Trade and Insecure Resources: Implications for Welfare and Comparative Advantage†

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Abstract: We augment the canonical neoclassical model of trade to allow for interstate disputes over land, oil, water, or other resources. The trade regime in place has important implications for the costs of such disputes in terms of arming. Depending on world prices, free trade can intensify arming incentives to such an extent that the additional security costs swamp the traditional gains from trade and thus render autarky more desirable for one or both rival states. Furthermore, contestation of resources can reverse a country's apparent comparative advantage relative to its comparative advantage in the absence of conflict. And, where such conflict is present, comparisons of autarkic prices to world prices could be inaccurate predictors of trade patterns.

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1 Introduction

> A country of our size, with its focus on exports and thus reliance on foreign trade, must be aware that military deployments are necessary in an emergency to protect our interests, for example, when it comes to trade routes, for example, [sic] when it comes to preventing regional instabilities that could negatively influence our trade, jobs and incomes.
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> Horst Köhler, former President of Germany (NY Times, May 31, 2010)

It is unusual for prominent public officials like the former President of Germany to make such seemingly politically incorrect statements. Military deployments for the protection of a country's own interest and trade routes—instead of, say, the protection of human rights and the promotion of democracy—perhaps sound too crass and cynical for today's international norms. Although Dr. Köhler was forced to resign from the Presidency of Germany for uttering the words quoted above, he did not ultimately disavow his essential belief in them.

For economists it would not appear to be controversial to state that the defense expenditures of countries are related to their perceived interests, including maintaining access to resources that might be in dispute, given that the international system is essentially anarchic without the third-party enforcement that usually exists within individual states. After all, as amply demonstrated in Findlay's and O'Rourke's (2007) magisterial survey of Eurasia's economic history, military competition for resources and the expansion of world trade were inextricably linked over the whole of the past millennium. While interstate wars have become less common in the post-World War II period than they had been in the thirty years prior to that, there have been both enough of them and, more seriously, enough disputes to keep almost all countries armed. Examples of hot disputes in the postwar period include the Suez Canal crisis in the 1950s, Iraq's invasion of Kuwait that resulted in the first Gulf war in the early 1990s, and the Kashmir dispute between India and Pakistan. Numerous other disputes—from that over the Spratly and Paracel islands in the South China Sea, to disputes over water (e.g. flowing through rivers like the Nile and the Brahmaputra), to those that might involve oil, minerals, or simply land—might have not resulted in hot incidents; however, they keep the militaries of almost all countries busy.[1] The direct and indirect costs of such disputes are large. For example, the latest estimates of the costs of the Iraq and Afghanistan wars to the United States are around 4 to 6 trillion dollars (Stiglitz and Bilmes, 2011).[2]

[1] See, Klare (2001), for an overview and many examples.

[2] Military expenditures alone were about 2.6 percent of world GDP during 2004, varying from less than 1 percent for a few countries to more than 10 percent for Saudi Arabia (SIPRI, 2005). As for the overall costs of conflict (including civil war), Blomberg and Hess (2011) estimate a lower bound for the yearly cost

Given the quantitative importance of security costs in reality and their absence in canonical models of trade, the question arises whether the major results of trade theory are robust to the presence of insecurity. There are two main results of neoclassical trade theory that concern us here. First, for small countries (i.e., those that have no influence on world prices) free trade is always superior to autarky. Second, a country's comparative advantage is determined by the interplay of its factor endowments, technologies, and world prices.

In this paper we examine the robustness of these two major results by augmenting the canonical 2×2×2 Heckscher-Ohlin-Samuelson model of trade to allow for insecurity and its accompanying costs. The neoclassical model (which we also call the "Nirvana" model, to use Demsetz's (1969) apt term) is a limiting case of our model when security is (costlessly) perfect. We find that the two main results of traditional trade theory are no longer generally true, and we characterize and interpret the conditions under which the traditional results do and do not hold.

In our model, one factor of production ("labor") is perfectly secure, while the other ("land") is, in part, insecure. The distribution of insecure land between the two countries depends on the relative amount of arming by each. Arming itself is produced with the two factors of production and the cost of its production represents security costs. A novel feature of the setup is that it captures the trade-regime dependence of the net marginal benefit of arming and thus of the incentive to arm. With arming endogenous, the factor endowments left over for use in civilian production of the two final goods are also endogenous and depend on the trade regime prevailing in the two countries. Thus, both security costs and the factor endowments used in civilian production are endogenous to the prevailing trade regime. The two trade regimes that we consider and compare are autarky and free trade.

Our comparison of welfare under these two regimes reveals that the relative factor intensities of the two civilian goods play an important role. For example, when the countries are identical and they both import the land-intensive good under free trade, then free trade is superior to autarky for both countries. When they both export the land-intensive good, however, and the price of that good is not too high, both countries prefer autarky. In the first case, free trade reduces the security costs relative to autarky because the land-intensive good can be obtained more cheaply in world markets than it could be produced domestically under autarky. Therefore, free trade is better due to both the traditional gains from trade and the lower costs of security. In the second case, though, when the land-intensive good is exported, the higher export price compared to the price of the good under autarky makes competition over land more intense, increasing the costs of security

of conflict of 9 percent of steady state consumption for the 1950 to 2004 period. For high-income countries like the United States and France the cost was roughly 4.5 percent of consumption, whereas for Iraq and Iran, largely as a result of the war between then, it was nearly 77 percent and 16 percent of their respective yearly consumptions.

enough relative to autarky so as to outweigh the gains from trade.

In general, the security costs under the two trading regimes considered can be very different. Under autarky they depend on the domestic factor and goods prices of both countries, whereas under free trade the costs of security tend to be equalized because of factor price equalization. Autarky can be preferable for one or both countries when free trade involves higher added security costs relative to the gains from trade.

We also show how insecurity induces distortions in comparative advantage in at least two possible ways: (i) by causing trade patterns to differ from the ones that would have emerged under Nirvana; and, (ii) by altering the information content of the difference between free-trade and autarkic prices, and thus possibly leading to erroneous predictions of the direction of trade flows. If, for example, the technology for arming is sufficiently intensive in the use of the perfectly secure resource (labor), then insecurity implies relatively less of that resource is left for the production of traded goods. Consequently, the world price of the consumption good employing the secure resource intensively that implies no trade tends to exceed the analogous price that would have prevailed under Nirvana. The net effect is that there exists a range of world prices for which a country is an importer of that consumption good when there is insecurity, whereas it would have been an exporter of the same good under Nirvana. Similarly, because the introduction of free trade in consumption goods alters product prices, factor prices, arming incentives, and thus resources left for the production of consumption goods, a country's true comparative advantage (given insecurity) can differ from that which is implied by a simple comparison of autarkic prices to world prices. Both of these distortions imply that the presence of insecurity plays an important role in the determination of a country's actual trade patterns that traditional theory fails to capture.

Our substantive characterization results do not depend on specific functional forms of production or utility functions. The resulting generalized treatment sets the stage for both applications of the augmented canonical trade model that allows for insecure property rights and extensions that include the important case of large countries, the latter being of great relevance to the fields of international relations and international political economy for studying the relationship between trade and security policies at the global level.

This paper's contribution is related to literatures in both political science and economics. Political scientists have long been interested in the linkages between international trade and conflict.[3] Economists, by contrast, have only begun to explore these linkages. Examples

[3] See Barbieri and Schneider (1999), who survey much of the theoretical and empirical literatures on the subject. Many of the analyses, in contrast to ours, emphasize the aggregate income effects of trade, with the gains of trade reflected in higher incomes amplifying incentives to arm. Rowe (1999, 2005) is, to our knowledge, the sole political scientist who emphasizes the role of factor endowments. Although he does so in a qualitative fashion—focusing on military costs, while effectively abstracting from the potential benefits of security policies,—his analysis of how globalization in late 1800s and early 1900s set the stage for World War I points to the importance of the mechanism highlighted in our study—namely, the link between product

include Anderson and Marcouiller (2005) and Anderton et al. (1999), who analyze Ricardian models in which traded goods are insecure either because of the presence of pirates and bandits or because the contending sides influence the terms of trade through arming. Both approaches emphasize the important, though basic, point that international trade can be hampered by the anarchic nature of international relations. Skaperdas and Syropoulos (2001, 2002) address some of the implications of insecure property in the context of simple exchange models. Acemoglu et. al. (2011) explore the implications for intertemporal pricing and exhaustion of a contested resource in a dynamic setting.

While extant trade theory has ruled out security problems by assumption, there are some exceptions that focus on the related problem of open-access resources. Chichilnisky (1994) argues that trade can reduce welfare in the South by accentuating the over-exploitation of an open-access resource in which it has a comparative advantage, and Brander and Taylor (1997a) formally prove this idea. Hotte et al. (2000) also study the effects of trade in an open-access resource and extend the analysis to consider the evolution of private enforcement in dynamic environments. Margolis and Shogren (2002) consider a North-South trade model with enclosures. The key difference between these models and ours is that enforcement costs are due to active contestation of resources. There are also important differences in the models considered and most of the questions addressed.

In the next section, we present the formal model and a preliminary analysis that proves useful in subsequent sections. Then, in Section 3, we investigate optimal security policies under autarky and free trade. In Section 4, we explore the implications of international conflict for trade patterns and trade volumes. In Section 5, we compare autarky and free trade in terms of their implications for security costs and welfare. Lastly, in Section 6, we offer several concluding comments. All technical arguments and proofs have been relegated to the Appendix.

2 Framework and Preliminary Analysis

Consider a global economy that consists of two countries, indexed by $i = 1, 2$, and the rest of the world (ROW), which for simplicity is treated as a single entity and taken as exogenous. Each country can produce two consumption goods (say "butter" and "oil"), indexed by $j = 1, 2$, using labor and land under constant returns to scale. In the spirit of the Heckscher-Ohlin-Samuelson (HOS) trade model, we assume the countries have access to the same production technology; consumers have identical and homothetic preferences defined over the two consumption goods; and, all markets are perfectly competitive. Each country i possesses L^i units of *secure* labor and K^i units of *secure* land. However, departing from the HOS trade model, we assume there exists additional land of K_0 units. Although

and factor prices that determines the costs of security.

this additional land is divisible, its division between the two countries is subject to dispute.[4] Policymakers use arming to gain control of the disputed resource (K_0), with the ultimate goal of maximizing national welfare.

Let country i's "guns" be denoted by G^i, a variable most accurately viewed as a producible composite good that reflects country i's military capability. Country i's share of K_0, then, is determined by the contest success function (CSF):

$$\phi^i(G^i, G^j) = \begin{cases} \frac{f(G^i)}{f(G^1)+f(G^2)} & \text{if} \quad \sum_{i=1,2} G^i > 0; \\ \frac{1}{2} & \text{if} \quad \sum_{i=1,2} G^i = 0, \end{cases} \tag{1}$$

for $i = 1, 2$ ($j \neq i$), where $f(\cdot) \geq 0$, $f(0) = 0$, $f'(\cdot) > 0$, $\lim_{G^i \to 0} f'(G^i) = \infty$, and $f''(\cdot) \leq 0$.[5] According to (1), the fraction of the disputed resource a country secures in the contest depends on its own guns as well as those of its adversary. Specifically, it is increasing in the country's own guns ($\phi^i_{G^i} \equiv \partial\phi^i/\partial G^i > 0$) and decreasing in the guns of its adversary ($\phi^i_{G^j} \equiv \partial\phi^i/\partial G^j < 0$, $j \neq i$). The influence of guns on a country's share, $\phi^i(G^i, G^j)$, could be taken literally or viewed as the reduced form of a bargaining process, in which relative arming figures prominently in the division of the contested resource.[6] In any case, each country has an incentive to produce guns, whereby it can obtain a larger share of the contested land and thus more income. But, there is an opportunity cost of doing so—namely, the loss in income as resources are diverted away from the production of consumption goods. This trade-off, which is trade-regime dependent, plays a prominent role in the determination of the countries' security policies.[7]

The setting here is an anarchic one, so that writing enforceable (binding) contracts on the proliferation of arms and the division of K_0 is not possible. Instead, we view guns as the "enforcement" variable that determines each country's share of the contested resource that, in turn, can be combined with the country's remaining secure endowments of labor

[4] The insecure resource could also be interpreted as a natural resource (e.g., oil, water) or simply physical capital.

