha - (1-\sigma)R]G_B}{\beta(G_A + G_B)} - \frac{(G_A + \alpha - R)G_A + (G_A + \alpha - \sigma R)G_B}{\beta(G_A + G_B)}, \tag{12.b}$$

$$t_Y < P_A^Y - P_B^Y = \frac{[\alpha - (1-\sigma)R]G_A + \alpha G_B}{\beta(G_A + G_B)} - \frac{(G_B + \alpha - \sigma R)G_A + (G_B + \alpha - R)G_B}{\beta(G_A + G_B)}. \tag{12.c}$$

[9] See, for example, Sachs and Warner (2001) and Mehlum, Moene, and Torvik (2006).

Making use of the inequalities in Equations 12.b and 12.c and the symmetry assumptions ($G_A = G_B = G$ and $t_X = t_Y = t$), we see that the trade patterns stay put when trade costs satisfy the following condition:

$$t < t^{C}, \text{where } t^{C} \equiv \frac{\sigma R - G}{\beta}. \tag{12.d}$$

Equation 12.d indicates that trade costs must be sufficiently low for two adversaries to engage in trade.[10] In other words, trade emerges if arming is such that $G < \sigma R - \beta t$. That is, each country's arming should be lower than the inalienable portion of its endowment, σR, minus the incidence of trade costs on demand for the imported final good, βt. Alternatively, trade arises when $\sigma R > G + \beta t$, or when secure resource (σR) exceeds arming plus the incidence of trade costs. If arming is such that $G \geq \sigma R - \beta t$, there will be no trade. We thus have the following Lemma 1.

LEMMA 1. In a world of two symmetric resource-conflict countries, each one exports its specific consumption good produced by a unique resource input and imports a different consumption good from its rival that possesses a different resource input, provided that arming satisfies the following condition: $G < R\sigma - \beta t$. There will be no trade when arming falls within the following range: $\sigma R - \beta t \leq G \leq \sigma R$.

Based on the comparative advantage principle, the conditions that facilitate trading depends on differences between the autarky prices of the tradable goods for countries A and B. Take good X as an example and look at its prices in the two countries, which are shown in Equations 8.a and 8.b. It is clear that given other parameters, P_B^X is entirely driven by relative arming, G_A/G_B, but that is not true for P_A^X. This is because P_A^X is determined both by predation and by resource cost of conflict, while P_B^X is determined by predation only. Thus, if both countries keep raising their arming at the same rate, P_B^X remains unchanged, but resource scarcity due to funding of G_A reduces the production of good X in A and drives P_A^X up. This reduces the assumed comparative advantage of country A in X (measured at autarky by $P_B^X - P_A^X$). Accordingly, the incentive for trade diminishes with more arming (under symmetry).[11]

According to Lemma 1, whether two enemy countries start trading or not depends on factors including (i) trade costs, t; (ii) resource endowment, R; (iii) resource security level, σ; and (iv) arming allocation, G. The traditional peacetime analysis of international trade appears to ignore the last two factors: σ and G. This analysis suggests that only taking into account possible measures to reduce trade barriers may be insufficient to conclude trade between adversaries. It is necessary to consider both resource insecurity and military buildup when analyzing the incentives for two adversaries to trade. In the subsequent analysis, we examine the endogenous arming decisions of two adversary countries under trade.

3. Resource Conflict in the Presence of Trade

In this section, we analyze how greater trade openness affects the optimal arming decisions of two adversary countries and the equilibrium quantities of the final goods for consumption and exportation.

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[10] Positive trade costs ($t^C > 0$) imply that the level of arming can never be greater than the inalienable portion of a country's endowment, that is, $G < \sigma R$.

[11] We owe an anonymous for suggesting that we use the notion of relative arming to explain why more arming reduces the incentives for trade.

Trade between Resource-Conflict Countries and their Optimal Arming Decisions

We introduce elements of resource-based conflict into the Bagwell and Staiger (1997, 1999) framework of international trade to examine the dispute between two large open economies.[12] Trade equilibrium for a consumption good $k(=X, Y)$ requires that aggregate demand be equal to the aggregate supply of the good:

$$C_A^k + C_B^k = Q_A^k + Q_B^k.$$

Based on the production equations in Equation 3 and the consumption equations in Equation 4 under resource predation, we have the market equilibrium conditions for both goods X and Y as follows:

$$\left(\alpha - \beta P_A^X\right) + \left(\alpha - \beta P_B^X\right) = R_A - G_A \text{ and } \left(\alpha - \beta P_A^Y\right) + \left(\alpha - \beta P_B^Y\right) = R_B - G_B. \tag{13.a}$$

We assume there are no arbitrages in the markets across the national boundaries. As in Bagwell and Staiger (1997), the nonarbitrage conditions are

$$P_B^X = P_A^X + t_X \text{ and } P_A^Y = P_B^Y + t_Y, \tag{13.b}$$

where t_X (resp, t_Y) as defined earlier, is per-unit trade cost that country A (resp, country B) incurs in exporting good X (resp. good Y) to country B (resp. country A).

Making use of the four equilibrium conditions in Equations 13.a and 13.b, we solve for the equilibrium prices of the two goods in their markets. This yields

$$P_A^X = \frac{2\alpha + G_A - R_A - \beta t_X}{2\beta}, \quad P_A^Y = \frac{2\alpha + G_B - R_B + \beta t_Y}{2\beta}, \tag{14.a}$$

$$P_B^X = \frac{2\alpha + G_A - R_A + \beta t_X}{2\beta}, \quad P_B^Y = \frac{2\alpha + G_B - R_B - \beta t_Y}{2\beta}. \tag{14.b}$$

We have from Equations 14 that the equilibrium market prices are functions of arming allocations but are independent of the resource security level. The economic intuition is as follows. From the perspective of the two-country world, the total amounts of inputs A and B, netting of those amounts allocated to arming, remain unchanged despite international redistributions of the two inputs through predation or non-market means. Accordingly, market supplies of the consumption goods are unaffected such that their equilibrium prices are independent of σ_A and σ_B. For the presence of bilateral trade under resource conflict, we further assume that the goods' prices in Equations 14.a and 14.b are positive. This assumption places the restrictions on the values of the parameters:

$$R_A < 2\alpha + G_A - \beta t_X \text{ and } R_B < 2\alpha + G_B - \beta t_Y. \tag{14.c}$$

[12] This differs from the assumption of "small open economies" in the standard trade analysis, where trading nations accept as given the prices of tradable goods in their competitive world markets. The models of international trade developed by Bagwell and Staiger (1997, 1999) are examples of trade among large open economies. Chang and Sellak (2018) analyze the behavior of conflict over external territories between two large open countries in which their optimal arming decisions affect the equilibrium terms of trade.

We assume that these conditions hold.

Substituting prices from Equations 14.a and 14.b back into the demand functions in Equation 4, we calculate the consumptions of the final goods in countries A and B:

$$C_A^X = \frac{R_A - G_A + \beta t_X}{2},\ C_A^Y = \frac{R_B - G_B - \beta t_Y}{2},\ C_B^X = \frac{R_A - G_A - \beta t_X}{2}, \text{and } C_B^Y = \frac{R_B - G_B + \beta t_Y}{2}. \tag{15}$$

Based on the productions of the final goods in Equation 3, their prices in Equation 14, and the consumption functions in Equation 15, we calculate consumer and producer surplus for each country:[13]

$$\mathrm{CS}_i = \frac{(C_i^X)^2 + (C_i^Y)^2}{2\beta} \text{ and } \mathrm{PS}_i = P_i^X Q_i^X + P_i^Y Q_i^Y \text{ for } i = A, B. \tag{16}$$

Moreover, we derive the volume of trade for good Y (resp. X) that country A (resp. country B) imports from country B (resp. country A), net of the amount of the good that country A (resp. country B) produces using input B (resp. input A) predated. This yields

$$\mathrm{IM}_A = C_A^Y - Q_A^Y = \frac{R_B - G_B - \beta t_Y}{2} - \frac{G_A}{G_A + G_B}(1 - \sigma_B) R_B, \tag{17}$$

$$\mathrm{IM}_B = C_B^X - Q_B^X = \frac{R_A - G_A - \beta t_X}{2} - \frac{G_B}{G_A + G_B}(1 - \sigma_A) R_A. \tag{18}$$

The objective of country A is to determine an optimal arming, which solves its welfare maximization problem: $\underset{\{G_A\}}{\mathrm{Max}}\, \mathrm{SW}_A = \mathrm{CS}_A + \mathrm{PS}_A$, where CS_A and PS_A are given in Equation 16. We provide in Appendix A.2 the detailed results for the two derivatives: $\partial \mathrm{CS}_A/\partial G_A$ and $\partial \mathrm{PS}_A/\partial G_A$. After substituting these derivatives back into country A's FOC, $\partial \mathrm{SW}_A/\partial G_A = 0$, we decompose the welfare effect of arming into three separate terms: (i) an export-revenue effect, (ii) a resource-predation effect, and (iii) an output-distortion effect. Formally, the welfare decomposition is

$$\frac{\partial (\mathrm{SW}_A)^{\mathrm{Trade}}}{\partial G_A} = \underbrace{\underbrace{\frac{(Q_A^X - C_A^X)}{2\beta}}_{\substack{\text{Export-revenue effect} \\ \text{of arming under trade} \\ (+)}} + \underbrace{P_A^Y \frac{(1-\sigma_B) R_B G_B}{(G_A + G_B)^2}}_{\substack{\text{Resource-predation effect} \\ \text{of arming under trade} \\ (+)}}}_{\text{Marginal revenue of arming}} + \underbrace{\underbrace{P_A^X \left[\frac{(1-\sigma_A) R_A G_B}{(G_A + G_B)^2} - 1\right]}_{\substack{\text{Output-distortion effect} \\ \text{of arming under trade} \\ (-)}}}_{\text{Marginal cost of arming}} = 0. \tag{19.a}$$

Due to the arming-induced price increase in P_B^X (see Eqn. 14.b), that is, $\partial P_A^X/\partial G_A = 1/2\beta > 0$, an increase in arming by country A raises its revenue from exporting good X, which is welfare-

[13] We show in Appendix A.4 that our partial equilibrium model is closed by introducing a third good as a numeraire good and that the two countries' overall trade balance requirements are satisfied. That is, the trade balance conditions will not qualitatively alter the central results of this article. The inclusion of the proof is due to an anonymous referee's insightful comments.

increasing. In trade equilibrium under resource conflict, arming thus induces a terms-of-trade improvement. Arming, however, exerts two opposite effects on the total value of domestic outputs. When country A allocates more of its endowed resource to arming, the amount of input A available for producing good X decreases, which reduces domestic production of its consumption good and hence is welfare-decreasing. However, country A's increase in arming increases the appropriation of resource input B to produce more good Y for consumption, which is welfare-increasing. Interestingly, the first and second terms of the welfare decomposition in Equation 19.a measure country A's MR of arming while the third term (in absolute value) measures its MC of arming. Country A allocates its secure resource to armaments up to where the MR = MC condition is satisfied for domestic welfare maximization.