[5] In the Appendix we derive some useful properties of this specification. As revealed in the Supplementary Appendix (available from the authors upon request), the condition that $\lim_{G^i \to 0} f'(G^i) = \infty$ and the assumed concavity of $f(\cdot)$ help establish existence and uniqueness of equilibrium. See Skaperdas (1996) for an axiomatization of (1), requiring only that $f(\cdot)$ is a non-negative, increasing function. One functional form for $f(\cdot)$ that has been widely used in the rent-seeking literature, as well as in the literatures on tournaments and conflict, is $f(G) = G^\gamma$ where $\gamma \in (0, 1]$ (Tullock, 1980). See Hirshleifer (1989) for a comparison of the properties of this form with those of $f(G) = e^{\gamma G}$. As noted below, neither the additive nor symmetric nature of the specification in (1) is crucial for our results that follow. For an analysis of the comparative static results of conflict without any functional form assumptions, see Acemoglu and Jensen (2011).

[6] See Anbarci et al. (2002) for an analysis of this issue and how, in particular, different bargaining solution concepts lead to division rules that vary in their sensitivity to guns.

[7] While countries often build their own military constellation, they can, in practice, also buy or sell certain weapons in the world market, as well as hire mercenaries or foreign security experts. However, to highlight how pure trade in goods affects arming incentives, we abstract from such possibilities in this analysis.

and land employed in the production of final consumption goods. Accordingly, the sequence of events is as follows:

(i) Given the initial distribution of secure factor endowments (L^i and K^i), the two countries ($i = 1, 2$) simultaneously choose their (irreversible) production of guns G^i.

(ii) Once these choices are made, the contested land is divided according to (1): each country i receives $\phi^i K_0$ units of the contested resource.

(iii) With the quantities of land and labor left for the production of consumption goods having thus been determined, private production and consumption decisions take place. Under autarky, prices adjust to clear domestic markets. Under free trade, the prices of consumption goods are fixed in the world market.

A conflictual equilibrium is the Nash equilibrium in guns, conditional on the prevailing trade regime.

To complete the basic model, we now specify the supply and demand sides of each economy. Starting with the supply side, let $\psi^i \equiv \psi(w^i, r^i)$ and $c_j^i \equiv c_j(w^i, r^i)$ represent respectively the unit cost functions of guns and goods $j = 1, 2$ in country i, where w^i and r^i denote competitively determined factor prices—respectively, the wage paid to labor and the rental rate paid to landowners. These unit cost functions have the usual properties, including concavity and linear homogeneity in factor prices. By Shephard's lemma, the unit labor and land requirements in arms production are given respectively by $\psi_w^i \equiv \partial\psi^i/\partial w^i > 0$ and $\psi_r^i \equiv \partial\psi^i/\partial r^i > 0$. Similarly, $a_{Kj}^i \equiv \partial c_j^i/\partial r^i > 0$ and $a_{Lj}^i \equiv \partial c_j^i/\partial w^i > 0$ represent the unit land and labor requirements in producing good j. Therefore, the land/labor ratio in guns is $k_G^i \equiv \psi_r^i/\psi_w^i$, and the corresponding ratio in industry j is $k_j^i \equiv a_{Kj}^i/a_{Lj}^i$. Industry 2 is land-intensive if $k_2^i > k_1^i$ (or labor-intensive if $k_2^i < k_1^i$) at all relevant factor prices.[8] Although we will show how the ranking of factor intensities across industries $j = 1, 2$ matters, for specificity we emphasize throughout much of the discussion the case where good 2 is produced intensively with the insecure resource (i.e., land).

Taking good 1 as the numeraire, let p^i denote the relative price of good 2 in country i. With diversification in production, perfect competition requires

$$c_1(w^i, r^i) = a_{L1}^i w^i + a_{K1}^i r^i = 1 \tag{2}$$

$$c_2(w^i, r^i) = a_{L2}^i w^i + a_{K2}^i r^i = p^i, \tag{3}$$

for $i = 1, 2$. These equations, together with the assumption of identical technologies across countries and the properties of unit cost functions, imply that the wage/rental ratio, $\omega^i \equiv$

[8] We follow much of the literature based on the HOS trade model in ruling out factor intensity reversals.

w^i/r^i, can be written as a function of p^i (i.e., $\omega^i = \omega(p^i)$). By the Stolper-Samuelson (1941) theorem, a rise in the relative price p^i increases the return to that factor which is used most intensively in the production of good 2, and at the same time decreases the return to the other factor: $\omega_p^i (\equiv \partial\omega/\partial p^i) \lesseqgtr 0$ as $k_2^i \gtreqless k_1^i$ (see Lemma A.1(a) in the Appendix).

Let (K_X^i, L_X^i) denote the vector of residual quantities of resources left for the production of consumption goods in country i at the end of stage (ii), once labor and land resources have already been employed in the production of guns G^i, respectively $\psi_w^i G^i$ and $\psi_r^i G^i$, and the distribution of the contested resource has been realized, $\phi^i K_0$. Furthermore, let X_j^i denote the output of good j. Then, factor market clearing and diversification in production require in each country i,

$$a_{K1}^i X_1^i + a_{K2}^i X_2^i = K_X^i \quad (\equiv K^i + \phi^i K_0 - \psi_r^i G^i) \tag{4}$$

$$a_{L1}^i X_1^i + a_{L2}^i X_2^i = L_X^i \quad (\equiv L^i - \psi_w^i G^i). \tag{5}$$

Now, let k_X^i denote country i's residual land/labor ratio:

$$k_X^i \equiv \frac{K_X^i}{L_X^i} = \frac{K^i + \phi^i K_0 - \psi_r^i G^i}{L^i - \psi_w^i G^i}, \quad \text{for } i = 1, 2. \tag{6}$$

Then, it is straightforward to verify, from (4) and (5) along with the linear homogeneity of unit cost functions and the fact that $\omega^i = \omega(p^i)$, that the relative supply of good 2 (oil), $RS^i \equiv X_2^i/X_1^i$, can be written as $RS^i = RS(p^i, k_X^i)$. In the Appendix (Lemma A.1) we show that the relative supply of good 2 is increasing it the relative price due to increasing opportunity costs: $\partial RS^i/\partial p^i > 0$. In addition, we establish, consistent with the Rybczynski (1955) theorem, that an increase in the residual land/labor ratio causes an increase in the relative supply of the good that uses land intensively: $\partial RS^i/\partial k_X^i \gtreqless 0$ as $k_2^i \gtreqless k_1^i$. Further, as can be seen from (6), when both goods are produced, the residual land/labor ratio can be written as a function of the relative price of good 2, the guns produced by the two countries, and resource endowments. To avoid cluttering of notation, we write this function as $k_X^i = k_X^i(p^i, G^i, G^j)$. Lemma A.2 in the Appendix describes the dependence of k_X^i on its arguments. The important point to recognize at this stage is that the relative supply of good 2 can also be written as a function of the price and guns: $RS^i = RS(p^i, G^i, G^j)$. In the next section, we characterize the exact nature of this relationship, as needed in the identification of market-clearing prices and in the analysis of conflict under autarky.

Turning to the demand side, let R^i and $\mu^i \equiv \mu(p^i)$ denote respectively net national income and the marginal utility of income. Country i's indirect utility (aggregate welfare) function can then be written as[9]

$$V^i \equiv V^i(p^i, G^i, G^j) = \mu(p^i)R^i(p^i, K_X^i, L_X^i), \text{ for } i = 1, 2 \ (j \neq i). \tag{7}$$

Equation (7) implicitly assumes that policymakers finance the cost of arming with nondistortionary income taxes. This assumption, together with that of perfect competition, implies that country i's net national income (R^i) is the country's maximized value of domestic production of consumption goods and, at the same time, the minimized value of rental payments paid to residual labor and land owners. Then, equations (2)–(5) imply $R^i = X_1^i + p^i X_2^i = r^i K_X^i + w^i L_X^i$ for $i = 1, 2$, which explains the arguments of R^i and V^i in (7). R^i should be identified with the familiar gross domestic product (*GDP)* or revenue function (Dixit and Norman, 1980), excluding arms expenditures. As one can verify, R^i is increasing and convex in p^i, and increasing and concave in the residual factor inputs (K_X^i, L_X^i). Furthermore, the supply of good 2 satisfies $X_2^i = R_p^i$ $(\equiv \partial R^i/\partial p^i)$ and $\partial X_2^i/\partial p^i = R_{pp}^i \geq 0$, while factor prices satisfy $w^i = R_L^i$ $(\equiv \partial R^i/\partial L_X^i)$ and $r^i = R_K^i$ $(\equiv \partial R^i/\partial K_X^i)$.

Using Roy's identity, country i's demand function for good 2 can be written as $D_2^i = \alpha_D^i R^i/p^i$, where the associated expenditure share is given by $\alpha_D^i \equiv \alpha_D(p^i) = -p^i\mu_p^i/\mu^i$ (> 0).[10] Now, since the supply of good 2 is given by $X_2^i = R_p^i$, the excess demand for (or net imports of) good 2 is given by $M^i \equiv D_2^i - X_2^i$.[11] Then, holding fixed the secure resource endowments (K^i and L^i) as well as the disputed resource (K_0), total differentiation of (7) yields

$$dV^i = \mu(p^i)\left[-M^i dp^i + (r^i K_0 \phi_{G^i}^i - \psi^i)dG^i + r^i K_0 \phi_{G^j}^i dG^j\right] \quad \text{for } i = 1, 2 \ (j \neq i). \tag{8}$$

The first term inside the square brackets, weighted by the marginal utility of income $\mu(p^i)$, is a terms of trade effect. For net importers of good 2, an increase in p^i increases the domestic cost of good 2, and is thus welfare-reducing. By contrast, such an increase in the relative price is welfare-improving for net exporters of good 2.

The second term in the brackets (weighted by $\mu(p^i)$) captures the welfare effect of a change in country i's guns, G^i. Ceteris paribus, an increase in G^i increases country i's share of the contested land and thus its national income (the first term inside the parentheses). At the same time, however, the increase in G^i draws additional resources away from the production of consumption goods and thus reduces national income (the second term).

The third term in the brackets (again weighted by $\mu(p^i)$) captures the welfare effect of

[9] In this expression, we suppress the obvious dependence of V^i on resource endowments to avoid cluttering.

[10] It can be shown that this share is decreasing or increasing in p^i, depending on whether the elasticity of substitution in consumption is larger or smaller than unity, respectively.

[11] We omit subscript "2" from "M^i" to avoid cluttering of notation.

a change in arms by country i's opponent, G^j. An increase in G^j reduces country i's share of the contested resource and thus its income, and thereby adversely affects that country. Note that, for fixed product prices, an equi-proportionate expansion of both countries' guns, where $G^1 = G^2$ initially, implies no change in the division of the contested land, while increasing the resource cost of guns, and thus necessarily leaves both countries worse off.

We now demonstrate how the above ideas inform the derivation of the optimizing security policies (arming) under alternative trade regimes. A key feature of the optimization problem for the choice of arming for each country i is that, with diversification in production, the corresponding first-order condition (FOC), given by

$$V^i_{G^i}(p^i, G^i, G^j) = \mu(p^i) r^i \left[K_0 \phi^i_{G^i} - \psi^i / r^i \right] = 0 \text{ for } i = 1, 2 \ (j \neq i), \tag{9}$$

is the same regardless of the trade regime in place.[12] Under autarky, domestic product market clearing requires p^i to adjust so that $M^i = 0$, which implies that the first term inside the brackets in (8) vanishes, thereby yielding (9) as the relevant FOC. Under free trade in consumption goods, product prices are invariant to security policies for "small" countries; thus, the first term also vanishes under this trade regime.

Equation (9) shows that country i's net marginal payoff from arming consists of two key components: (i) the marginal benefit of producing guns, which is given by $MB^i \equiv K_0 \phi^i_{G^i}$ when measured in land units; and (ii) the marginal cost of producing guns, which is given by $MC^i \equiv \psi^i / r^i$ (again measured in land units).

In the Appendix (Lemma A.3), we establish some important properties of both of these components and thus of net marginal payoff from arming, particularly their dependence on arming by both countries and on the relative price. For now, observe from equation (A.3) in the Appendix that MB^i is decreasing in i's guns (G^i) given the guns chosen by its rival (G^j), as illustrated in Fig. 1.[13] Furthermore, from (A.4), MB^i rises or falls with its rival's arms (i.e., MB^i in Fig. 1 shifts up or down) depending on which contender initially produces more guns.[14] But, since changes in the relative price p^i (given arming by both countries) have no influence on MB^i, the marginal benefit is independent of the trade regime in place.

By contrast, MC^i does depend on p^i through factor prices and is thus trade-regime dependent.[15] At an optimum, the qualitative nature of this influence depends on the ranking

[12] Our discussion here and to follow is based on the assumption that, under autarky, the distribution of factor endowments between the adversaries is such that their production of arms is not constrained by their secure land holdings. Under free trade, we assume further that technology, the distribution of factor endowments, the quantity of the contested resource and the world price are such that production of consumption goods is diversified.

[13] In addition, from equation (A.3), the condition that $\lim_{G^i \to 0} f'(G^i) = \infty$ implies $\lim_{G^i \to 0} MB^i = \infty$.

[14] Of course, MB^i also depends positively on the amount of land being disputed, K_0.

[15] The link between product and factor prices breaks down even when secure resource constraints are not binding in the production of guns, if guns are produced with land only.

of the factor intensities in industries 1 and 2. To see this effect, first observe that the linear homogeneity of the unit cost function for guns (ψ^i) and the fact that $\psi^i_w > 0$ imply that country i's marginal cost of arming can be written as $MC^i = \psi^i/r^i = \psi(\omega^i, 1)$ and is increasing in ω^i, country's wage/rental ratio. By the Stolper-Samuelson theorem (Lemma A.1(a)), if $k^i_2 > k^i_1$ ($k^i_2 < k^i_1$), an increase in p^i decreases (increases) ω^i and thus decreases (increases) MC^i. Under free trade when production is diversified, the world price alone determines ω^i. Since ω^i is thus invariant to changes in G^i, so is the marginal cost of guns, as illustrated by MC^i_F (the dotted line) in Fig. 1. Under autarky, by contrast, product (and thus factor) prices are endogenous. In the next section, we show that the marginal cost under this regime is generally increasing in G^i, as depicted by MC^i_A in Fig. 1.

3 Trade Regimes and Insecurity

Building on the results above, we now explore the implications of autarky and free trade for arming. The central objective here is to characterize how the trade regime in place influences arming incentives. We differentiate between trade regimes with subscripts "A" for *autarky* and "F" for *free trade*.

3.1 Autarky

The first-order conditions in (9) reveal that, regardless of the trade regime in place, the two countries' optimizing choices for guns (G^{i*} for $i = 1, 2$) depend on the product prices prevailing in the respective country, p^i. Thus, to close the model we need two additional conditions that determine the autarkic prices, p^i_A for $i = 1, 2$. These conditions require domestic markets to clear: $M^i = 0$ or equivalently,

$$RD\left(p^i\right) = RS\left(p^i, k^i_X\left(p^i, G^i, G^j\right)\right) \quad \text{for} \quad i = 1, 2, \, j \neq i \tag{10}$$

where $RD(p^i)$ denotes the relative demand for good 2. While the demand for good 2, as noted above, is given by $D^i_2 = \alpha^i_D R^i/p^i$, the demand for good 1 is $D^i_1 = (1 - \alpha^i_D)R^i$; as such, the relative demand for good 2 is $RD(p^i) \equiv D^i_2/D^i_1 = \frac{1}{p^i}\frac{\alpha_D(p^i)}{1-\alpha_D(p^i)}$. One can show that $RD(p^i)$ is uniquely determined by and decreasing in the relative price of good 2, p^i. In addition, as noted above and shown in Lemma A.1(c), the relative supply of good 2 (RS^i) is increasing in p^i.

Using (10), Lemma A.4 presented in the Appendix shows how the equilibrium price is influenced by changes in the land/labor ratio (k^i_X) induced by exogenous changes in guns and resource endowments. Most important for our purposes here, part (a) of the lemma implies that a country's marginal cost of producing guns under autarky, $MC^i_A = \psi(\omega(p^i_A), 1)$, is increasing in the country's own guns regardless of the ranking of factor intensities in the consumption goods industries. The logic here is as follows. In the neighborhood of the optimum implicitly defined by (9), an increase in G^i raises country i's residual land/labor ratio, k_X^i (see Lemma A.2(b)). Now, suppose $k_2^i > k_1^i$. Then, as shown in Lemma A.1(b), this increase translates into an increase in the relative supply of good 2 (RS^i), causing the autarkic price of good 2 (p_A^i) to fall. Alternatively, if $k_2^i < k_1^i$, the increase in k_X^i causes p_A^i to rise. In both cases, by the Stolper-Samuelson theorem (Lemma A.1(a)), these price adjustments, in turn, force the wage/rental ratio (ω^i) to rise and thus induce MC_A^i to rise with G^i.

Obviously, the intersection of MC_A^i with MB^i at point A in Fig. 1 gives country i's best-response function under autarky, $B_A^i(G^j)$. The shape of this function depends on how both the marginal cost and marginal benefit functions are influenced by the rival's arming. As implied by Lemma A.4(b), MC_A^i is negatively related to the rival's arming; and, from Lemma A.3(b), MB^i is increasing (decreasing) in the rival's arming when $G^i > G^j$ ($G^i < G^j$). Thus, as illustrated with solid-line curves in Fig. 2,[16] $B_A^i(G^j)$ depends positively on G^j (reflecting strategic complementarity) up to and beyond its point of intersection with the 45° line; however, at some point beyond that intersection, the function can become negatively related to G^j (reflecting strategic substitutability).

One can show, under fairly general circumstances, that an interior Nash equilibrium in pure strategies (security policies) exists in the autarkic trade regime. Furthermore, the equilibrium is unique if the technology for arms is sufficiently labor-intensive or the inputs to arms are not very close complements.[17] The conflictual (Nash) equilibrium under autarky is depicted by the intersection of the best-response functions.[18] One such equilibrium—a symmetric one—is point A in Fig. 2, where B_A^1 and B_A^2 intersect along the 45° line. Point A' (where $B_A^{1\prime}$ and $B_A^{2\prime}$ intersect) shows an asymmetric equilibrium.

Whether the equilibrium under autarky is symmetric or asymmetric depends on the technologies for producing consumption goods, the technology of conflict (1), the degree of resource insecurity (institutions), and the size of the secure endowments of land and labor, as each influences autarkic prices and thus the marginal cost of arming.[19] To proceed, consider first the benchmark case, where countries 1 and 2 have identical secure endowments. We

[16]Ignore the other curves drawn in the figure for now.

[17]The proof, which is presented in the Supplementary Appendix available from the authors upon request, is based on the assumption that not all secure land supplies are absorbed into the production of guns, but can be amended to allow this possibility. One sufficient condition that precludes this complication from arising is that the degree of land insecurity (i.e., the fraction of contested land) is not too high. Another possible condition is that guns are produced with labor only ($k_G^i = 0$). Note that, in any case, provided that both factors are essential to the production of consumption goods, labor will never be fully absorbed in the production of guns in the autarkic regime.

[18]Note that, because each country always has an incentive to produce a small (but positive) quantity of arms when its rival produces none, $(0, 0)$ is not a Nash equilibrium.

[19]Recall that MB^i is independent of p^i.

differentiate the resulting symmetric equilibrium values from others, by placing a tilde ($\sim$) over the associated variables. Since the countries are identical, they face identical arming incentives; therefore, $G_A^{i*} = \widetilde{G}_A^*$ for $i = 1, 2$, with each country thus receiving one half of the contested resource, K_0. Furthermore, by Lemma A.5 presented in the Appendix, $p_A^{i*} = \widetilde{p}_A^*$, and thus $\omega_A^{i*} = \widetilde{\omega}_A^*$ and $k_X^{i*} = \widetilde{k}_X^*$ for each i.

In what follows, we distinguish between two distinct sets of secure endowments of land and labor that differ in their predictions for the relative amounts of arms the two countries produce under autarky: $\mathcal{S}^0$ denotes the set of secure endowment distributions implying a symmetric solution such that $G_A^{*1} = G_A^{*2} = \widetilde{G}_A^*$, and $\mathcal{S}^i$ denotes the set of secure endowment distributions implying an asymmetric outcome such that $G_A^{*i} > G_A^{*j}$. Clearly, $\mathcal{S}^0$ includes the benchmark case where the two countries have identical secure endowments. The next lemma establishes that $\mathcal{S}^0$ includes other distributions as well.

Lemma 1 (*Arming and Autarkic Prices*) *Under autarky, there exists a non-empty set of asymmetric factor distributions under which contending states face identical market-clearing prices, produce identical quantities of arms, and are equally powerful. All other asymmetric distributions generate different prices and unequal arming and power. Specifically, for each country* $i = 1, 2$ $(j \neq i)$,

(a) $G_A^{i*} = \widetilde{G}_A^*$ *and* $p_A^{i*} = \widetilde{p}_A^*$ *for secure factor distributions in* $\mathcal{S}^0$, *where* $k_X^{i*} = \tilde{k}_X^*$;

(b) $G_A^{i*} > G_A^{j*}$ *and* $p_A^{i*} \gtreqless p_A^{j*}$ *as* $k_2^i \gtreqless k_1^i$ *for secure factor distributions in* $\mathcal{S}^i$, *where* $k_X^{i*} < k_X^{j*}$.

To see what other distributions yield the symmetric outcome, suppose that, starting from the benchmark case, both land and labor resources are transferred from country 2 to country 1, such that $\frac{dk_X^i}{k_X^i}\big|_{dG^i = dp^i = 0} = \frac{dK^i}{K_X^i} - \frac{dL^i}{L_X^i} = 0$, which requires $\frac{dK^i}{dL^i} = \frac{K_X^i}{L_X^i} = \widetilde{k}_X^*$ for each i. By construction, such a redistribution of resources, for constant guns and prices, leaves the value of country i's residual land/labor ratios unchanged at $k_X^i = \widetilde{k}_X^*$, $i = 1, 2$. Thus, the countries' relative supply and relative demand functions do not shift; and, there is no pressure for autarkic prices to change. But, given prices do, in fact, remain fixed at $\widetilde{p}_A^*$, arming incentives remain unchanged in both countries. Thus, $\mathcal{S}^0$ consists of all secure resource distributions implying the same residual land/labor ratio as that for two identical countries, $k_X^{1*} = k_X^{2*} = \widetilde{k}_X^*$. They all imply the same symmetric outcome.[20]

To see how $\mathcal{S}^0$ differs from $\mathcal{S}^i$, the set of secure resource endowments implying an asymmetric outcome such that $G_A^{*i} > G_A^{*j}$, consider an initial secure resource distribution in $\mathcal{S}^0$. From the discussion above, the conflictual equilibrium is initially on the 45° line of Fig.

[20]Note that uneven distributions of secure factor endowments in $\mathcal{S}^0$ imply different ex ante and ex post ratios of secure land to labor (K^i/L^i and $k^i = (K^i + \phi^i K_0)/L^i$ respectively) across countries i, but the same autarkic price. Thus, contrary to the traditional theory, the equilibrium price of the good produced intensively with land need not be lower in the country having the higher ratio of secure land to labor.

2, at point A, where B_A^1 and B_A^2 intersect. Now arbitrarily transfer labor only from country 2 to country 1, and to fix ideas suppose that $k_2^i > k_1^i$. Then, according to Lemma A.4(d), this transfer of labor raises country 1's autarkic price, which in turn decreases its marginal cost of arming (Lemma A.3(c)); at the same, the loss of labor for country 2 reduces its autarkic price, and thus increases its marginal cost of arming. As a consequence, country 1 (2) will behave more (less) aggressively, as shown in Fig. 2 by the clockwise rotation of B_A^1 to $B_A^{1'}$ and that of B_A^2 to $B_A^{2'}$. The uniqueness of equilibrium ensures that the intersection of the new best response functions, $B_A^{1'}$ and $B_A^{2'}$, lies below the 45° line, such as point A' in the figure, where clearly country 1 arms more heavily than its adversary. As confirmed in the Appendix, this effect on the countries' arming incentives holds regardless of the ranking of factor intensities of the two consumption goods. But, this ranking does matter for the ranking of their autarkic prices. In particular, by Lemma A.5, the divergence in the two countries' guns production $G^{1*} > G^{2*}$ implies $p_A^{1*} \gtrless p_A^{2*}$ when $k_2^i \gtrless k_1^i$. Finally, note that we can further distinguish $\mathcal{S}^0$ from $\mathcal{S}^1$ using Lemma A.4 while noting the difference in p_A^{i*} across countries $i = 1, 2$. Specifically, whereas $k_X^{1*} = k_X^{2*} = \widetilde{k}_X^*$ for distributions of secure endowments in $\mathcal{S}^0$, we have $k_X^{1*} < k_X^{2*}$ for distributions in $\mathcal{S}^1$ regardless of the ranking of factor intensities across industries.[21]

3.2 Free trade

Turning to trade, we suppose the contending countries are "small" in world markets and that there are no trade costs. Letting π denote the international price of the non-numeraire good, free trade in consumption goods requires $p^i = \pi$, for $i = 1, 2$. Since π is given by world markets and is thus independent of national security policies, a country's payoff function can be identified with its indirect utility function, V^i. Depending on fundamentals, the degree of land insecurity, and the international price level, it is possible, as in the case of autarky, for arms production to be constrained by the countries' secure land holdings.[22] However, it is also possible now for one or both contestants to specialize completely in the production of one consumption good. But, to highlight the factor-price effects of opening borders up to free trade and the striking implications this can have for arming incentives, we abstract from these two possible complications.