There are some interesting observations about the three separate effects, as shown in Equation 19.a. First, the export-revenue effect of country A's arming on raising its welfare is stronger when the volume of export, $\left(Q_A^X - C_A^X\right)$, increases. Second, for an exogenous decrease in the rival's resource security (σ_B), the resource-predation effect of A's arming on raising its welfare strengthens. Third, for an exogenous increase in A's resource security (σ_A), the output-distortion effect of arming in reducing its welfare aggravates.

Similarly, country B decides on its arming, G_B, which solves the following welfare maximization problem: $\underset{\{G_B\}}{\text{Max}}\ \text{SW}_B = \text{CS}_B + \text{PS}_B$, where CS_B and PS_B are given in Equation 16. For country B, we can also decompose the welfare effect of its arming into three separate terms:

$$\frac{\partial(\text{SW}_B)^{\text{Trade}}}{\partial G_B} = \underbrace{\underbrace{\frac{\left(Q_B^Y - C_B^Y\right)}{2\beta}}_{\substack{\text{Export-revenue effect}\\ \text{of arming under trade}\\ (+)}} + \underbrace{P_B^X \frac{(1-\sigma_A)R_A G_A}{(G_A+G_B)^2}}_{\substack{\text{Resource-predation effect}\\ \text{of arming under trade}\\ (+)}}}_{\text{Marginal revenue of arming}} + \underbrace{P_B^Y \underbrace{\left[\frac{(1-\sigma_B)R_B G_A}{(G_A+G_B)^2} - 1\right]}_{\substack{\text{Output-distortion effect}\\ \text{of arming under trade}\\ (-)}}}_{\text{Marginal cost of arming}} = 0. \tag{19.b}$$

Denote $\left\{G_A^{\text{Trade}}, G_B^{\text{Trade}}\right\}$ as the equilibrium arming levels of countries A and B under trade. Assuming symmetry in all dimensions, we have $G_A^{\text{Trade}} = G_B^{\text{Trade}} = G^{\text{Trade}}$. Using the FOCs for A and B in Equations 19.a and 19.b, we solve for the optimal arming:

$$G^{\text{Trade}} = \frac{(3R - 4\alpha + t\beta) + \sqrt{L}}{6}, \tag{20}$$

where $L \equiv t^2\beta^2 + 16\alpha^2 + 3(4\sigma - 1)R^2 + 6Rt\beta - 24R\alpha\sigma - 8t\alpha\beta$. Given the condition as shown in Lemma 1 that $G < \sigma R - \beta t$ for two symmetric adversaries to trade, we examine the possibility of a corner solution. Setting G^{Trade} in Equation 20 to be identical to the trade-under-conflict condition: $\sigma R - \beta t$, we solve for the critical value of σ (denoted σ_S) above which there is an interior solution for the optimal arming, as shown in Equation 20. This yields

$$\sigma_S = \frac{(4R - 6\alpha + 7t\beta) + \sqrt{t^2\beta^2 + 36\alpha^2 + 4R^2 - 24R\alpha - 36\alpha\beta t + 20t\beta R}}{6R}. \tag{21}$$

It is easy to verify from Equation 21 that the value of σ_S equals 1/3 when trade costs are zero, $t = 0$. Also, the value of σ_S increases with t. This implies that $\sigma_S \geq 1/3$ for $t \geq 0$. Given G^{Trade} in Equation 20 and G^{Autarky} in Equation 12, we have two results of interest:

(i) $G^{\text{Trade}} = G^{\text{Autarky}}$ for $\sigma = \sigma_S$ and (ii) $G^{\text{Trade}} < G^{\text{Autarky}}$ for $\sigma > \sigma_S$.

The latter finding has an important implication: optimal arming is lower under trade than under autarky. For the entire level of security ($0 < \sigma \leq 1$), we have

$$G = \begin{cases} \sigma R & \text{if } 0 < \sigma \leq \frac{1}{3}; \\ G^{\text{Autarky}} & \text{if } \frac{1}{3} < \sigma < \sigma_S; \\ G^{\text{Trade}} & \text{if } \sigma_S \leq \sigma < 1; \\ 0 & \text{if } \sigma = 1. \end{cases} \tag{22}$$

Figure 2 presents a graphical illustration of these results. We, therefore, have Proposition 2.

Proposition 2. In the presence of trade under resource conflict, each country's arming affects its domestic welfare through three different channels. They are the export-revenue effect, the resource-predation effect, and the output-distortion effect. Under symmetry in all aspects, optimal arming is strictly positive and depends on such factors as the level of resource security, the amount of national resource endowment, and the size of trade costs. More importantly, equilibrium arming is strictly lower under trade than under autarky when resource security is at a level sufficiently high ($1 > \sigma > \sigma_S > 1/3$).

We can show that arming under trade is lower than arming under autarky by evaluating the slopes of the welfare function $(SW_i)^{\text{Trade}}$ in Equation 19 at $\left\{G_A^{\text{Autarky}}, G_B^{\text{Autarky}}\right\}$, and see whether the sign is indeed negative. Under symmetry, $G_A^{\text{Autarky}} = G_B^{\text{Autarky}}$, we look at country A. We have from the FOC in Equation 9 that

$$\left(P_A^Y\right)^{\text{Autarky}} \frac{\partial Q_A^Y}{\partial G_A} + \left(P_A^X\right)^{\text{Autarky}} \frac{\partial Q_A^X}{\partial G_A} = 0,$$

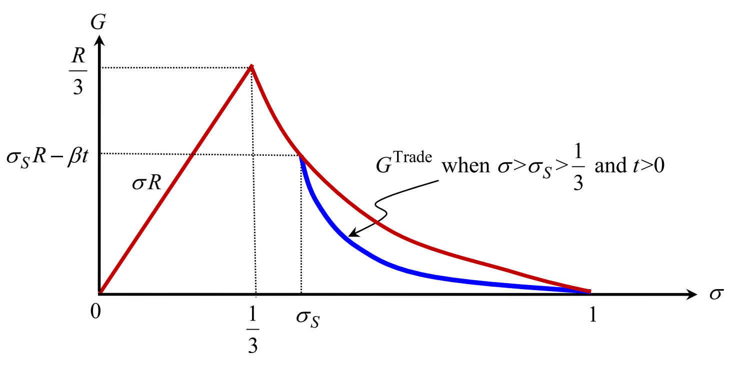

Figure 2. Optimal Arming Under Trade Decreases as the Level of Security Increases. [Color figure can be viewed at wileyonlinelibrary.com]

where $\left(P_A^j\right)^{\text{Autarky}}$ is the equilibrium autarky price of good $j(j = A, B)$ in country A (see Eqn. 8.a). Next, we calculate the derivative $\partial(\text{SW}_A)^{\text{Trade}}/\partial G_A$ as shown in Equation 19.a at the point where $G_A^{\text{Autarky}} = G_B^{\text{Autarky}} = G^{\text{Autarky}}$. We show in Appendix A.3 that this exercise yields

$$\frac{\partial(\text{SW}_A)^{\text{Trade}}}{\partial G_A}\Big|_{G_A = G_B = G^{\text{Autarky}}} = \frac{G^{\text{Autarky}} - (\sigma R - \beta t)}{4\beta} < 0.$$

The strict concavity of the SW function implies that $G^{\text{Trade}} < G^{\text{Autarky}}$. Based on the welfare decomposition in Equation 19.a, the negativity of the above derivative indicates that the negative output-distortion effect dominates the export-revenue effect and the resource-predation effect, both of which are positive. In other words, the MC of arming exceeds its MR. There is an incentive for each country to lower its arming under trade.

Alternatively, the result that arming under autarky exceeds arming under trade can be explained by comparing Equations 9 and 19.a. Consider Equation 9 and use the expressions for Q_A^Y and Q_A^X provided in Equation 3.a, we get

$$\frac{\partial(\text{SW}_A)^{\text{Autarky}}}{\partial G_A} = P_A^Y\frac{\partial Q_A^Y}{\partial G_A} + P_A^X\frac{\partial Q_A^X}{\partial G_A} = P_A^Y\frac{(1-\sigma_B)R_B G_B}{(G_A+G_B)^2} + P_A^X\left[\frac{(1-\sigma_A)R_A G_B}{(G_A+G_B)^2} - 1\right].$$

The expression above mirrors the last two terms of Equation 19.a. Therefore, if we were to evaluate these terms at the same arming and output price levels, it would seem that trade raises the incentive for arming because the first term in Equation 19.a is unambiguously positive. Of course, this is not true as Proposition 2 shows. The reason is that trade will raise P_A^X and reduce P_A^Y relative to autarky (see Figure 3) and this magnifies the output-distortion effect and diminishes the resource-predation effect, thereby reducing the incentive to engage in arming.[14]

We proceed to present some comparative-static results for trade between enemy countries.

Effects of Changes in Trade Costs, Resource Security, and the National Endowment

Under the shadow of resource conflict, the expressions in Equation 17 showing the amount of a consumption good imported by each country are functions of G_A and G_B. With symmetry, substituting $G_A = G_B = G^{\text{Trade}}$ from Equation 20 into Equation 17 and considering the sufficient conditions (see Lemma 1) for trade between the adversaries, we find that

$$\text{IM}^* = \begin{cases} 0 & \text{if } \sigma \le \sigma_{\text{S}}, \\ \dfrac{(6R\sigma - 3R + 4\alpha - 7t\beta)\text{-}\sqrt{L}}{12} > 0 & \text{if } \sigma > \sigma_{\text{S}}. \end{cases} \tag{23}$$

Note that σ_{S} is the critical level of resource security above which optimal arming is G^{Trade}. The results in Equation 23 confirm that the volumes of imports are positive ($\text{IM}^* > 0$) when $\sigma > \sigma_{\text{S}}$.

[14] We thank an anonymous referee for pointing out this alternative approach to explain why arming under autarky exceeds arming under trade.

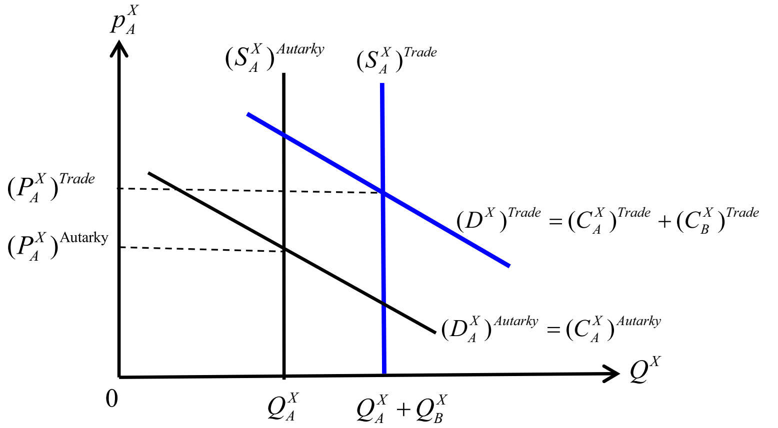

Figure 3. Trade Will Raise P_A^X and Reduce P_A^Y Relative to Autarky. [Color figure can be viewed at wileyonlinelibrary.com]

One question of interest concerns how arming is affected by greater trade openness when trade costs are lower. To answer this question, we look at the following derivative:

$$\frac{\partial G}{\partial t} = \begin{cases} 0 & \text{for } 0 \le \sigma \le \sigma_{\mathrm{S}}; \\ \dfrac{\beta G^{\mathrm{Trade}}}{\sqrt{L}} > 0 & \text{for } \sigma_{\mathrm{S}} < \sigma < 1. \end{cases} \tag{24}$$

Figure 4 presents a graphical illustration of the results. A decrease in t causes the optimal arming curve under trade (G^{Trade}) to shift down to the left, noting that σ_{S} decreases as t decreases and that the lowest value of σ_{S} is 1/3 when t equals zero.

Moreover, in the case of trade under resource conflict (i.e., $\sigma > \sigma_{\mathrm{S}}$), we have the following comparative-static derivative:

$$\frac{\partial G^{\mathrm{Trade}}}{\partial \sigma} = -\frac{R(2\alpha - R)}{\sqrt{L}} < 0. \tag{25}$$

These findings lead to the following Proposition 3.

Proposition 3. For the scenario that two symmetric countries engage in trade despite resource appropriations, if the level of resource security is sufficiently high ($\sigma > \sigma_{\mathrm{S}}$), lower trade costs lead each country to reduce its arming ($\partial G^{\mathrm{Trade}}/\partial t > 0$). Consequently, greater trade openness through lowering trade costs reduces conflict intensity. All else being equal, a lower level of resource security causes each country to increase arming ($\partial G^{\mathrm{Trade}}/\partial \sigma < 0$).

The first result in Proposition 3 that arming is positively related to trade costs suggests the pacifying effect of greater trade openness between adversaries. The second result suggests that we can use the level of resource security to reflect a country's concerns over resource predation. Under symmetry, a decrease in security level naturally causes a country to increase its arming. That explains why the derivative $\partial G^{\mathrm{Trade}}/\partial \sigma$ is negative.

Next, we examine impacts on the volume of trade due to lower trade costs when there is resource conflict (as compared to the case without such conflict). To see this, we first look at the

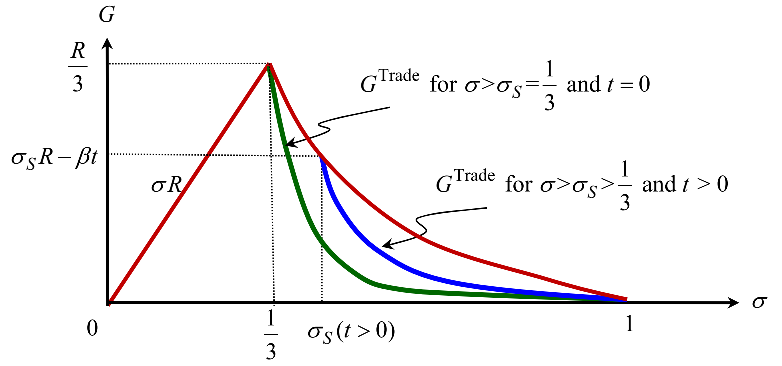

Figure 4. Optimal Arming Decreases With Trade Costs (the Pacifying Effect of Opening Trade). [Color figure can be viewed at wileyonlinelibrary.com]

import price of good Y in country A, P_A^Y, and see how it is affected by lower trade costs under resource conflict.[15] It follows from P_A^Y in Equation 14.a that

$$\frac{dP_A^Y}{dt} = \frac{\partial P_A^Y}{\partial t} + \frac{\partial P_A^Y}{\partial G}\frac{\partial G^{\text{Trade}}}{\partial t}, \tag{26}$$

where the first term, $\partial P_A^Y/\partial t$, is the *direct* effect of trade costs on P_A^Y due to the arbitrage behavior,[16] and the second term, $\left(\partial P_A^Y/\partial G\right)\left(\partial G^{\text{Trade}}/\partial t\right)$, is the *indirect* effect of trade costs through its impact on arming. We have from Equation 14.a that $\partial P_A^Y/\partial t = 1/2 > 0$, which shows the direct effect that lower trade costs will have in lowering the import price of good Y. Note that, for the symmetric case of trade without resource predation, we have $\sigma = 1$ and $G_A = G_B = 0$ which imply that $dP_A^Y/dt = 1/2 > 0$. This explains why the first term on the left-hand side (LHS) of Equation 26 depicts the traditional (peacetime) perspective of how lower trade costs affect import price. With resource predation possibilities, lower trade costs cause each country to reduce arming when resource security is at a level sufficiently high. Based on the result in Equation 24 that $G^{\text{Trade}}/\partial t > 0$ for $\sigma > \sigma_{\text{S}}$, we have from the import price P_A^Y in Equation 14.a that

$$\frac{dP_A^Y}{dt} = \frac{1}{2} + \frac{1}{2\beta}\frac{\partial G^{\text{Trade}}}{\partial t} > \frac{1}{2} \text{ when } \sigma > \sigma_{\text{S}}. \tag{27}$$

The economic implication is as follows. When security is sufficiently high ($\sigma > \sigma_{\text{S}}$), lowering trade costs encourages both adversaries to reduce arming for producing more tradable goods. As a result, the total volume of trade (imports and exports) will increase. We, therefore, have Proposition 4.

Proposition 4. For the symmetric case in which two resource-conflict countries engage in trade, greater trade openness by lowering trade costs will generate two positive effects in lowering

[15] Note that in trade equilibrium under symmetry, we have $P_A^Y = P_B^X$. This means that the importing price of good Y to consumers in country A, P_A^Y, is identical to the importing price of good X to consumers in country B, P_B^X.

[16] Note that at the trade equilibrium, an exogenous decrease in trade cost makes P_A^Y to be higher than the good's domestic price in country B $\left(P_B^Y\right)$ plus the trade cost. That is, $P_A^Y > P_B^Y + t$. This discrepancy in prices resulting from a lower trade cost encourages the sales of good Y to country A, causing its importing price to decline.

the prices of consumption goods exported to their markets in the two adversaries. Consequently, the impact that greater trade openness has on trade volumes is *stronger* when there is resource conflict ($\sigma_S < \sigma < 1$) than when there is peace without such a conflict ($\sigma = 1$).

As long as two adversaries begin trading, the effects that lower trade barriers have on reducing the import prices of consumption goods are in line with the traditional theory of international trade without conflict. More importantly, we can see from Equation 27 that effects on reducing the import prices of the consumption goods (X and Y) under conflict exceed those under peace. Note the positive sign for the derivative: $\partial G^{\text{Trade}}/\partial t > 0$, which demonstrates the pacifying effect of greater trade openness on reducing arming. It comes as no surprise that the *marginal* increase in trade volume is greater under conflict than under peace.

The Relationship Between Resource Security and Trade Costs Leading to Trade or no Trade

It is instructive to derive the conditions for trade between adversaries by looking at the relationship between resource security (σ) and trade costs (t). Recall that in determining the equilibrium arming, we see that trade will not emerge unless resource security exceeds σ_S (see Eqn. 21). Here are some observations. (i) When trade is frictionless ($t = 0$), security should exceed the critical level of 1/3 for two enemy countries to trade. (ii) The value of σ_S increases with t, which means that the trading condition ($\sigma \geq \sigma_S$) becomes harder (easier) to hold when trade costs are higher (lower). (iii) When trade costs are critically high to approach $t = R/\beta$, resource security must also be critically high (i.e., approaching 1) for trade to emerge.

Figure 5 presents a graphical illustration of the curve σ_S. It shows that σ_S is increasing in t, equals to 1/3 when $t = 0$, and is identical to 1 when $t = R/\beta$. Because bilateral trade will not embark unless security is sufficiently high ($\sigma \geq \sigma_S$), we can justify that the *area* above the $\sigma = \sigma_S$ curve but below the $\sigma = 1$ line up to where $t = R/\beta$ is the collection pairs (t, σ) for trade despite resource predation. The area below the $\sigma = \sigma_S$ curve shows the conflict case of resource predation without trade.