One can show that when (i) free trade in consumption goods leads to international factor price equalization, and (ii) the production of arms does not exhaust either country's secure land endowment, an interior Nash equilibrium in security policies will exist, and will be unique and symmetric Here we focus on the logic underlying the symmetric feature of the

[21] For distributions in $\mathcal{S}^1$ adjacent to $\mathcal{S}^0$, we have $k_X^{1*} < \widetilde{k}_X^* < k_X^{2*}$, as implied by the proof to Lemma A.6 in the Appendix.

[22] As in the case of autarky, countries will not use their entire labor endowments in the production of guns, provided that both factors are essential in the production of consumption goods.

free-trade equilibrium.[23]

Suppose for now that $\pi = \widetilde{p}_A^*$ and that the two countries have identical secure resource endowments. Provided conditions (i) and (ii) stated above are satisfied, the intersection of MB^i and MC_F^i (as illustrated in Fig. 1 at point A) determines country i's best-response under free trade, $B_F^i(G^j)$. Since under free trade product and thus factor prices are independent of either country's security policy, the shapes of best-response functions are determined solely by the properties of the CSF (1), ϕ^i—that is, $\partial B_F^i/\partial G^j = -V_{G^iG^j}^i/V_{G^iG^i}^i = -\phi_{G^iG^j}^i/\phi_{G^iG^i}^i \gtreqless 0$ when $G^i \gtreqless G^j$. Thus, as illustrated in Fig. 2, the best-response functions under free trade are upward-sloping (reflecting strategic complementarity) up to their point of intersection with the 45° line, and downward sloping (reflecting strategic substitutability) thereafter. When secure resources are identically distributed across the two countries, they face identical marginal benefit and marginal cost functions for guns, thereby yielding the symmetric equilibrium, point A in Figure 2 where $G_F^{i*} = \widetilde{G}_A^*$ for $i = 1, 2$.[24] What about when secure endowments are unevenly distributed across the two countries? Provided that the distribution is such that free trade in consumption goods implies international factor price equalization[25] and such that the production of guns does not exhaust either country's secure land resources,[26] the contending states will continue to face identical marginal benefit and marginal cost functions for guns, thus again yielding the symmetric Nash equilibrium: $G_F^{i*} = \widetilde{G}_A^*$ when $\pi = \widetilde{p}_A^*$. We label this set of distributions the "arms equalization set" (AES). Under free trade, redistributions of secure endowments across the two contending countries within the AES have no effect on their arming.[27]

[23]The proofs of existence and uniqueness of equilibrium are similar to those presented for the case of autarky (see the Supplementary Appendix). To be sure, existence and uniqueness of equilibrium arise under less restrictive conditions than (i) and (ii). However, relaxing these two conditions only complicates the analysis without altering the key insights of our comparison of conflict under autarky and free trade.

[24]As before, the point $(0, 0)$ is not an equilibrium. That the level of arming by both countries under free trade, $G_F^{i*} = G_F^*$ for $i = 1, 2$, equals that which emerges under autarky assuming identical adversaries, $\widetilde{G}_A^*$, is due to our (benchmark) assumption that $\pi = \widetilde{p}_A^*$. Below we show how changes in π influence the level of arming by both countries.

[25]The conditions for international factor price equalization include, as in the standard HOS trade model, constant returns to scale in production, the absence of factor intensity reversals, identical technologies across countries, diversification in production, absence of market failures or distortions, no trade barriers, and the existence of at least as many productive factors in the tradable goods sectors as there are traded goods (Samuelson, 1949). For distributions of secure resources where these conditions are not satisfied, at least one country will specialize in the production of one consumption good. Such specialization precludes the possibility of international factor price equalization and renders a country's marginal cost of producing guns independent of the world price, but increasing in its arms.

[26]Even where one country's secure land constraint binds in the production of guns, free trade in consumption goods can nonetheless lead to factor price equalization. Once the disputed land is divided, both countries diversify in their production of the two goods. However, due to the binding resource constraint, the marginal benefit of producing more arms is not equalized across countries. Accordingly, free trade does not lead to arms equalization in this case, and more generally factor price equalization alone need not imply arms equalization.

[27]Note that these findings would remain intact assuming an asymmetric version of the contest success function in (1) as axiomatized by Clark and Riis (1998: $\phi^i(G^1, G^2) = \varphi f(G^1)/[\varphi f(G^1) + (1-\varphi)f(G^2)]$,

We now turn to explore the implications of changes in international prices for arming. To proceed, note that, for each country i, there exists a range of prices $(\underline{\pi}^i, \overline{\pi}^i)$ that ensures diversification in the production of consumption goods for country i. Then, for world prices $\pi \in (\underline{\pi}, \overline{\pi})$, where $\underline{\pi} = \max\{\underline{\pi}^1, \underline{\pi}^2\}$ and $\overline{\pi} = \min\{\overline{\pi}^1, \overline{\pi}^2\}$, production is diversified in both countries. By contrast, for world prices $\pi \notin (\underline{\underline{\pi}}, \overline{\overline{\pi}})$, where $\underline{\underline{\pi}} \equiv \min\{\underline{\pi}^1, \underline{\pi}^2\} \leq \underline{\pi}$ and $\overline{\overline{\pi}} \equiv \max\{\overline{\pi}^1, \overline{\pi}^2\} \geq \overline{\pi}$, both countries specialize in production.[28] Using these definitions, we have the following:

Lemma 2 (*Arming and International Prices*) *Assume that secure land endowments are not exhausted in the production of guns. Then,*

(a) *equilibrium guns are increasing in the world price of the land-intensive good for world prices $\pi \in (\underline{\pi}, \overline{\pi})$ (i.e., $dG_F^{i*}/d\pi \gtrless 0$ $\forall \pi \in (\underline{\pi}, \overline{\pi})$ if $k_2^i \gtrless k_1^i$, for $i = 1, 2$); and,*

(b) *equilibrium guns are invariant to price changes for all world prices $\pi \notin (\underline{\underline{\pi}}, \overline{\overline{\pi}})$ (i.e., $dG_F^{i*}/d\pi = 0$, $\forall \pi \notin (\underline{\underline{\pi}}, \overline{\overline{\pi}})$).*

We prove this lemma informally. To fix ideas, suppose good 2 is land-intensive ($k_2^i > k_1^i$) and that the conditions specified in part (a) are satisfied. Thus, factor prices and arms are equalized across countries. Now, let the world price of good 2 (π) rise. While this price change has no effect on either country's marginal benefit of arming (MB^i), by the Stolper-Samuelson theorem (Lemma A.1(a)) the wage/rental ratio in each contending country (ω^i) will fall; and, as previously discussed, this factor price adjustment will cause each country i's marginal cost of arming (MC_F^i) to fall (Lemma A.3(c)), thereby inducing both to arm more heavily. (Analogous reasoning establishes that, when good 1 is land-intensive ($k_1^i > k_2^i$), an increase in $\pi \in (\underline{\pi}, \overline{\pi})$ will induce less arming.) Turning to part (b), note that, from equations (2)–(5), price changes outside the relevant range for country i, $\pi \notin (\underline{\pi}^i, \overline{\pi}^i)$, force all factor prices to rise proportionately in that country and thus have no effect on the marginal cost of arming. Part (b), then, follows from the condition imposed implying both countries specialize in production. But, for our purposes, the important point is that changes in the world price have important implications for security policies when production is diversified. Furthermore, the qualitative nature of that linkage hinges on the technology—namely, the ranking of factor intensities, k_j^i $j = 1, 2$.

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where $\varphi \in (0, 1)$. Assuming instead a non-additive but symmetric form for the conflict technology would not change our findings either. Even if the conflict technology were neither additive nor symmetric, the results would be qualitatively unchanged. That is to say, given factor price equalization that implies equalization of the marginal cost of arming across the two contending countries, there would be a tendency for arms equalization as well.

[28] Of course, for identical adversaries, $\underline{\underline{\pi}} = \underline{\pi}$ and $\overline{\overline{\pi}} = \overline{\pi}$. But, for adversaries having different secure factor endowments, there also exist price ranges for which one country's gun choices depend on prices while the other country's do not—namely, $(\underline{\underline{\pi}}, \underline{\pi})$ and $(\overline{\pi}, \overline{\overline{\pi}})$. However, these complications are not relevant for our arguments.

However, for simplicity and clarity, henceforth we maintain the assumption that good 2 is land-intensive—i.e., $k_2^i > k_1^i$. Unless otherwise noted, the results that follow remain intact regardless of the ranking of factor intensities.

4 Trade Patterns and Trade Volumes

Naturally, the direction of a country's trade flows depends on the world price. To explore this issue, define π_A^i as the level of the world price that eliminates country i's trade: $M_F^{i*}(\pi) \lesseqgtr 0$ if $\pi \gtreqless \pi_A^i$.[29] In what follows, we contribute two ideas to the literature. First, we illustrate that international contestation of resources alters a country's trade-eliminating price relative to the case of no conflict and can thus affect its observed comparative advantage. Second, we show that such conflict can drive a wedge between a country's autarkic price and trade-eliminating price under free trade such that a simple comparison of international and autarkic prices need not provide an accurate prediction of trade patterns in contending countries.

To explore the effects of conflict on a contending country's comparative advantage, consider the case of identical adversaries. Let $p_A(G)$ denote the representative country's autarkic price as it depends on the common quantity of guns, G. When evaluated at the conflictual equilibrium level of arming under autarky, $G_A^{i*} = \widetilde{G}_A^*$, $p_A(G) = \widetilde{p}_A^*$ holds. Furthermore, when $\pi = \widetilde{p}_A^*$, the equilibrium under free trade corresponds precisely with the equilibrium under autarky. That is to say, the world price that eliminates a contending country's trade flows equals the equilibrium price that obtains under autarky (i.e., $\pi_A^i = \widetilde{p}_A^*$). Therefore, under conflict and trade, both adversaries will export the land-intensive good $j = 2$ if $\pi > \widetilde{p}_A^*$ and will import it if $\pi < \widetilde{p}_A^*$. In the hypothetical case of no arming, from equation (1), each adversary would receive $\frac{1}{2}$ of the contested resource K_0, and the autarkic price would coincide with the price $p_A^n = p_A(0)$.[30] Thus, in the absence of conflict, the representative country would export the land-intensive good if $\pi > p_A^n$ and would import it if $\pi < p_A^n$.

The effect of conflict on the contending countries' pattern of trade works through its effect on the countries' residual factor endowments. This effect depends specifically on the relative ranking of k^i and $k_G^i(\omega)$, as it determines whether an exogenous equi-proportionate

[29] As in the neoclassical version of this setting with no insecurity, the negative influence of the world price π on each country's excess demand $M_F^{i*}(\pi)$ is effectively a condition for stability of general equilibrium under free trade. However, when there is insecurity, one has to account for the indirect influence of a change in π on k_X^i through its effect on arming by both countries. As such, the condition for stability becomes slightly more complicated. Interestingly, this condition is identical to a sufficient condition for uniqueness of the Nash equilibrium (see equation (B.4) and the surrounding discussion in the Supplementary Appendix). Intuitively, this makes sense, since prices under autarky change to clear domestic markets and policymakers take that effect into account when choosing their guns.