We can see from Figure 5 that for a given value of σ, there is a critical value of t above which there is *no* trade. This critical level defines the prohibitive level of trade costs (denoted as $\hat{t}^{\text{Conflict}}$).[17] The value $\hat{t}^{\text{Conflict}}$ is positively related to σ. For a low level of security σ_1, the prohibitive trade cost is $\hat{t}_1^{\text{Conflict}}$. In this case, trade is *less* likely to arise as compared to the case when security is at a higher level σ_2 and the prohibitive trade cost is $\hat{t}_2^{\text{Conflict}}$. For the particular case when security is the highest such that $\sigma = 1$ (there is "full peace"), the prohibitive trade cost is $\hat{t}^{\text{Peace}} (= R/\beta)$ and the likelihood of trading is the highest, compared to any other case with $\sigma \in (1/3, 1)$.

The results are summarized as follows: (i) At a critically low level of security ($\sigma \leq 1/3$), both adversaries do not trade but to predate each other's resources. (ii) When the security level is such that $\sigma > 1/3$, trade will not emerge unless trade costs are sufficiently lower than $\hat{t}^{\text{Conflict}}$. (iii) Given

[17] As it has been shown that σ_S increases with t, finding the condition for a bilateral trade to emerge ($\sigma > \sigma_S$) is equivalent to solving the critical vale of t, denoted as $\hat{t}^{\text{Conflict}}$, above which there is no trade. This value of $\hat{t}^{\text{Conflict}}$ can also be found by setting the volume of import to zero, that is, $IM^* = 0$ (see Eqn. 23).

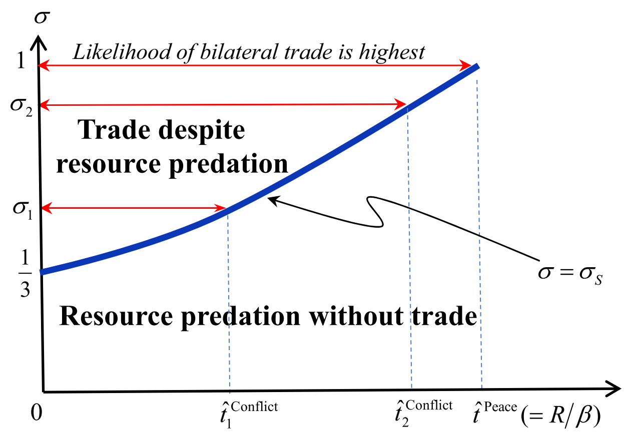

Figure 5. The Relationship Between Trade Costs and the Level of Resource Security. [Color figure can be viewed at wileyonlinelibrary.com]

that $\hat{t}^{\text{Conflict}}$ increases with σ, the likelihood of trading is higher when trade costs are lower $\left(t \le \hat{t}^{\text{Conflict}}\right)$ and σ is higher. We thus have Proposition 5.

Proposition 5. There is a positive relationship between the prohibitive levels of trade costs and the level of resource security. The implications are twofold. (i) Given trade costs, two symmetric adversaries are more (less) likely to trade when their levels of resource security are higher (lower). (ii) Given the levels of resource security, two symmetric adversaries are more (less) likely to trade when trade costs are lower (higher).

4. Conflict and Trade under Resource Security Asymmetry

Countries have different concerns over the security of their natural resource endowments when engaging in trade with rivals. In a classic essay, Wolfers (1952) remarks that different countries may face different levels of security or threats due to their differences in geographical, economic, political, and ecological environment. It is instructive to investigate how security asymmetry affects the relationship between conflict and trade.

In this section, we explore the more general case with different levels of resource security. We consider that σ_A and σ_B differ despite $R_A = R_B = R$. We assume that $\sigma_A > \sigma_B$ which implies that $(1 - \sigma_A)R < (1 - \sigma_B)R$. Under this presumption that country A is more secure than country B, we answer two questions: (i) How does resource security asymmetry affect the optimal arming decisions of the adversary countries? (ii) How does greater trade openness change the resulting asymmetric equilibrium? Answers to these questions have implications for whether the liberal peace proposition continues to hold under asymmetry in resource security.

Effects of Resource Security Asymmetry on Optimal Arming and Conflict Intensity

Without loss of generality, we introduce a new parameter $\varepsilon(>0)$ with $\varepsilon < \min\{1 - \sigma, \sigma\}$ and assume that $\sigma_A = \sigma + \varepsilon$ and $\sigma_B = \sigma - \varepsilon$, where σ is the average level of resource security in the two-country world. The difference in insecure endowments between B and A is

$$(1-\sigma_B)R-(1-\sigma_A)R=(\sigma_A-\sigma_B)R=2\varepsilon R>0.$$

The parameter ε reflects the degree of resource security asymmetry between the adversaries.[18] An increase in ε implies A becomes relatively more secure than B.

As in section 3, we consider that countries A and B engage in trade. For SW maximization, their FOCs are given, respectively, as

$$\frac{\partial \mathrm{SW}_A(G_A,G_B;\varepsilon)}{\partial G_A}=0 \tag{28.a}$$

and

$$\frac{\partial \mathrm{SW}_B(G_A,G_B;\varepsilon)}{\partial G_B}=0, \tag{28.b}$$

where SW_A and SW_B are, respectively, given in Equations A8 and A9 of Appendix A5. The FOC for Country A in Equation 28.a defines its arming reaction function to the arming level chosen by country B. That is, $G_A = G_A(G_B; \varepsilon)$. Similarly, the FOC for Country B in Equation 28.b defines its arming reaction function to the arming level chosen by country A. That is, $G_B = G_B(G_A; \varepsilon)$. Given ε, these reaction functions jointly determine the equilibrium arming allocations, $\{\tilde{G}_A,\tilde{G}_B\}$, that maximize the SW of the two asymmetric adversaries.

Due to the analytical intractability of finding the reduced-form solutions for $\tilde{G}_A$ and $\tilde{G}_B$ under asymmetry, we adopt a comparison methodology by utilizing the symmetric Nash equilibrium as the benchmark. For $\varepsilon = 0$ such that $\sigma_A = \sigma_B = \sigma$, we have the equilibrium arming under symmetry as discussed in section 3. Denote these optimal arming allocations as $\{G_A^*,G_B^*\}$. We use Figure 6 to illustrate the symmetric Nash equilibrium at a point (denoted S) on the 45° line, where $G_A^*=G_B^*$. This is the point of intersection between A's arming reaction curve, $\mathrm{RF}_A^{\mathrm{Sym}}$, and B's arming reaction curve, $\mathrm{RF}_B^{\mathrm{Sym}}$.

Under resource security asymmetry ($\sigma_A > \sigma_B$ and $\varepsilon > 0$), we investigate what effects an exogenous increase in ε would have on the two derivatives: $\partial\mathrm{SW}_A/\partial G_A$ and $\partial\mathrm{SW}_B/\partial G_B$. These derivatives measure the marginal effects of arming. Substituting the conditions that $\sigma_A = \sigma + \varepsilon$ and $\sigma_B = \sigma - \varepsilon$ into country A's SW function SW_A (see Appendix A.4), other things ($R_A = R_B = R$ and $t_A = t_B = t$) being unchanged, we have

$$\frac{\partial}{\partial\varepsilon}\left(\frac{\partial \mathrm{SW}_A}{\partial G_A}\right)=\frac{(G_B+t\beta)G_BR}{\beta(G_A+G_B)^2}>0. \tag{29.a}$$

With a relatively higher level of resource security than its rival, country A's marginal welfare of arming, $\partial\mathrm{SW}_A/\partial G_A$, increases with ε. When the degree of security asymmetry increases, an increase in arming by country A is welfare-improving, given the arming level by its rival. As can be

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[18] For the case of asymmetry in resource endowments, other things such as the level of resource security being equal, we can assume that $R_A > R_B$ and $\sigma_A = \sigma_B$. We can use the same methodology by introducing a new parameter ε' (>0) such that $R_A = R + \varepsilon'$ and $R_B = R - \varepsilon'$, where R is the average amount of resource endowments. It follows that $(1-\sigma)R_A - (1-\sigma)R_B = (1-\sigma)(R_A - R_B) = (1-\sigma)[(R+\varepsilon') - (R-\varepsilon')] = 2(1-\sigma)\varepsilon' > 0$. In the case, an increase in ε' implies that the degree of resource endowment asymmetry increases.

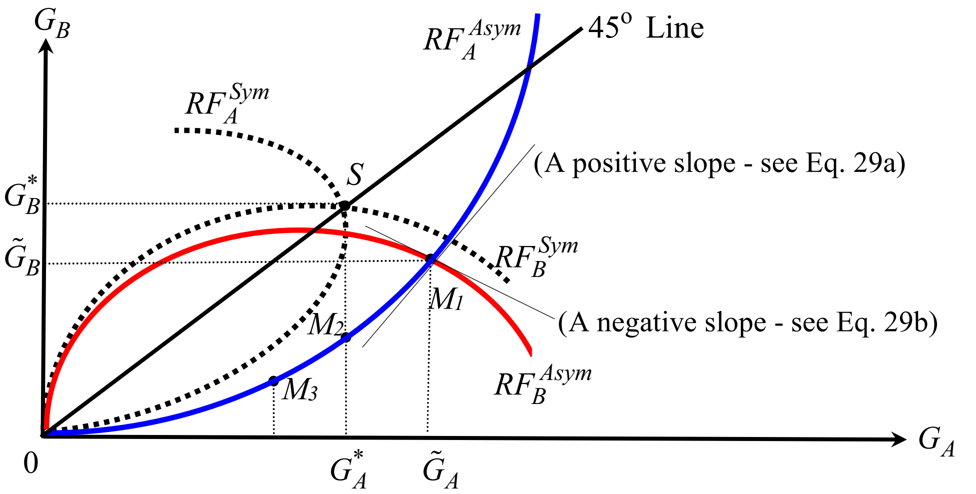

Figure 6. Optimal Arming and Conflict Intensity Under Resource Security Asymmetry. [Color figure can be viewed at wileyonlinelibrary.com]

seen from Figure 6, an exogenous increase in ε (relative to the symmetric equilibrium) causes a rightward shift in country A's arming reaction curve to the curve as shown by $\mathrm{RF}_A^{\mathrm{Asym}}$.