[30] The superscript "n" stands for "no conflict" or "Nirvana".

increase in guns produced by both countries (where initially $G^i = G^j$) increases or decreases k_X^i (by Lemma A.2(d)), and thus determines the qualitative nature of the dependence of $p_A(G)$ on the common quantity of guns G. In particular, from Lemma A.4(c) with the maintained assumption that good 2 is land-intensive, the additional assumption that guns production is sufficiently labor-intensive—i.e., $k^i > k_G^i(\omega)$—implies that $p_A(G)$ depends negatively on G. In this case, $p_A^n = p_A(0) > p_A(\widetilde{G}_A^*) = \widetilde{p}_A^*$. Now suppose $\pi \in (\widetilde{p}_A^*, p_A^n)$. Obviously, since $\pi < p_A^n$, under no conflict both contestants would import good 2. But, since $\pi > \widetilde{p}_A^*$ at the same time, under conflict each country exports good 2. Alternatively, if $k^i < k_G^i(\omega)$, then $p_A(G)$ would be increasing in G and as a result $p_A^n < \widetilde{p}_A^*$. Thus, if $\pi \in (p_A^n, \widetilde{p}_A^*)$, then each country would export the land-intensive good $j = 2$ in the hypothetical case of no conflict, and import the good under conflict. The following proposition summarizes these results.

Proposition 1 (*Trade Patterns with Identical Adversaries*) *Conflict over land reverses the contending countries' comparative advantage for $\pi \in (\widetilde{p}_A^*, p_A^n)$ if $k^i > k_G^i(\omega)$, or for $\pi \in (p_A^n, \widetilde{p}_A^*)$ if $k^i < k_G^i(\omega)$, as compared with what would be observed in the hypothetical case of no conflict.*

Although the nature of the distortion of conflict on trade patterns also depends on the relative ranking of factor intensities in industries $j = 1, 2$, the result that such a distortion can emerge does not.[31]

Our analysis suggests further that viewing international conflict over productive resources as a type of trade cost that necessarily reduces the size of a contending country's trade flows might be inappropriate. If, for example, $\pi = p_A^n$, then in the absence of conflict the contestants would not engage in trade. But, as we have just seen, in the presence of conflict and under free trade, the contending countries will be net exporters (importers) of the land-intensive good if $k^i > k_G^i(\omega)$ ($k^i < k_G^i(\omega)$); consequently, depending on the world price, international conflict may very well expand, rather than shrink, trade volumes.[32]

Moving on to the second main point of this section, neoclassical trade theory tells us that a country's trade pattern can be identified by comparing the world price to its autarkic price. However, in the world of insecure property and international conflict, a country's trade-eliminating price under free trade need not coincide with its autarkic price, particularly when there are differences in secure factor ownership across the two contending

[31] This result is reminiscent of Brander and Taylor's (1997b) finding that, over time, the depletion of a common-pool resource in a country with ill-defined property rights can reverse its comparative advantage. In our setting, residual factor endowments (and thus comparative advantage) can change because the dissipation of resources in conflict is trade-regime dependent.

[32] The relationship between the volume of trade and conflict has been addressed empirically in the political science literature (e.g., Barbieri, 2002), which appears to find support for the idea that conflict might stimulate trade.

countries. As such, an unqualified application of the standard logic normally used in trade theory can lead to erroneous inferences about trade patterns.

Now, it should be clear from our earlier discussion in Section 3.2 that, when the (uneven) distribution of secure resources lies in the *AES* subset of $\mathcal{S}^0$, the trade-eliminating price coincides with the autarkic price: $\pi_A^i = \widetilde{p}_A^*$. In this case, the standard logic does apply: if $\pi \gtreqless \widetilde{p}_A^*$, then $M_F^{i*}(\pi) \lesseqgtr 0$. Matters differ, however, when the distribution falls in the *AES* subset of $\mathcal{S}^i$, $i = 1$ or 2. For in this case, the introduction of free trade, through its impact on factor prices and thus arming incentives, alters the countries' residual factor endowments and therefore their excess demand functions.

To see the logic here, consider a distribution of secure resources in the *AES* subset of $\mathcal{S}^1$, where country 1 is relatively more aggressive under autarky, and suppose $\pi = p_A^{2*}$. Thus, the autarkic conflictual equilibrium can be identified with point A' in Fig. 2. Since $\pi = p_A^{2*}$, the introduction of free trade gives country 2 no incentive to adjust its guns choice as long as $G^2 = G_A^{2*}$. However, since $\pi = p_A^{2*} < p_A^{1*}$, a shift to free trade induces country 1 to be less aggressive, and (given the negative influence of G^1 on $B_F^2(G^1)$ for $G^2 < G^1$) this in turn induces country 2 be more aggressive until the free trade equilibrium is reached (at point A in Fig. 2).[33] With these adjustments in guns, country 2's residual land/labor ratio, k_X^2, necessary increases (Lemma A.7(a)). Then, appealing to Lemma A.1(b), with the assumption that $k_2^i > k_1^i$, shows that country 2's excess supply of good 2, when evaluated at the autarkic price, p_A^{2*}, is strictly positive. As such, the world price that eliminates trade, π_A^2, must be below the autarkic price, p_A^{2*}.[34] Similar reasoning establishes that $\pi_A^1 > p_A^{1*}$ under most circumstances.[35]

The following proposition summarizes these results and takes them a step further:

Proposition 2 (Trade Patterns with Nonidentical Adversaries) *For uneven secure factor endowments in the AES subset of* $\mathcal{S}^0$, *we have* $\pi_A^i = \widetilde{p}_A^*$, *as in the neoclassical trade theory. But, for distributions in the AES subset of* $\mathcal{S}^i$, *we have* $\pi_A^i > p_A^{i*}$ *under most circumstances, and* $\pi_A^j < p_A^{j*}$ *always, such that comparing the international price to a contending country's autarkic price need not give an accurate prediction of that country's trade pattern.*

The key point to take from Proposition 2 is only that there can be some divergence between a country's autarkic price and its trade-eliminating price under free trade so as to alter the

[33]Note that, in previous references to Fig. 2 (Section 3.2), $B_F^2(G^1)$ was drawn for $\pi = \widetilde{p}_A^*$. Here, by contrast, this best response function is taken as that which holds for $\pi = p_A^{2*}$. One can also draw in Fig. 2, the best response function for country 1 assuming $\pi = p_A^{1*}$. It will similarly pass through point A'. But, since $\pi = p_A^{2*} < p_A^{1*}$, $B_F^1(G^2)$ will rotate counterclockwise with a move to free trade until it hits the 45° line at point A.

[34]Assuming instead that $k_1^i > k_2^i$ implies a reversal in the ranking of π_A^2 and p_A^{2*}.

[35]As shown in the proof to Lemma A.7(b), a sufficient (but not necessary) condition is that two times country 1's labor share in total net income ($s_L = w^1 L_X^1 / R^1$) be greater than the country's cost share of labor in the production of guns ($\theta_{LG}^1 = r^1 \psi_w^1 / \psi^1$). This condition ensures that the (positive) adjustment in guns by both countries induced by a move to free trade where $\pi = p_A^{1*}$ decreases k_X^1.

informational content of the difference between the world price and the autarkic price. Returning to our example, for $\pi \in (p_A^{2*}, \pi_A^2)$, the less aggressive country ($i = 2$) in the autarkic equilibrium imports good 2 under free trade, whereas neoclassical theory predicts that it exports the good. Clearly, if arming were independent of the trade regime considered, such a divergence would not emerge. But, given an uneven distribution of secure endowments across the two countries, the trade regime can influence arming that, in turn, influences each country's excess demand function to drive a wedge between these two prices. In short, the direction of trade flows is not determined simply by how the international price (π) differs from the country's autarkic price, p_A^{i*}, but rather how it differs from π_A^i.

However, the effect of conflict to cause a country's trade-eliminating price under free trade to diverge from its autarkic price derives not only from differences in the endowments of secure factors of production across countries, but also from the strategic considerations that come into play when both countries engage in free trade. To see this, consider again a distribution of secure resources in the AES subset of $\mathcal{S}^1$ and suppose now that, while country 2 engages in free trade, country 1 does not. Country 1's choice of guns and equilibrium autarkic price will change relative to the case where neither country engages in free trade, only if country 2's choice of guns changes. Now suppose that $\pi = p_A^{2*}$, in which case from (9) country 2's gun choice will not change. Indeed, for this price, the equilibrium outcome is identical to that which emerges when neither country engages in free trade. Furthermore, although country 2 will adjust its guns when the world price differs from p_A^{2*}, its pattern of trade will be just as predicted by neoclassical trade theory: $M_F^2(\pi) \gtreqless 0$, when $\pi \lesseqgtr p_A^{2*}$. Thus, the effect of conflict on the informational content of the difference between the world price and a country's autarkic price also depends partly on how the adversary responds with it arming given a move to free trade.

5 Welfare Comparison of Trade Regimes

In this section, we illustrate that the costs of arming can overwhelm a country's traditional gains from trade. The analysis not only clarifies how international conflict generates a trade-regime dependent distortion (Bhagwati, 1971), but also sheds light on the conditions under which free trade intensifies this distortion.

To start, consider the welfare decomposition in (8) where $p^i = \pi$. With the envelope theorem, it implies

$$\frac{dV_F^{i*}}{d\pi} = \mu(\pi)\left[-M_F^{i*} + r(\pi)K_0\phi_{G^j}^i \frac{dG_F^{j*}(\pi)}{d\pi}\right], \quad \text{for } i = 1, 2 \text{ and } j \neq i. \tag{11}$$

The first term inside the brackets, weighted by the marginal utility of income ($\mu(\pi)$), captures the direct welfare effect of a price change, and its sign is determined by the country's trade pattern. It is positive for net exporters of the non-numeraire good ($M_F^{i*} < 0$), and negative for net importers ($M_F^{i*} > 0$). The second term (again weighted by $\mu(\pi)$) captures the strategic welfare effect of a price change. By the properties of the CSF (1) and Lemma 2(a) under the maintained assumption that $k_2^i > k_1^i$, this indirect effect is negative when arms are equalized internationally. But, by Lemma 2(b), the effect vanishes when the world price rises above $\overline{\overline{\pi}}$ or falls below $\underline{\underline{\pi}}$. The next lemma takes these ideas one step further.

Lemma 3 (*International Prices and Welfare*) *A contending country i's welfare is*

- (a) *decreasing in the world price of the good that employs intensively the contested resource, in the neighborhood of $\pi = \pi_A^i$ (i.e., $dV_F^{i*}(\pi_A^i)/d\pi < 0$);*
- (b) *increasing in the world price of the good that employs intensively the contested resource for $\pi > \overline{\overline{\pi}}$; and,*
- (c) *minimized at a world price, $\pi = \pi_{\min}^i > (\pi_A^i)$.*

Part (a) points out that an improvement in a contending country's terms of trade is necessarily "immiserizing" if the country exports the land-intensive product and provided that π does not differ considerably from its trade eliminating price, π_A^i. Specifically, in the neighborhood of π_A^i, the direct, positive effect of a terms of trade improvement on country's i income (the first term in (11)) is swamped by the loss in income due to its opponent's increased aggressiveness (the second term in (11)). However, part (b) indicates that when the world price becomes sufficiently large to induce specialization in production by both countries ($\pi > \overline{\overline{\pi}}$ such that $\partial G_F^i/\partial\pi = 0$), this latter effect vanishes, leaving only the direct (positive) welfare effect of the terms of trade improvement. Finally, part (c) indicates that a country's welfare is minimized at some price, $\pi_{\min}^i > \pi_A^i$, where the beneficial, direct effect of a terms of trade improvement equals the adverse strategic effect that results from increased arms production by the rival country.[36]

Thus, there exists a range of world prices, $\pi \in (\pi_A^i, \pi_{\min}^i)$, for which international conflict over resources can expose contending countries with an apparent comparative advantage in the contested-resource-intensive products to the "resource curse" problem. Others have attributed the problem to domestic rent-seeking (e.g., Torvik, 2002; Mehlum et al. 2006), redistributive politics (e.g., Robinson et al., 2005), and domestic conflict (Garfinkel et al., 2008). But, our finding suggests that the absence and/or ineffectiveness of international institutions aimed at managing international conflict has a bearing on this problem as well.

Although country size is inconsequential in the determination of the quantity of guns that adversaries produce under free trade for secure factor endowments in the *AES*, country

[36]The proof of this lemma, presented in the Appendix, verifies that analogous results obtain when $k_1^i > k_2^i$. Thus, the point that increases in the relative price of the good produced intensively with land ($j = 1$ when $k_1^i > k_2^i$ or $j = 2$ when $k_2^i > k_1^i$) holds regardless of the ranking of factor intensities.

size does matter for the determination of the range of international prices for which the resource curse problem arises.[37] Consider, for example, an uneven distribution of secure resources in the *AES* subset of $\mathcal{S}^0$, where country 1 is larger than country 2 and where initially $\pi = \pi_A^i = \widetilde{p}_A^*$. From (11), the strategic welfare effect of an increase in the world price, π, above $\widetilde{p}_A^*$ (the second term in (11)) will not differ across adversaries. However, the marginal benefit from such a price increase (the first term in (11)) will differ. Since, by construction, country 1 is larger than country 2, country 1 will be relatively more involved in trade than its rival (i.e., $-M_F^{1*} > -M_F^{2*} > 0$) for $\pi > \widetilde{p}_A^*$, which implies $\pi_{\min}^1 < \pi_{\min}^2$. Accordingly, for uneven factor distributions in $\mathcal{S}^0$, the relatively smaller adversary ($i = 2$ in our example) will experience the resource curse problem over a larger range of international prices.

To proceed with our comparison of welfare across the two trade regimes, we consider two possibilities: (i) when adversaries are identical, which unveils the gist of the argument and the circumstances under which autarky dominates trade; and, (ii) when adversaries have different endowment profiles, which sheds some light on the conditions under which national preferences over trade regimes can diverge.

Proposition 3 (*Relative Appeal of Free Trade with Identical Adversaries*) *If free trade in consumption goods induces adversaries with identical endowment profiles to*

(a) ***export*** *the land-intensive good, then the adversaries will arm more heavily under free trade than under autarky, and free trade will be Pareto dominated by autarky for a certain range of international prices close enough to the autarkic price;*

(b) ***import*** *the land-intensive good, there will be less arming under free trade than under autarky, and free trade will Pareto dominate autarky.*

To understand the logic here, let $G^*(\pi)$ denote the equilibrium quantity of guns under free trade, as implicitly defined by (9), when the two adversaries are identical. Of course, this function when evaluated at $\pi = \widetilde{p}_A^* \in (\underline{\pi}, \overline{\pi})$ also gives us the equilibrium level of arming under autarky. By Lemma 2(a) with $k_2^i > k_1^i$, $G^*(\pi)$ is increasing in π for $\pi \in (\underline{\pi}, \overline{\pi})$. Thus, for $\pi > \widetilde{p}_A^*$, where the adversaries export the land-intensive good ($j = 2$), a discrete move from autarky to free trade intensifies the conflict between them, inducing more arming. By contrast, for $\pi < \widetilde{p}_A^*$, where the adversaries import the land-intensive good, a move to free trade from autarky weakens the conflict, inducing less arming.[38]

[37] Sufficiently large differences in the endowments of secure resources can move us outside of the *AES*.

[38] Note the difference between this result and that of Hirshleifer (1991), who explored the implications of conflict over output, identifying market integration with the degree of complementarity between the inputs in useful production. Specifically, he observed that the diversion of resources into arms falls with the degree of market integration, although the size of this effect is small. Our approach suggests that, when conflict is over resources and market integration takes the form of a move from more protected (autarky) to less protected (free trade) trade regimes, the severity of conflict (measured by the level of arming) can rise or fall depending on, among other things, technology, the degree of resource insecurity and international prices.

Turning to payoffs, first note that, for given guns, a country's welfare increases with the deviation of the world price from its autarky level $\widetilde{p}_A^*$ (Lemma A.3(d)). This effect reflects the familiar gains from trade. Observe further that, regardless of the trade regime considered, equi-proportionate arms increases do not alter the division of the contested land but raise the resource costs of insecurity. As such, the representative country's welfare is decreasing in guns, G. Since $G^*(\pi)$ is increasing in π for $\pi \in (\underline{\pi}, \bar{\pi})$, these security costs are strictly increasing in π over that range. Now, when $\pi = \widetilde{p}_A^*$, $\widetilde{G}_A^* = \widetilde{G}_F^*$; thus, the security costs are strictly positive, but the same across trade regimes. Furthermore, since $\widetilde{p}_A^* = \pi_A^*$, the gains from trade are equal to zero at this world price. As such, welfare is the same across the two trade regimes: $V_F^*(\widetilde{p}_A^*) = \widetilde{V}_A^*$.

For world prices $\pi < \widetilde{p}_A^*$, where countries import the land-intensive product, the familiar gains from trade reinforces the effect of trade on equilibrium security costs, such that free trade is Pareto superior to autarky: $V_F^*(\pi) > \widetilde{V}_A^*$. By the continuity of $V_F^*(\pi)$ in π and Lemma 3, there exists a world price π' that satisfies $V_F^{i*}(\pi) = \widetilde{V}_A^*$. Given $k_2^i > k_1^i$, we have $\pi' > \pi_{\min} > \widetilde{p}_A^*$. Then, for international prices $\pi > \widetilde{p}_A^*$, each contestant exports the contested-resource-intensive product; furthermore, for international prices within the range $(\widetilde{p}_A^*, \pi')$, autarky will Pareto dominate free trade.

What about adversaries with different endowment profiles? Arbitrary factor distributions in $\mathcal{S}^i$ can complicate the welfare ranking of trade regimes for at least two reasons. First, because adversaries begin to specialize in production at different international prices, it becomes necessary to investigate arming incentives outside the *AES* for one country initially and eventually for both. Second, the endogeneity of trade patterns together with the fact that $V_F^{i*} \neq V_A^{i*}$ at $\pi = p_A^{i*}$ for arbitrary distributions in $\mathcal{S}^i$ make it difficult to identify workable benchmarks for comparison purposes. Still, as the next proposition illustrates, there exist two noteworthy asymmetries that yield tractable comparisons.

Proposition 4 (*Relative Appeal of Free Trade with Nonidentical Adversaries*)

(a) *For any uneven factor distribution in the AES subset of $\mathcal{S}^0$, there exists a range of international prices that render autarky Pareto superior to free trade.*

(b) *If $\pi = \widetilde{p}_A^*$, there exist subsets $\mathcal{D}^i \subseteq \mathcal{S}^i$ of factor distributions adjacent to the AES subset of $\mathcal{S}^0$ such that one country prefers autarky over free trade while its adversary does not.*

Part (a) extends Proposition 3 to uneven distributions in the *AES* subset of $\mathcal{S}^0$. Part (b) clarifies how countries' preferences over trade regimes might differ when more general factor endowment asymmetries are considered. As shown in the proof (presented in the Appendix), the divergence in preferences arises from the presence of a strategic effect when redistributing resources under autarky (Lemma A.6), and the absence of such a strategic effect under free trade.

6 Concluding Remarks

In the decades leading up to World War I, the proportion of world trade to world GDP reached unprecedented magnitudes (O'Rourke and Williamson, 2000). Yet, international conflict ensued with much ferocity and despite expectations to the contrary.[39] Similarly, the expansion of trade in the post World War II era has been spectacular. Still, while interstate conflict might have subsided over this latter period, insecurity and contention continue to flare up in many parts of the world. Whereas not all disputes can be considered to have material causes, there is no doubt that contestation of water resources, land, oil, diamonds and other resources by different countries has at least some role to play in many international disputes and drives the military expenditures and security policies of the countries that are involved in such disputes.

The extent to which disputed resources or the goods they produce are tradable can have implications for the security policies that countries pursue and the costs those countries realize as a result. At the same time, the presence of such conflict can have implications for patterns of trade and welfare. We have explored these implications, using the neoclassical trade model, augmented by a disputed resource that is costly to contest, and considering two polar regimes: autarky and free trade. The key difference between these regimes for small countries is that prices are endogenously determined under autarky but not under free trade. As a consequence, arming incentives are trade-regime dependent.

Depending on the level of world prices, free trade in consumption goods might intensify arming incentives to generate additional security costs that swamp the traditional gains from trade and thus render autarky more desirable for one or both rival states. Furthermore, in the presence of international conflict, a country's apparent comparative advantage can differ from its natural comparative advantage (absent insecurity) and comparisons of autarkic prices to world prices could be inappropriate predictors of trade patterns. This finding suggests that empirical work aiming to relate trade volumes to fundamentals would be incomplete if it did not include insecurity and contestation of resources.

With a focus on small countries, the analysis ignores the possible terms of trade effects in security policy that would be especially relevant for those countries having monopoly or monopsony power in world trade. Accordingly, it would be worthwhile to extend the analysis in that direction. One important difference from the current setting is that free trade in consumption goods need not equalize arming incentives even when factor prices are equalized and guns production is unconstrained. Another difference is that trade and security policies could be used simultaneously, the former to balance the terms of trade

[39] The prediction before World War I, for example, that war was impossible or unthinkable—because Britain and Germany had become so economically interdependent that conflict was viewed as "commercial suicide" (Angell, 1933)—was flatly contradicted by experience.

effects with the volume of trade effects, and the latter for security considerations. Such an extension of the basic model would be a rich and promising environment within which to explore the implications of policy interactions, including the economics of free trade agreements and their possible interactive effects with national security.

However, our analysis even with small countries can say something about trade policies. In particular, whereas our focus has been on based on the implicit assumption that the two countries both commit to either autarky or free trade, the analysis could easily be extended to consider the non-cooperative choice of trade regimes by the two countries. When each country chooses its security and trade regimes simultaneously, it is possible that both countries choose free trade even when the outcome is Pareto dominated by that which arises when both choose autarky.

The model presented here could be fruitfully extended in a number of other ways. For example, the analysis could assign an active role to the rest of the world (ROW). Furthermore, the analysis could be generalized to situations where trade does not necessarily result in the equalization of factor prices, and thus give a meaningful role to the possibility of trade in arms. Last but not least, policy objectives could be specified to consider the role of politics.

Ultimately, solving the problem of insecurity entails the design and development of commitment devices that can reduce, and possibly eliminate, the need to arm. Such commitment devices, however, are not easy to come by and, judging from particular historical instances, they take a long time to develop. Europe is a good example of this. After the experience of the two world wars, the original six members of the European Community slowly began to develop mechanisms of economic integration that were, in large part, institutions of conflict management. This twin process of economic integration and conflict resolution through bureaucratic and political struggle, instead of conflict in the battlefield, is ongoing and far from complete, even after a century of tribulations. Trade openness and, more generally, economic interdependence might help to ameliorate conflict, but it would be naive to think that promoting such interdependence could achieve this by itself.

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A Appendix

We first present several useful properties of the CSF in (1). For convenience, define $f_i \equiv f(G^i)$, where from our previous assumptions $f_i' > 0$ and $f_i'' \leq 0$. Now, differentiate $\phi^i(G_i, G_j)$ with respect to its arguments, G^i and G^j for $i = 1, 2$ $(j \neq i)$, to obtain

$$\phi^i_{G^i} = \frac{f_i' f_j}{(f_1 + f_2)^2} > 0 \tag{A.1}$$

$$\phi^i_{G^j} = -\frac{f_j' f_i}{(f_1 + f_2)^2} < 0 \tag{A.2}$$

$$\phi^i_{G^i G^i} = \frac{f_j}{(f_1 + f_2)^3}[f_i''(f_1 + f_2) - 2(f_i')^2] < 0 \tag{A.3}$$

$$\phi^i_{G^i G^j} = \frac{(f_i - f_j) f_i' f_j'}{(f_1 + f_2)^3} \gtreqless 0 \text{ if } G^i \gtreqless G^j \tag{A.4}$$

Lemma A.1 *If production in a country is diversified (i.e., $X^i_j > 0$, for both countries $i = 1, 2$ and both goods $j = 1, 2$), then*

(a) $\frac{\partial \omega^i / \partial p^i}{\omega^i / p^i} \lesseqgtr 0$ *if* $k^i_2 \gtreqless k^i_1$;

(b) $\frac{\partial RS^i / \partial k^i_X}{RS^i / k^i_X} \gtreqless 0$ *if* $k^i_2 \gtreqless k^i_1$;

(c) $\frac{\partial RS^i / \partial p^i}{RS^i / p^i} > 0$.

Proof: Following Jones (1965), we denote the shares of factor $h = K, L$ in the cost of producing good $j = 1, 2$ by θ^i_{hj}: $\theta^i_{Kj} = r^i a^i_{Kj} / c^i_j$ and $\theta^i_{Lj} = w^i a^i_{Lj} / c^i_j$. Similarly, $\theta^i_{KG} \equiv r^i \psi^i_r / \psi^i$ and $\theta^i_{LG} \equiv w^i \psi^i_w / \psi^i$ indicate the corresponding cost shares in guns. Now denote the amount of land and labor employed in industry $j = 1, 2$ respectively by K^i_j and L^i_j. Then, these quantities as a fraction of resources remaining once land and labor for producing guns have been set aside are respectively indicated by $\lambda^i_{Kj} \equiv K^i_j / K^i_X$ and $\lambda^i_{Lj} \equiv L^i_j / L^i_X$. Finally, let a percentage change be indicated by a hat ($\hat{}$) over the associated variable (e.g., $\widehat{x} = \frac{dx}{x}$).