On the other hand, substituting the conditions that $\sigma_A = \sigma + \varepsilon$ and $\sigma_B = \sigma - \varepsilon$ into country B's SW function SW_B (see Appendix A.5), other things ($R_A = R_B = R$ and $t_A = t_B = t$) being unchanged, we have

$$\frac{\partial}{\partial \varepsilon}\left(\frac{\partial \mathrm{SW}_B}{\partial G_B}\right) = -\frac{(G_A + t\beta)G_A R}{\beta(G_A+G_B)^2} < 0. \tag{29.b}$$

Equation 29.b indicates that, with a relatively lower level of resource security than its rival, country B's marginal welfare of arming, $\partial \mathrm{SW}_B/\partial G_B$, decreases with ε. This implies that country B's decision to increase arming turns out to be welfare-reducing, given the arming level by its rival. As can be seen from Figure 6, a relatively lower level of security (as compared to the symmetric equilibrium) causes a downward shift in B's arming reaction curve to the curve as shown by $\mathrm{RF}_B^{\mathrm{Asym}}$.

Depending on the relative shifts between the two reaction curves: $\mathrm{RF}_A^{\mathrm{Asym}}$ and $\mathrm{RF}_B^{\mathrm{Asym}}$, there are three possibilities. Assuming that country A's arming reaction curve is given by $\mathrm{RF}_A^{\mathrm{Asym}}$ under asymmetry, the three possible cases are as follows:

Case (i): $\tilde{G}_A > G_A^*$ and $\tilde{G}_B < G_B^*$ when $\mathrm{RF}_B^{\mathrm{Asym}}$ passes through a point M_1 on $\mathrm{RF}_A^{\mathrm{Asym}}$.
Case (ii): $\tilde{G}_A = G_A^*$ and $\tilde{G}_B < G_B^*$ when $\mathrm{RF}_B^{\mathrm{Asym}}$ passes through a point M_2 on $\mathrm{RF}_A^{\mathrm{Asym}}$.
Case (iii): $\tilde{G}_A < G_A^*$ and $\tilde{G}_B < G_B^*$ when $\mathrm{RF}_B^{\mathrm{Asym}}$ passes through a point M_3 on $\mathrm{RF}_A^{\mathrm{Asym}}$.

Figure 6 illustrates an asymmetric equilibrium at M_1 for case (i).[19] It follows that the intensity of arming under asymmetry, $\tilde{G}_A + \tilde{G}_B$, can be higher, equal to, or lower than that under symmetry

[19] The asymmetric equilibrium at M_2 or M_3 for case (ii) or (iii) can be shown straightforwardly.

$G_A^* + G_B^*$. Note that, irrespective of the three possible outcomes, the equilibrium outcome under security asymmetry always occurs at a point below the 45° line such that $\tilde{G}_A > \tilde{G}_B$.

It is necessary to explain why the relatively more security country (A) arms more heavily than the relatively less security country (B). Recall the three separate effects that determine how a country's arming affects its domestic welfare (see Eqn. 19). Under security asymmetry ($\varepsilon > 0$), we find that $\partial \mathrm{SW}_A/\partial G_A$ *increases* with ε for country A (see Eqn. 29.a). The export-revenue effect plus the resource-predation effect, both of which are positive, dominate the output-distortion effect, which is negative.[20] Namely, an exogenous increase in the degree of security asymmetry causes the MR of arming to increase relative to the MC. Consequently, it is welfare-increasing for A (the more security country) to increase arming.

For country B, we find that the value of the derivative $\partial \mathrm{SW}_B/\partial G_B$ *decreases* with ε (see Eqn. 29.b). It indicates that the adverse output-distortion effect of arming dominates the export-revenue effect and the resource-predation effect. Namely, an exogenous increase in the degree of security asymmetry causes the MC of arming to increase relative to the MC. As a consequence, it is welfare-improving for B (the less security country) not to increase but to reduce arming. Combining the above results, we have: $\tilde{G}_A > G_A^* = G_B^* > \tilde{G}_B$. We, therefore, have Proposition 6.

Proposition 6. Under resource security asymmetry between two adversaries, other things being equal, the socially optimal level of arming is *greater* for the relatively more secure country than for the relatively less secure country. When comparing the overall intensity of arming under security asymmetry to that under security symmetry, the equilibrium comparison cannot be determined unambiguously, however.

Proposition 6 implies that, compared to the symmetric equilibrium, resource security asymmetry does not necessarily reduce conflict intensity. From the perspective of resource insecurity, a world with two asymmetric adversaries may not necessarily be "safer" (or "dangerous") than a world with two symmetric adversaries.

Effects of Greater Trade Openness on Arming and Conflict Intensity under Asymmetry

The next issue concerns what effect greater trade openness has on the intensity of arming under resource security asymmetry. Assuming that the asymmetric equilibrium occurs at the point M_1 as illustrated in Figure 6, we investigate possible impacts on M_1 by lowering trade costs. To do so, we examine how the welfare effects of arming for countries A and B, $\partial \mathrm{SW}_A/\partial G_A$ and $\partial \mathrm{SW}_B/\partial G_B$, are affected by reducing trade costs, t. We present detailed derivations in Appendix A.6 for country A and record the result as follows:

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[20] An increase in ε is equivalent to a higher security level (σ_A) for country A and a lower security level (σ_B). Recall the welfare decomposition in Equation 19.a that there are three marginal effects of arming. First, note that the export volume of country A is identical to the import volume of country B and Equation 17.b shows that country B's import volume increases with σ_A. This implies that a higher level of σ_A strengthens the export-revenue effect of arming. Second, a lower security level of σ_B for country B increases the resource-predation of country A's arming. Third, when the security level of σ_A for country A increases, the output-distortion of arming decreases.

$$\frac{\partial}{\partial t}\left(\frac{\partial \mathrm{SW}_A}{\partial G_A}\right) = \underbrace{\underbrace{\underbrace{\left(-\frac{1}{4}\right)}_{\substack{\text{Export-revenue effect} \\ \text{of arming increases} \\ \text{as } t \text{ decreases} \\ (-)}} + \underbrace{\left(\frac{1}{2}\right)\frac{(1-\sigma_B)\mathrm{RG}_B}{(G_A+G_B)^2}}_{\substack{\text{Resource-predation effect} \\ \text{of arming decreases} \\ \text{as } t \text{ decreases} \\ (+)}}}_{\text{Marginal revenue of arming}} + \underbrace{\underbrace{\frac{1}{2}\left[1-\frac{(1-\sigma_A)\mathrm{RG}_B}{(G_A+G_B)^2}\right]}_{\substack{\text{Output-distortion effect} \\ \text{of arming decreases} \\ \text{as } t \text{ decreases} \\ (+)}}}_{\text{Marginal cost of arming}}. \tag{30.a}$$

Combining the three terms on the right-hand side (RHS) of Equation 30.a yields

$$\frac{\partial}{\partial t}\left(\frac{\partial \mathrm{SW}_A}{\partial G_A}\right) = \frac{1}{4} + \frac{(\sigma_A-\sigma_B)\mathrm{RG}_B}{2(G_A+G_B)^2} > 0. \tag{30.b}$$

Thus, under resource security asymmetry that $\sigma_A > \sigma_B$, the derivative in Equation 30.b is strictly positive. This positive sign implies that the marginal welfare of arming ($\partial \mathrm{SW}_A/\partial G_A$) decreases as trade costs are lower. To raise welfare when there is greater trade openness (resulting from lower trade costs), country A is better off by reducing its arming.

It is instructive to use the three marginal effects of arming, as shown in Equation 30.a, to explain the positivity of the derivative in Equation 30.b. When trade costs are lower, country A's arming affects its national welfare, $\partial \mathrm{SW}_A/\partial G_A$ in three separate ways. (i) The negative sign for the first term on the RHS of Equation 30.a indicates that lowering trade costs will make the export-revenue effect of arming stronger. That is, country A has a stronger incentive to increase arming because the terms-of-trade improvement causes export revenue to go up. (ii) The positive sign for the second term on the RHS of Equation 30.a indicates that lowering trade costs will make the resource-predation effect of arming weaker. That is, country A's arming incentive (to appropriate input B for producing good Y) declines.[21] (iii) The positive sign for the third term on the RHS of Equation 30.a indicates that lowering trade costs will make the output-distortion effect of arming *stronger*, discouraging arming by country A. Simultaneously taking into account these three effects, we have from Equation 30.b that the marginal welfare of arming $\partial \mathrm{SW}_A/\partial G_A$ decreases as t decreases. This implies that, as trade costs are lower, the output-distortion effect (which measures the MC of arming) is strong enough to dominate the sum of the export-revenue effect and the resource-predation effect (which measures the MR of arming). Namely, greater trade openness (by lowering trade costs) will make the MC of arming to be higher than its MR. In response, country A finds it better off to reduce arming, other things being equal (i.e., given the arming level by its rival). We illustrate this result in Figure 7, where A's decrease in arming is shown by a leftward shift in its reaction curve from $\mathrm{RF}_A^{\mathrm{Asym}}$ to $\mathrm{RF}_A^{\mathrm{Asym}\prime}$.

Next, we examine how the derivative $\partial \mathrm{SW}_B/\partial G_B$ is affected by lowering trade costs. We present detailed derivations in Appendix A.6 and record the result as follows:

[21] As a result, the rival country's production of good Y increases, causing its market price to go down and A's import demand for the good to increase.

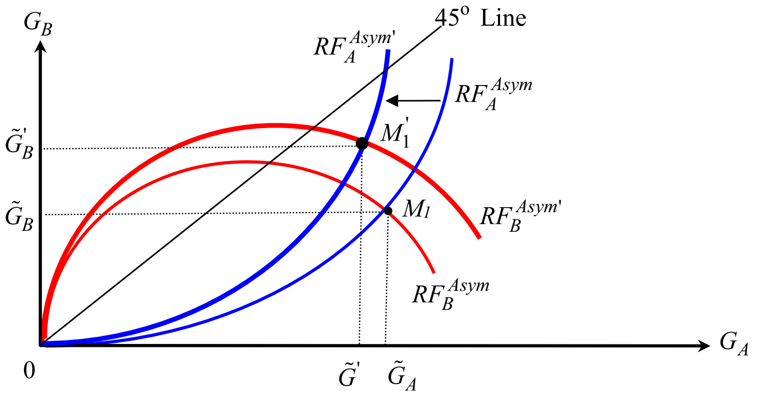

Figure 7. Greater Trade Openness May Increase Conflict Intensity Under Security Asymmetry. [Color figure can be viewed at wileyonlinelibrary.com]

$$\frac{\partial}{\partial t}\left(\frac{\partial \mathrm{SW}_B}{\partial G_B}\right) = \underbrace{\left(-\frac{1}{4}\right)}_{\substack{\text{Export-revenue effect}\\ \text{of arming as } t \text{ decreases}\\ (-)}} + \underbrace{\left(\frac{1}{2}\right)\frac{(1-\sigma_A)\mathrm{RG}_A}{(G_A+G_B)^2}}_{\substack{\text{Resource-predation effect}\\ \text{of arming as } t \text{ decreases}\\ (+)}} + \underbrace{\left(\frac{1}{2}\right)\left[1-\frac{(1-\sigma_B)\mathrm{RG}_A}{(G_A+G_B)^2}\right]}_{\substack{\text{Output-distortion effect}\\ \text{of arming as } t \text{ decreases}\\ (+)}}. \quad (31.a)$$

Combining the three terms on the RHS of Equation 31.a yields

$$\frac{\partial}{\partial t}\left(\frac{\partial \mathrm{SW}_B}{\partial G_B}\right) = \frac{1}{4} + \frac{(\sigma_B-\sigma_A)\mathrm{RG}_A}{2(G_A+G_B)^2} > (=) < 0. \quad (31.b)$$

Under security asymmetry ($\sigma_A > \sigma_B$), the second term on the RHS of Equation 31.b is negative such that the derivative can be positive, zero, or negative. Accordingly, greater trade openness may cause country B's arming reaction function to shift upward or downward (or remain unchanged), depending on the degree of resource security asymmetry ($\sigma_A - \sigma_B = 2\varepsilon > 0$).

We cannot rule out the possibility that the sum of the export-revenue effect and the resource-predation effect dominates the output-distortion effect for country B. If resource security for country B is sufficiently lower than its rival, the derivative $\partial \mathrm{SW}_B/\partial G_B$ may increase when trade costs are lower. In this case, the MR of arming exceeds the MC implying that the best strategy for country B is to increase its arming.

We use Figure 7 to illustrate this result and note that country B's arming reaction curve shifts upward from $\mathrm{RF}_B^{\mathrm{Asym}}$ to $\mathrm{RF}_B^{\mathrm{Asym}'}$. The two arming reaction curves $\mathrm{RF}_A^{\mathrm{Asym}'}$ and $\mathrm{RF}_B^{\mathrm{Asym}'}$, then determine the new equilibrium at a point like $M_1^{'}$. Comparing $M_1^{'}$ to the original equilibrium at M_1, we have

$$\tilde{G}_A^{'} < \tilde{G}_A,\ \tilde{G}_B^{'} > \tilde{G}_B,\ \text{and}\ \tilde{G}_A^{'} + \tilde{G}_B^{'} > \tilde{G}_A + \tilde{G}_B.$$

These results indicate that country A lowers its arming, whereas country B increases it. The overall intensity of arming increases despite that trade costs are lower. Note that although there is arms reduction by the more secure country (A), its optimal arming continues to exceed the arming level chosen by the less secure country (B). We thus have Proposition 7.

PROPOSITION 7. Under resource security asymmetry, greater trade openness resulting from lowering trade costs causes the more secure country (A) to cut back on its arming. However, the effect on the arming level of the less secure country (B) can be positive, zero, or negative. The impact that greater trade openness has on the overall conflict intensity is thus indeterminate.

The intuition behind Proposition 7 is that resource-conflict countries with different levels of resource security respond to lower trade costs differently: the more secure country finds it welfare-improving in arms reduction, but the less secure country may find it optimal to increase its military buildup. The liberal peace hypothesis that trade reduces conflict may or may not be valid in the presence of resource security asymmetry.

5. Concluding Remarks

In this article, we have presented a conflict-theoretic model to examine two related issues. One concerns how resource predation possibilities affect trade incentives of two adversary countries, and the other concerns whether greater trade openness through lowering trade costs reduces the intensity of arming. Explicitly, we incorporate elements of resource-based conflict and a Tullock–Hirshleifer–Skaperdas-type CSF into the framework of competing exporters *à la* Bagwell and Staiger to derive the conditions under which two contending countries may or may not trade while making their socially optimal arming decisions.

In pure conflict without trade, we show that increases in arming by two adversary countries raise the autarky price ratios of tradable goods. The resulting terms-of-trade deterioration negatively affects the incentives of two adversaries to trade. In trade and resource predation, a country's army affects domestic welfare via three different channels. Both the export-revenue effect and the resource-predation effect define the MR of arming, while the output-distortion effect defines the MC of arming. These three effects (and hence the MR = MC conditions for optimal arming) determine how resource predation affects the volumes of trade between two adversaries, and how lower trade barriers affect arming allocations. Whether greater trade openness will reduce conflict intensity depends on factors such as the level of resource security, the size of trade costs, national endowment, and arming. For two symmetric adversaries with resource security being higher (lower), the likelihood of engaging in trade is higher (lower). This finding confirms the liberal peace perspective that trade reduces conflict.

We further discuss arming decisions under resource security asymmetry. We find that the relatively more secure country arms more heavily than the relatively less secure country. Greater trade openness has a positive effect on inducing the more secure country to cut back on its arming. Nevertheless, the less secure country may increase arming.

Consequently, whether greater trade openness reduces the overall intensity of conflict is indeterminate.

Given the growing tensions in the international arena due to resource insecurity, our theoretical findings have relevant implications for trade between resource-conflict countries and optimal arming decisions. However, we admittedly recognize that we develop our trade-conflict model upon some simplifying assumptions. A potentially interesting extension of the model is to see how the conflict-trade equilibrium in a two-country framework is affected by strategic interventions of a third country[22] or the possibility of mediation proposals (Herbst, Konrad, and Morath 2017).[23] Another possible extension is to see how differences in production technologies affect the trade equilibrium of two resource-conflict nations and their optimal arming decisions. One extension is to introduce conflict-related destructions into the analysis.[24] In this case, destructions of resources will affect the availability of inputs for output production and, hence, the equilibrium quantities and prices of the consumption goods. It is our future research agenda to elaborate on our findings in a more general setting.

Appendix

A.1. Effects of a Country's Arming on Its Domestic Welfare Under Autarky

Given the CS measure in Equation 5 and the consumption functions in Equation 4, we have

$$\frac{\partial \mathrm{CS}_A}{\partial G_A} = \frac{1}{\beta}\left(C_A^X \frac{\partial C_A^X}{\partial G_A} + C_A^Y \frac{\partial C_A^Y}{\partial G_A}\right) = -\left(C_A^X \frac{\partial P_A^X}{\partial G_A} + C_A^Y \frac{\partial P_A^Y}{\partial G_A}\right).$$

Given the producer surplus measure in Equation 6.a and the production functions of the final goods in Equation 3, we have

$$\frac{\partial \mathrm{PS}_A}{\partial G_A} = \frac{\partial P_A^X}{\partial G_A} Q_A^X + P_A^X \frac{\partial Q_A^X}{\partial G_A} + \frac{\partial P_A^Y}{\partial G_A} Q_A^Y + P_A^Y \frac{\partial Q_A^Y}{\partial G_A}.$$

It follows that the effect of country A's arming on its domestic welfare is

[22] Garfinkel, Skaperdas, and Syropoulos (2015) examine an interesting case where two conflicting countries choose not to trade with each other but do engage in trade with a third country. For issues on how the equilibrium outcome of an interstate conflict is affected by the strategic involvement of a third country, see Chang, Potter, and Sanders (2007), Chang and Sanders (2009), and Sanders and Walia (2014).

[23] Stressing the role of mediation proposals, Herbst, Konrad, and Morath (2017) analyze how a disparity in fighting strengths between rivals affects the equilibrium outcome of bargaining under the shadow of conflict. The authors show experimentally that the possibility of fighting is not affected by power disparity with an exogenous mediation proposal. If, however, bargaining involves an endogenous mediation proposal, the possibility of fighting increases when power disparity increases.

[24] For studies on conflict that takes into account destruction costs see, for example, Chang and Luo (2013, 2017), Sanders and Walia (2014), and Chang, Sanders, and Walia (2015).

$$
\begin{aligned}
\frac{\partial \mathrm{SW}_A}{\partial G_A} &= \frac{\partial \mathrm{CS}_A}{\partial G_A} + \frac{\partial \mathrm{PS}_A}{\partial G_A} \\
&= -\left(C_A^X \frac{\partial P_A^X}{\partial G_A} + C_A^Y \frac{\partial P_A^Y}{\partial G_A}\right) + \left(\frac{\partial P_A^X}{\partial G_A} Q_A^X + P_A^X \frac{\partial Q_A^X}{\partial G_A} + \frac{\partial P_A^Y}{\partial G_A} Q_A^Y + P_A^Y \frac{\partial Q_A^Y}{\partial G_A}\right) \\
&= \frac{\partial P_A^X}{\partial G_A} \underbrace{\left(Q_A^X - C_A^X\right)}_{=0,\,\text{under autarky}} + \frac{\partial P_A^Y}{\partial G_A} \underbrace{\left(Q_A^Y - C_A^Y\right)}_{=0,\,\text{under autarky}} + P_A^X \frac{\partial Q_A^X}{\partial G_A} + P_A^Y \frac{\partial Q_A^Y}{\partial G_A} \\
&= \underbrace{P_A^Y \frac{\partial Q_A^Y}{\partial G_A}}_{\substack{\text{Resource-predation effect} \\ \text{of arming under autarky} \\ (+)}} + \underbrace{P_A^X \frac{\partial Q_A^X}{\partial G_A}}_{\substack{\text{Output-distortion effect} \\ \text{of arming under autarky} \\ (-)}}
\end{aligned}
$$