Part (a): Noting that $c_1 = 1$ and $c_2 = p$, differentiation of (2) and (3) totally gives

$$\begin{aligned}
\frac{\partial c_1^i}{\partial w^i} dw^i + \frac{\partial c_1^i}{\partial r^i} dr^i = 0 \quad &\Longrightarrow \quad a_{L1}^i \frac{w^i}{c_1^i}\frac{dw^i}{w^i} + a_{K1}^i \frac{r^i}{c_1^i}\frac{dr^i}{r^i} = 0 \\
\frac{\partial c_2^i}{\partial w^i} dw^i + \frac{\partial c_2^i}{\partial r^i} dr^i = dp^i \quad &\Longrightarrow \quad a_{L2}^i \frac{w^i}{c_2^i}\frac{dw^i}{w^i} + a_{K2}^i \frac{r^i}{c_2^i}\frac{dr^i}{r^i} = \frac{dp^i}{p^i}.
\end{aligned}$$

With the definitions given above, we can write this system of equations as

$$\begin{pmatrix} \theta_{L1}^i & \theta_{K1}^i \\ \theta_{L2}^i & \theta_{K2}^i \end{pmatrix} \begin{pmatrix} \widehat{w}^i \\ \widehat{r}^i \end{pmatrix} = \begin{pmatrix} 0 \\ \widehat{p}^i \end{pmatrix}. \tag{A.5}$$

Now, since $\sum_{h=K,L} \theta_{hj} = 1$ for $j = 1, 2$ by definition, the determinant of the coefficient matrix above, denoted by $\left|\theta^i\right|$, can be written as

$$\left|\theta^i\right| \equiv \theta_{K2}^i - \theta_{K1}^i = \theta_{L1}^i - \theta_{L2}^i = \frac{\omega^i \left(k_2^i - k_1^i\right)}{\left(\omega^i + k_1^i\right)\left(\omega^i + k_2^i\right)} \gtreqless 0 \text{ if } k_2^i \gtreqless k_1^i.$$

Then, solving (A.5) for the p^i-induced changes in factor prices yields

$$\frac{p^i w_p^i}{w^i} = -\frac{\theta_{K1}^i}{|\theta^i|} \quad \text{and} \quad \frac{p^i r_p^i}{r^i} = \frac{\theta_{L1}^i}{|\theta^i|} \tag{A.6}$$

From (A.6), then, we have $p^i \omega_p^i / \omega^i = p^i w_p^i / w^i - p^i r_p^i / r^i = -1/|\theta^i| \lesseqgtr 0$ when $k_2^i \gtreqless k_1^i$, which completes the proof to part (a).

Parts (b) and (c): Note first that we can combine (4) and (5) to obtain $\lambda_{L1}^i k_1^i + \lambda_{L2}^i k_2^i = k_X^i$. Then, following the strategy above in part (a), we differentiate (4) and (5) totally and solve the resulting system of equations to obtain

$$\begin{aligned}
\widehat{X}_1^i &= \frac{1}{|\lambda^i|}\left(-\lambda_{L2}^i \widehat{K}_X^i + \lambda_{K2}^i \widehat{L}_X^i\right) - \frac{1}{|\lambda^i|\,|\theta^i|}\left(\lambda_{L2}^i \delta_K^i + \lambda_{K2}^i \delta_L^i\right)\widehat{p}^i \\
\widehat{X}_2^i &= \frac{1}{|\lambda^i|}\left(+\lambda_{L1}^i \widehat{K}_X^i - \lambda_{K1}^i \widehat{L}_X^i\right) + \frac{1}{|\lambda^i|\,|\theta^i|}\left(\lambda_{L1}^i \delta_K^i + \lambda_{K1}^i \delta_L^i\right)\widehat{p}^i,
\end{aligned}$$

where $\delta_K^i \equiv \lambda_{K1}^i \theta_{L1}^i \sigma_1^i + \lambda_{K2}^i \theta_{L2}^i \sigma_2^i > 0$ and $\delta_L^i \equiv \lambda_{L1}^i \theta_{K1}^i \sigma_1^i + \lambda_{L2}^i \theta_{K2}^i \sigma_2^i > 0$, with $\sigma_j^i = c_j^i \frac{\partial^2 c_j^i}{\partial w^i \partial r^i} / \frac{\partial c_j^i}{\partial w^i}\frac{\partial c_j^i}{\partial r^i}$ being the (absolute value of the) elasticity of substitution between land and labor in industry j; $\left|\lambda^i\right|$ denotes the determinant of the coefficient matrix obtained from differentiating (4) and (5); recalling $\sum_{j=1,2} \lambda^i_{hj} = 1$ for $h = K, L$, we have

$$\left|\lambda^i\right| \equiv \lambda^i_{K2} - \lambda^i_{L2} = \lambda^i_{L1} - \lambda^i_{K1} = \frac{\left(k^i_2 - k^i_X\right)\left(k^i_X - k^i_1\right)}{k^i_X\left(k^i_2 - k^i_1\right)} \gtrless 0 \text{ if } k^i_2 \gtrless k^i_1.$$

Now, observe that $\widehat{k}^i_X = \widehat{K}^i_X - \widehat{L}^i_X$, which implies

$$\widehat{RS}^i = \widehat{X}^i_2 - \widehat{X}^i_1 = \frac{1}{|\lambda^i|}\widehat{k}^i_X + \frac{\delta^i_K + \delta^i_L}{|\lambda^i|\,|\theta^i|}\widehat{p}^i. \tag{A.7}$$

Inspection of (A.7) confirms parts (b) and (c). ‖

In Lemma A.1 the residual land/labor ratio, k^i_X, is treated as exogenous. However, from (6) it is clear that k^i_X depends on price, guns, and factor supplies. The next lemma clarifies this dependence.

Lemma A.2 *Let* $k^i \equiv \frac{K^i + \phi^i K_0}{L^i}$ *and suppose the production of consumption goods is diversified. Then* $k^i_X = k^i_X(p^i, G^i, G^j; K_0, K^i, L^i)$ *and*

(a) $\frac{\partial k^i_X}{\partial p^i} \gtrless 0$ *if* $k^i_2 \gtrless k^i_1$*;*

(b) $\frac{\partial k^i_X}{\partial G^i} > 0$, $\forall G^i$ *that satisfy* $K^i_0 \phi^i_{G^i} - \psi^i/r^i + \varepsilon > 0$, *for some* $\varepsilon > 0$*;*

(c) $\frac{\partial k^i_X}{\partial G^j} < 0$, $\forall i \neq j$*;*

(d) $\frac{\partial k^i_X}{\partial G^i} + \frac{\partial k^i_X}{\partial G^j} \gtrless 0$ *if* $k^i \gtrless k^i_G$ *whenever* $G^i = G^j$, $\forall i \neq j$*;*

(e) $\frac{\partial k^i_X}{\partial L^i} < 0$ *and* $\frac{\partial k^i_X}{\partial K_0} > 0$, $\frac{\partial k^i_X}{\partial K^i} > 0$.

Proof: Denote country i's land and labor shares in total net income R^i by with $s^i_K \equiv r^i K^i_X / R^i$ and $s^i_L \equiv w^i L^i_X / R^i$, and let $\sigma^i_G = \psi^i \psi^i_{wr} / \psi^i_w \psi^i_r$ be the (absolute value of the) elasticity of substitution between land and labor in the guns sector. Total differentiation of (6), using the linear homogeneity of ψ^i, yields

$$\begin{aligned}\widehat{k}^i_X \;=\; & \left(\frac{\psi^i \theta^i_{LG} \theta^i_{KG} \sigma^i_G G^i}{|\theta^i|\, R^i s^i_K s^i_L}\right)\widehat{p}^i + \frac{\psi^i}{R^i s^i_K s^i_L}\left[\frac{r^i s^i_L}{\psi^i}\left(K_0 \phi^i_{G^i} - \frac{\psi^i}{r^i}\right) + \theta^i_{LG}\right] dG^i \\ & + \frac{r^i K_0 \phi^i_{G^j}}{R^i s^i_K} dG^j + \frac{\phi^i dK_0}{K^i_X} + \frac{dK^i}{K^i_X} - \frac{dL^i}{L^i_X}.\end{aligned} \tag{A.8}$$

Parts (a)–(c) & (e): The proofs follow from (A.8).

Part (d): Suppose $G^i = G^j$ so that $\phi^i_{G^i} = -\phi^i_{G^j}$. Now use $dG^i = dG^j$ in (A.8) to obtain

$$\frac{\partial k^i_X / \partial G^i}{k^i_X} = \frac{\psi^i\left(\theta^i_{LG} - s^i_L\right)}{R^i s^i_K s^i_L}.$$

Using the definitions of θ^i_{LG}, s^i_L, and R^i, along with those for K^i_X and L^i_X in (4) and (5), tedious algebra verifies the following transformation of this relationship:

$$\frac{\partial k^i_X/\partial G^i}{k^i_X} = \frac{\psi^i\left(\theta^i_{LG} - s^i_L\right)}{R^i s^i_K s^i_L} = \frac{\psi^i_w\left(k^i_X - k^i_G\right)}{K^i_X} = \frac{\psi^i_w L^i\left(k^i - k^i_G\right)}{K^i_X L^i_X}. \tag{A.9}$$

Inspection of this expression confirms part (d). ||

Lemma A.3 *Each country i's indirect utility function, V^i, has the following properties:*

(a) $V^i_{G^iG^i} < 0$*;*

(b) $V^i_{G^iG^j} \gtreqless 0$ *if* $G^i \gtreqless G^j$, $j \neq i$*;*

(c) $V^i_{G^ip^i} \gtreqless 0$ *if* $k^i_2 \gtreqless k^i_1$ *when evaluated at the value of* G^i *that solves* $V^i_{G^i} = 0$*;*

(d) V^i *is strictly quasi-convex in* p^i*, and is minimized at the value of* p^i *that solves* $M^i = 0$.

Proof:

Part (a): Differentiate (9) with respect to G^i and use (A.3) to obtain

$$V^i_{G^iG^i} = \mu^i r^i K_0 \phi^i_{G^iG^i} < 0. \tag{A.10}$$

Part (b): Differentiation of (8) with respect to G^j and use of (A.4) gives

$$V^i_{G^iG^j} = \mu^i r^i K_0 \phi^i_{G^iG^j} \gtreqless 0 \quad \text{if} \quad G^i \gtreqless G^j. \tag{A.11}$$

Part (c): Recall that $\psi^i/r^i = \psi(\omega^i, 1)$, implying that $\partial(\psi^i/r^i)/\partial p^i = \psi^i_w \omega^i_p$. Then, differentiating (8) with respect to price and evaluating the resulting expression at the optimum gives (by Lemma A.1(a))

$$\begin{aligned} V^i_{G^ip^i} &= -\mu^i r^i \frac{\partial(\psi^i/r^i)}{\partial p^i} = -\mu^i\left(\frac{\psi^i}{p^i}\right)\left(\frac{w^i\psi^i_w}{\psi^i}\right)\left(\frac{p^i\omega^i_p}{\omega^i}\right) \\ &= \mu^i\left(\frac{\psi^i}{p^i}\right)\frac{\theta^i_{LG}}{|\theta^i|} \gtreqless 0 \quad \text{if} \quad k^i_2 \gtreqless k^i_1. \end{aligned} \tag{A.12}$$

Part (d): This is a standard property of indirect (trade) utility functions, highlighting the important idea that, for given guns, a country's welfare is higher, the greater is the deviation of product prices from their autarkic levels (Dixit and Norman, 1980). ||

Lemma A.4 *Under autarky, country i's market clearing price of the non-numeraire good,* p^i_A*, and its residual land/labor ratio,* k^i_X*, are related as follows:*

$$\frac{\partial p^i_A}{\partial k^i_X} \lesseqgtr 0 \quad \text{if } k^i_2 \gtreqless k^i_1.$$

We thus have for each country $i = 1, 2$

(a) $\frac{\partial p_A^i}{\partial G^i} \lesseqgtr 0$ *if* $k_2^i \gtrless k_1^i$, $\forall G^i$ *that satisfy* $V_{G^i}^i + \varepsilon > 0$, *for some* $\varepsilon > 0$;

(b) $\frac{\partial p_A^i}{\partial G^j} \gtrless 0$ *if* $k_2^i \gtrless k_1^i$ $(j \neq i)$;

(c) $\left(k_2^i - k_1^i\right)\left(\frac{\partial p_A^i}{\partial G^i} + \frac{\partial p_A^i}{\partial G^j}\right) \lesseqgtr 0$ *for* $G^i = G^j$ $(j \neq i)$ *if* $k_G^i \lesseqgtr k^i \equiv \frac{K^i + \phi^i K_0}{L^i}$;

(d) $\frac{\partial p_A^i}{\partial L^i} \gtrless 0$, $\frac{\partial p_A^i}{\partial K_0} \lesseqgtr 0$, *and* $\frac{\partial p_A^i}{\partial K^i} \lesseqgtr 0$ *if* $k_2^i \gtrless k_1^i$.