A.2. Derivatives of Equation 19.a

The first term on the LHS of the FOC in Equation 19.a shows how country A's arming affects the benefits of its citizens/consumers. Noting that C_A^Y in Equation 15 is independent of G_A, it follows from CS_A in Equation 16 that

$$
\frac{\partial \mathrm{CS}_A}{\partial G_A} = \frac{C_A^X}{\beta} \frac{dC_A^X}{dG_A} = -\frac{C_A^X}{2\beta} < 0.
$$

This derivative indicates that an increase in arming raises the domestic price of good X, causing its total consumption to fall and CS to decline. The second term on the LHS of the FOC in Equation 19.a shows how country A's arming affects producer surplus, which measures the total value of domestic production. It follows from PS_A in Equation 16 that

$$
\frac{\partial \mathrm{PS}_A}{\partial G_A} = \underset{(+)}{Q_A^X \frac{\partial P_A^X}{\partial G_A}} + \underset{(-)}{P_A^X \frac{\partial Q_A^X}{\partial G_A}} + \underset{(0)}{Q_A^Y \frac{\partial P_A^Y}{\partial G_A}} + \underset{(+)}{P_A^Y \frac{\partial Q_A^Y}{\partial G_A}}.
$$

Making use of Q_A^X and Q_A^Y in Equation 3.a as well as P_A^X and P_A^Y in Equation 14.a, we have

$$
\frac{\partial Q_A^Y}{\partial G_A} = (1-\sigma_B) R_B \frac{\partial \Phi_A}{\partial G_A} = \frac{(1-\sigma_B) R_B G_B}{(G_A+G_B)^2} > 0, \quad \frac{\partial Q_X^A}{\partial G_A} = (1-\sigma_A) R_A \frac{\partial \Phi_A}{\partial G_A} - 1 = \frac{(1-\sigma_A) R_A G_B}{(G_A+G_B)^2} - 1 < 0,
$$
$$
\frac{\partial P_A^X}{\partial G_A} = \frac{1}{2\beta} > 0, \text{ and } \frac{\partial P_A^Y}{\partial G_A} = 0.
$$

Plugging the above derivatives into the FOC for country A yields

$$
\frac{\partial \mathrm{SW}_A}{\partial G_A} = \underbrace{\frac{\left(Q_A^X - C_A^X\right)}{2\beta}}_{\substack{\text{Export-revenue effect} \\ \text{of arming under trade} \\ (+)}} + \underbrace{P_A^Y \frac{(1-\sigma_B) R_B G_B}{(G_A+G_B)^2}}_{\substack{\text{Resource-predation effect} \\ \text{of arming under trade} \\ (+)}} + \underbrace{P_A^X \left[\frac{(1-\sigma_A) R_A G_B}{(G_A+G_B)^2} - 1\right]}_{\substack{\text{Output-distortion effect} \\ \text{of arming under trade} \\ (-)}} = 0.
$$

A.3. Optimal Arming is Lower Under Trade Than Under Autarky

We use the reduced-form solutions of optimal arming under trade and under autarky to conduct a comparison. Alternatively, we evaluate the slopes of the welfare functions SW_i (for $i = A$, B) in Equation 19 at the autarkic arming equilibrium, $\left\{G_A^{\text{Autarky}}, G_B^{\text{Autarky}}\right\}$. Under symmetry with $G_i^{\text{Autarky}} = G^{\text{Autarky}}$, we can merely look at country A. First, we have from the FOC in Equation 9 that $\left(P_A^Y\right)^{\text{Autarky}} \frac{\partial Q_A^Y}{\partial G_A} + \left(P_A^X\right)^{\text{Autarky}} \frac{\partial Q_A^X}{\partial G_A} = 0$, where $\left(P_A^j\right)^{\text{Autarky}}$ denotes the equilibrium autarky price of good j ($j = A$, B) in country A (see Eqn. 8.a). Next, taking into account this FOC under autarky and evaluating the derivative $\partial\mathrm{SW}_A/\partial G_A$ in Equation 19 at the point where $G_A^{\text{Autarky}} = G_B^{\text{Autarky}} = G^{\text{Autarky}}$, we have

$$\begin{aligned} &\frac{\partial \mathrm{SW}_A}{\partial G_A}\Big|_{G_A=G_B=G^{\text{Autarky}}} \\ &= \frac{\left(Q_A^X - C_A^X\right)}{2\beta} + \left[\left(P_A^Y\right)^{\text{Trade}} - \left(P_A^Y\right)^{\text{Autarky}}\right]\frac{\partial Q_A^Y}{\partial G_A} + \left[\left(P_A^X\right)^{\text{Trade}} - \left(P_A^X\right)^{\text{Autarky}}\right]\frac{\partial Q_A^X}{\partial G_A}. \end{aligned} \tag{A1}$$

Making use of the equilibrium outcomes under trade, we have

$$\frac{Q_A^X - C_A^X}{2\beta}\Big|_{G_A=G_B=G^{\text{Autarky}}} = \frac{1}{2\beta}\left[\frac{R-\beta t - G^{\text{Autarky}}}{2} - \frac{(1-\sigma)R}{2}\right] = \frac{(\sigma R - \beta t) - G^{\text{Autarky}}}{4\beta} > 0, \tag{A2}$$

where the positive sign follows from the trading condition that $G^{\text{Autarky}} < \sigma R - \beta t$ (see Lemma 1). Also, we have

$$\left[\left(P_A^Y\right)^{\text{Trade}} - \left(P_A^Y\right)^{\text{Autarky}}\right]\Big|_{G_A=G_B=G^{\text{Autarky}}} = \frac{(\sigma R - \beta t) - G^{\text{Autarky}}}{2\beta} > 0, \tag{A3}$$

$$\left[\left(P_A^X\right)^{\text{Trade}} - \left(P_A^X\right)^{\text{Autarky}}\right]\Big|_{G_A=G_B=G^{\text{Autarky}}} = \frac{G^{\text{Autarky}} - (\sigma R - \beta t)}{2\beta} < 0, \tag{A4}$$

$$\frac{\partial Q_A^Y}{\partial G_A}\Big|_{G_A=G_B=G^{\text{Autarky}}} = \frac{(1-\sigma)RG^{\text{Autarky}}}{\left(G^{\text{Autarky}} + G^{\text{Autarky}}\right)^2} = \frac{(1-\sigma)R}{4G^{\text{Autarky}}}, \tag{A5}$$

$$\frac{\partial Q_A^X}{\partial G_A}\Big|_{G_A=G_B=G^{\text{Autarky}}} = \frac{(1-\sigma)RG^{\text{Autarky}}}{\left(G^{\text{Autarky}} + G^{\text{Autarky}}\right)^2} - 1 = \frac{(1-\sigma)R}{4G^{\text{Autarky}}} - 1. \tag{A6}$$

Substituting Equations A3–A6 into the last two terms on the RHS of the derivate in Equation A1, we have

$$\begin{aligned} &\left[\left(P_A^Y\right)^{\text{Trade}} - \left(P_A^Y\right)^{\text{Autarky}}\right]\frac{\partial Q_A^Y}{\partial G_A} + \left[\left(P_A^X\right)^{\text{Trade}} - \left(P_A^X\right)^{\text{Autarky}}\right]\frac{\partial Q_A^X}{\partial G_A} \\ &= \frac{G^{\text{Autarky}} - (\sigma R - \beta t)}{2\beta}\left[\frac{\partial Q_A^Y}{\partial G_A} - \frac{\partial Q_A^X}{\partial G_A}\right] = \frac{G^{\text{Autarky}} - (\sigma R - \beta t)}{2\beta}\left[\frac{(1-\sigma)R}{4G^{\text{Autarky}}} - \left(\frac{(1-\sigma)R}{4G^{\text{Autarky}}} - 1\right)\right] \\ &= \frac{G^{\text{Autarky}} - (\sigma R - \beta t)}{2\beta} < 0. \end{aligned} \tag{A7}$$

Finally, substituting Equations A2 and A7 into the derivative in Equation A1 yields

$$\frac{\partial \mathrm{SW}_A}{\partial G_A}\Big|_{G_A=G_B=G^{\text{Autarky}}} = \frac{G^{\text{Autarky}} - (\sigma R - \beta t)}{4\beta} < 0.$$

This result indicates that, compared to optimal arming under autarky, each country's SW increases when its arming decreases. We thus have: $G^{\text{Trade}} < G^{\text{Autarky}}$.

A.4. The Trade Balance Conditions are Satisfied by Introducing a Traded Numeraire Good

To show that trade in the numeraire good *Z* is determined by the requirement of the overall trade balance, we introduce a numeraire good, denoted as *Z*, which can be traded freely between countries *A* and *B*. We then show that each country's balance of payment (BOP) condition or national budget constraint is satisfied automatically.

For country *A*, its BOP condition is

$$P_A^X C_A^X + P_A^Y C_A^Y + C_A^Z = P_A^X Q_A^X + P_A^Y Q_A^Y + Q_A^Z + t_Y\left(C_A^Y - Q_A^Y\right),$$

where P_A^i, C_A^i, and Q_A^i are, respectively, the market price, consumption, and production of good $i \in \{X, Y, Z\}$ in *A*. The LHS of the BOP condition is *A*'s total spending, while the RHS is its total market value of production, which represents *A*'s national budget. Note that the last term on the RHS of the BOP condition is: $t_Y\left(C_A^Y - Q_A^Y\right)$, which is the total amount of trade costs to country *A*. These trade costs will be collected by country *A*'s treasury when they take the form of tariffs on good *Y* imported from country *B*. Alternatively, if there are trade costs per se (rather than tariffs), they can be interpreted as transportation revenues to country *A*'s competitive transportation industry. Similarly, country *B*'s BOP condition is

$$P_B^X C_B^X + P_B^Y C_B^Y + C_B^Z = P_B^X Q_B^X + P_B^Y Q_B^Y + Q_B^Z + t_X\left(C_B^X - Q_B^B\right).$$

where P_B^i, C_B^i, and Q_B^i are, respectively, the market price, consumption, and production of good $i \in \{X, Y, Z\}$ in *B*.

To prove that our results, it suffices to show that the two BOP conditions for countries *A* and *B* hold simultaneously. In other words, it remains to demonstrate that the sum of the excess demands for the numeraire good Z by the two countries is *zero*. Define a country's excess demand for good Z as $\mathrm{ED}_J^Z = C_J^Z - Q_J^Z$, where $J \in \{A, B\}$. For country *A*, its exceed demand for good Z, which follows from its BOP condition, is

$$\begin{aligned}
&\mathrm{ED}_A^Z \\
&= C_A^Z - Q_A^Z \\
&= P_A^X Q_A^X + P_A^Y Q_A^Y - P_A^X C_A^X - P_A^Y C_A^Y + t_Y\left(C_A^Y - Q_A^Y\right) \\
&= \left(\frac{2\alpha + G_A - R_A - \beta t_X}{2\beta}\right)\left(\sigma_A R_A + \frac{G_A}{G_A + G_B}[(1-\sigma_A)R_A] - G_A\right) \\
&\quad + \left(\frac{2\alpha + G_B - R_B + \beta t_Y}{2\beta}\right)\left(\frac{G_A}{G_A + G_B}[(1-\sigma_B)R_B]\right) - \left(\frac{2\alpha + G_A - R_A - \beta t_X}{2\beta}\right)\left(\frac{R_A - G_A + \beta t_X}{2}\right) \\
&\quad - \left(\frac{2\alpha + G_B - R_B + \beta t_Y}{2\beta}\right)\left(\frac{R_B - G_B - \beta t_Y}{2}\right) + t_Y\left(\frac{R_B - G_B - \beta t_Y}{2} - \frac{G_A}{G_A + G_B}[(1-\sigma_B)R_B]\right),
\end{aligned}$$

where the market prices P_A^X and P_A^Y are derived in Equation 14.a, the quantities of consumption C_A^X are C_A^Y in Equation 15, and the quantities of production Q_A^X and Q_A^Y are in Equation 3.a.

Similarly, country *B*'s exceed demand for good Z, according to its BOP condition, is

$$
\begin{aligned}
&\mathrm{ED}_B^Z\\
&= C_B^Z - Q_B^Z\\
&= P_B^X Q_B^X + P_B^Y Q_B^Y - P_B^X C_B^X - P_B^Y C_B^Y + t_X\left(C_B^X - Q_B^X\right)\\
&= \left(\frac{2\alpha + G_A - R_A + \beta t_X}{2\beta}\right)\left(\frac{G_B}{G_A + G_B}[(1-\sigma_A)R_A]\right)\\
&\quad + \left(\frac{2\alpha + G_B - R_B - \beta t_Y}{2\beta}\right)\left(\sigma_B R_B + \frac{G_B}{G_A + G_B}[(1-\sigma_B)R_B] - G_B\right)\\
&\quad - \left(\frac{2\alpha + G_A - R_A + \beta t_X}{2\beta}\right)\left(\frac{R_A - G_A - \beta t_X}{2}\right) - \left(\frac{2\alpha + G_B - R_B - \beta t_Y}{2\beta}\right)\left(\frac{R_B - G_B + \beta t_Y}{2}\right)\\
&\quad + t_X\left(\frac{R_A - G_A - \beta t_X}{2} - \frac{G_B}{G_A + G_B}[(1-\sigma_A)R_A]\right),
\end{aligned}
$$

where the market prices P_B^X and P_B^Y are shown in Equation 14.b, the quantities of consumption C_B^X and C_B^Y in Equation 15, and the quantities of production Q_B^X and Q_B^Y are in Equation 3.b.

Taking the summation of ED_A^Z and ED_B^Z as shown above, after arranging terms, we have the following result:

$$\mathrm{ED}_A^Z + \mathrm{ED}_B^Z = 0.$$

This result indicates that the presence of a third good as a numeraire closes the partial equilibrium model and that the overall trade balance conditions for countries A and B are satisfied automatically.

Note that the above analysis is consistent with the discussion by Bagwell and Staiger (1997, p. 295, footnote 6). That is, our partial equilibrium model can be closed by including a traded numeraire good Z. Bagwell and Staiger (1997) further remark that Z is sufficiently abundant in each country and that it is consumed in positive amounts by each consumer. In this case, the marginal utility of income is fixed at one and the partial equilibrium analysis of the nonnumeraire sectors is appropriate. Trade in the numeraire good Z then is determined by the requirement of the overall trade balance.

We owe an anonymous referee for the valuable suggestions to include a traded numeraire good and verify that the trade balance conditions will not qualitatively alter the central results of this article.

A.5. SW function under resource security asymmetry

Under the assumptions that $\sigma_A = \sigma + \varepsilon$ and $\sigma_B = \sigma - \varepsilon$, other things being equal ($R_A = R_B = R$ and $t_A = t_B = t$), we have from Equation 16 that

$$
\begin{aligned}
\mathrm{SW}_A = \mathrm{CS}_A + \mathrm{PS}_A &= \frac{(R - G_A + \beta t)^2 + (R - G_B - \beta t)^2}{8\beta}\\
&+ \left(\frac{2\alpha - R + G_A - \beta t}{2\beta}\right)\left[(\sigma+\varepsilon)R + \frac{G_A}{G_A + G_B}(1-(\sigma+\varepsilon))R - G_A\right]\\
&+ \left(\frac{2\alpha - R + G_B + \beta t}{2\beta}\right)\left[\frac{G_A}{G_A + G_B}(1-(\sigma-\varepsilon))R\right],
\end{aligned}
\tag{A8}
$$

$$
\begin{aligned}
\mathrm{SW}_B = \mathrm{CS}_B + \mathrm{PS}_B &= \frac{(R - G_A - \beta t)^2 + (R - G_B + \beta t)^2}{8\beta}\\
&+ \left(\frac{2\alpha + G_A - R + \beta t}{2\beta}\right)\left[\frac{G_B}{G_A + G_B}(1-(\sigma+\varepsilon))R\right]\\
&+ \left(\frac{2\alpha + G_B - R - \beta t}{2\beta}\right)\left[(\sigma-\varepsilon)R + \frac{G_B}{G_A + G_B}(1-(\sigma-\varepsilon))R - G_B\right].
\end{aligned}
\tag{A9}
$$

A.6. How the welfare effect of arming is affected by changes in trade costs

For country A, we have from Equation 19.a that

$$\frac{\partial}{\partial t}\left(\frac{\partial \mathrm{SW}_A}{\partial G_A}\right)=\frac{1}{2\beta}\frac{\partial\left(Q_A^X-C_A^X\right)}{\partial t}+\left(\frac{\partial P_A^X}{\partial t}\right)\left[\frac{(1-\sigma_A)R_AG_B}{(G_A+G_B)^2}-1\right]+\left(\frac{\partial P_A^Y}{\partial t}\right)\frac{(1-\sigma_B)R_BG_B}{(G_A+G_B)^2}. \tag{A10}$$

Note that the results in Equations 3.a, 4.a, 8.a, and 14.a show the following derivatives:

$$\frac{\partial P_A^X}{\partial t}=-\frac{1}{2},\ \frac{\partial P_A^Y}{\partial t}=\frac{1}{2},\ \text{and}\ \frac{\partial\left(Q_A^X-C_A^X\right)}{\partial t}=-\frac{\beta}{2}.$$

Substituting the above derivatives back into Equation A10, assuming that $R_A = R_B = R$, yields

$$\frac{\partial}{\partial t}\left(\frac{\partial \mathrm{SW}_A}{\partial G_A}\right)=\underbrace{\left(-\frac{1}{4}\right)}_{\substack{\text{Export-revenue effect}\\ \text{of arming as } t \text{ decreases}\\ (-)}}+\underbrace{\left(\frac{1}{2}\right)\frac{(1-\sigma_B)\mathrm{R}G_B}{(G_A+G_B)^2}}_{\substack{\text{Resource-predation effect}\\ \text{of arming as } t \text{ decreases}\\ (+)}}+\underbrace{\left(-\frac{1}{2}\right)\left[\frac{(1-\sigma_A)\mathrm{R}G_B}{(G_A+G_B)^2}-1\right]}_{\substack{\text{Output-distortion effect}\\ \text{of arming as } t \text{ decreases}\\ (+)}}.$$

Similarly, for country B, we have from Equation 19.b that

$$\frac{\partial}{\partial t}\left(\frac{\partial \mathrm{SW}_B}{\partial G_B}\right)=\frac{1}{2\beta}\frac{\partial\left(Q_B^Y-C_B^Y\right)}{\partial t}+\left[\frac{(1-\sigma_B)R_BG_A}{(G_A+G_B)^2}-1\right]\left(\frac{\partial P_B^Y}{\partial t}\right)+\frac{(1-\sigma_A)R_AG_A}{(G_A+G_B)^2}\left(\frac{\partial P_B^X}{\partial t}\right). \tag{A11}$$

Note that the results in Equations 3.b, 4.b, 8.b, and 14.b show the following derivatives:

$$\frac{\partial P_B^Y}{\partial t}=-\frac{1}{2},\ \frac{\partial P_B^X}{\partial t}=\frac{1}{2},\ \text{and}\ \frac{\partial\left(Q_B^Y-C_B^Y\right)}{\partial t}=-\frac{\beta}{2}.$$

Substituting the above derivatives back into Equation A11, assuming that $R_A = R_B = R$, yields

$$\frac{\partial}{\partial t}\left(\frac{\partial \mathrm{SW}_B}{\partial G_B}\right)=\underbrace{\left(-\frac{1}{4}\right)}_{\substack{\text{Export-revenue effect}\\ \text{of arming as } t \text{ decreases}\\ (-)}}+\underbrace{\left(\frac{1}{2}\right)\frac{(1-\sigma_A)\mathrm{R}G_A}{(G_A+G_B)^2}}_{\substack{\text{Resource-predation effect}\\ \text{of arming as } t \text{ decreases}\\ (+)}}+\underbrace{\left(-\frac{1}{2}\right)\left[\frac{(1-\sigma_B)\mathrm{R}G_A}{(G_A+G_B)^2}-1\right]}_{\substack{\text{Output-distortion effect}\\ \text{of arming as } t \text{ decreases}\\ (+)}}.$$

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