Proof: Let $\sigma_D^i > 0$ be the elasticity of substitution in consumption. Focusing on percentage changes, note that $\widehat{RD}^i = -\sigma_D^i \widehat{p}^i$ and that the expression for $\widehat{RS}^i$ is given in (A.7). Totally differentiating (10) and rearranging terms gives

$$\widehat{RD}^i = \widehat{RS}^i \quad \Longrightarrow \quad \left(\sigma_D^i + \frac{\delta_K^i + \delta_L^i}{|\lambda^i|\,|\theta^i|}\right)\widehat{p}^i + \frac{1}{|\lambda^i|}\widehat{k}_X^i = 0.$$

The above relation and the definition of $\left|\lambda^i\right|$ reveal that p^i is decreasing (increasing) in k_X^i if $k_2^i > k_1^i$ ($k_2^i < k_1^i$). Combining (A.8), which gives an expression for $\hat{k}_X^i$, with the above expression gives

$$\widehat{p}_A^i = -\frac{1}{\Delta^i\,|\lambda^i|}\left[\frac{\partial k_X^i/\partial G^i}{k_X^i}dG^i + \frac{\partial k_X^i/\partial G^j}{k_X^i}dG^j + \frac{\phi^i dK_0}{K_X^i} + \frac{dK^i}{K_X^i} - \frac{dL^i}{L_X^i}\right] \tag{A.13}$$

where $\Delta^i \equiv \sigma_D^i + \frac{\delta_K^i + \delta_L^i}{|\lambda^i||\theta^i|} + \frac{\psi^i \theta_{LG}^i \theta_{KG}^i \sigma_G^i}{|\lambda^i||\theta^i| R^i s_K^i s_L^i} G^i > 0$. The proofs to parts (a)–(d) now follow from (A.13) and Lemma A.2. $\|$

Lemma A.5 *Under autarky, equilibrium product prices and security policies satisfy the following inequalities:*

$$(k_2^i - k_1^i)(p_A^{1*} - p_A^{2*}) \gtrless 0 \Longleftrightarrow G_A^{1*} \gtrless G_A^{2*}.$$

Proof: In (9) we can use (A.1) and (A.2) and the fact that $MC^i = \psi^i/r^i = \psi(\omega(p^i), 1)$ to obtain

$$\frac{MB^1}{MB^2} = \frac{f'(G^1)/f(G^1)}{f'(G^2)/f(G^2)} = \frac{\psi(\omega(p^1), 1)}{\psi(\omega(p^2), 1)} = \frac{MC^1}{MC^2}$$

where, for simplicity, we have omitted stars. Now if $k_2^i > k_1^i$, then by Lemma A.1(a), $\psi(\omega(p^i), 1)$ is decreasing in p^i; therefore, if $p^1 \gtrless p^2$, $MC^1/MC^2 \lesseqgtr 1$, which by the above equation requires $MB^1/MB^2 \lesseqgtr 1$; in turn, the concavity of $f(\cdot)$ implies $G^1 \gtrless G^2$. Alternatively, if $k_2^i < k_1^i$, $\psi_\omega^i \omega_p^i > 0$ (Lemma A.1(a)), which implies $MC^1/MC^2 \gtrless 1$ if $p^1 \gtrless p^2$. But then $MB^1/MB^2 \gtreqless 1$ which requires $G^1 \lesseqgtr G^2$. ‖

Proof of Lemma 1. Since the logic behind part (a) was outlined in the main text, here we prove part (b). A redistribution of a secure resource from country j to country $i(\neq j)$ expands (contracts) the "recipient" ("donor") country's resource endowment. Differentiating country i's FOC condition in (9) appropriately gives

$$\frac{\partial^2 V_A^i}{(\partial G^i)^2} dB_A^i + \frac{\partial^2 V_A^i}{\partial G^i \partial H^i} dH^i = 0 \implies \frac{dB_A^i}{dH^i} = -\frac{\partial^2 V_A^i/\partial G^i \partial H^i}{\partial^2 V_A^i/(\partial G^i)^2}$$

for $H = L, K$. Since $\partial^2 V_A^i/(\partial G^i)^2 < 0$, we have $\text{sign}[dB_A^i/dH^i] = \text{sign}[\partial^2 V_A^i/\partial G^i \partial H^i]$. Differentiation of (9) yields

$$\frac{\partial^2 V_A^i}{\partial G^i \partial H^i} = \left[V_{G^i p^i}^i \right]_{p^i = p_A^i} \frac{dp_A^i}{dH^i}. \tag{A.14}$$

From Lemma A.3(c) and Lemma A.4(d), it follows that, regardless of the ranking of k_1^i and k_2^i, $dB_A^i/dL^i > 0$ whereas $dB_A^i/dK^i < 0$. The signs of these derivatives imply that a transfer of labor from one country to another increases (decreases) arms production by the recipient (donor) for any given arms choice by the rival; yet, a transfer of land decreases (increases) arms production by the recipient (donor). Thus, if we start with an arbitrary secure endowment configuration in $\mathcal{S}^0$ and transfer a small amount of labor from country j to country i or land from country i to country j, so that we end up somewhere in $\mathcal{S}^i$, the properties of best-response functions and in particular the uniqueness of equilibrium (shown in the Supplementary Appendix) ensure that at the new equilibrium we will necessarily have $G_A^{i*} > G_A^{j*}$. We must also have, by Lemma A.5 $p_A^{i*} \gtreqless p_A^{j*}$ if $k_2^i \gtreqless k_1^i$, and by Lemma A.4 $k_X^{i*} < k_X^{j*}$. Notice that this proof does not require we obtain complete comparative statics results on equilibrium arming and applies for all secure resource allocations in $\mathcal{S}^i$. ‖

Lemma A.6 (*Transfers of Secure Resources*) *For initial factor distributions in $\mathcal{S}^0$, a small transfer of a secure resource from country j to its adversary i ($\neq j$) has the following implications for arming and welfare:*

(a) $\frac{dG_A^{i*}}{dL^i} = -\frac{dG_A^{j*}}{dL^i} > 0$ *but* $\frac{dG_A^{i*}}{dK^i} = -\frac{dG_A^{j*}}{dK^i} < 0$;

(b) $\frac{dV_A^{i*}}{dL^i} = -\frac{dV_A^{j*}}{dL^i} > \mu(\widetilde{p}_A^*)w(\widetilde{p}_A^*)$ *but* $\frac{dV_A^{i*}}{dK^i} = -\frac{dV_A^{j*}}{dK^i} < \mu(\widetilde{p}_A^*)r(\widetilde{p}_A^*)$.

Proof: To identify the effects of endowment changes on equilibrium security policies we differentiate the FOCs in (9) and solve the resulting system of equations to obtain

$$\begin{pmatrix} dG_A^{1*} \\ dG_A^{2*} \end{pmatrix} = \frac{1}{|J|} \begin{pmatrix} \frac{\partial^2 V_A^2}{(\partial G^2)^2} & -\frac{\partial^2 V_A^1}{\partial G^1 \partial G^2} \\ -\frac{\partial^2 V_A^2}{\partial G^2 \partial G^1} & \frac{\partial^2 V_A^1}{(\partial G^1)^2} \end{pmatrix} \begin{pmatrix} -\frac{\partial^2 V_A^1}{\partial G^1 \partial H^1} dH^1 \\ -\frac{\partial^2 V_A^2}{\partial G^2 \partial H^2} dH^2 \end{pmatrix} \tag{A.15}$$

for $H^i = L^i, K^i$ where $|J| = \frac{\partial^2 V_A^1}{(\partial G^1)^2}\frac{\partial^2 V_A^2}{(\partial G^2)^2} - \frac{\partial^2 V_A^1}{\partial G^1 \partial G^2}\frac{\partial^2 V_A^2}{\partial G^2 \partial G^1} > 0$ denotes the determinant of the Jacobian of the net marginal payoffs in (9) and all expressions are evaluated at the equilibrium.[40] Start with an endowment distribution in $\mathcal{S}^0$, so that $G_A^{i*} = \widetilde{G}_A^*$ and $p_A^{i*} = \widetilde{p}_A^*$ for $i = 1, 2$. At such a distribution and prices, we have the following:[41]

(i) $\frac{\partial^2 V_A^i}{\partial G^i \partial G^j} = \left[V^i_{G^i G^j}\right]_{p^i = p_A^i} + \overset{(\pm)}{\left[V^i_{G^i p^i}\right]_{p^i = p_A^i}} \overset{(\pm)}{\left(\frac{\partial p_A^i}{\partial G^j}\right)}$ is identical for $i = 1, 2$ ($j \neq i$) and strictly positive, since by Lemma A.3(b) $V^1_{G^1 G^2} = V^2_{G^2 G^1} = 0$;

(ii) $\frac{\partial^2 V_A^i}{(\partial G^i)^2} = \overset{(-)}{\left[V^i_{G^i G^i}\right]_{p^i = p_A^i}} + \overset{(\pm)}{\left[V^i_{G^i p^i}\right]_{p^i = p_A^i}} \overset{(\mp)}{\left(\frac{\partial p_A^i}{\partial G^i}\right)}$ is identical for $i = 1, 2$ ($j \neq i$) and strictly negative by Lemmas A.3(a), A.3(c) and A.4(b).

(iii) $\frac{\partial B_A^1}{\partial G^2} = -\frac{\partial^2 V_A^1 / \partial G^1 \partial G^2}{\partial^2 V_A^1 / (\partial G^1)^2} = -(\phi^1_{G^2}/\phi^1_{G^1})\Gamma_A^1 = \Gamma_A^1$ where

$$\Gamma_A^1 = \left[-\frac{\phi^1_{G^1 G^2}\Delta^1}{\phi^1_{G^2}} + \frac{\psi^1 \theta^1_{LG} s^1_L}{|\lambda^1|\,|\theta^1|\,R^1 s^1_K s^1_L}\right] \Big/ \left[-\frac{\phi^1_{G^1 G^1}\Delta^1}{\phi^1_{G^1}} + \frac{\psi^1 (\theta^1_{LG})^2}{|\lambda^1|\,|\theta^1|\,R^1 s^1_K s^1_L}\right],$$

which can be verified using equations (A.8) and (A.13) with (9) to find expressions for $\frac{\partial p_A^1}{\partial G^1}$ and $\frac{\partial p_A^1}{\partial G^2}$, and equations (A.10), (A.11), and (A.12). As shown in the Supplementary Appendix, $\Gamma_A^1 \in (0, 1)$.

(iv) $\frac{\partial^2 V_A^1}{\partial G^1 \partial L^1} = \frac{\partial^2 V_A^2}{\partial G^2 \partial L^2} > 0$ whereas $\frac{\partial^2 V_A^1}{\partial G^1 \partial K^1} = \frac{\partial^2 V_A^2}{\partial G^2 \partial K^2} < 0$ by (A.14) and the related discussion.

Part (a): Consider a small transfer of labor from country 2 to country 1, so that $-dL^2 = dL^1 > 0$. Using the above observations with (A.15) yields

$$\frac{dG_A^{1*}}{dL^1} = -\frac{dG_A^{2*}}{dL^1} = \overset{(+)}{\frac{1}{|J|}} \overset{(+)}{\left[-\frac{\partial^2 V_A^1}{(\partial G^1)^2}\right]} \overset{(+)}{\left(1 - \frac{\partial B_A^1}{\partial G^2}\right)} \overset{(+)}{\left(\frac{\partial^2 V_A^1}{\partial G^1 \partial L^1}\right)} > 0.$$

Similar logic for land redistributions shows that $dG_A^{1*}/dK^1 = -dG_A^{2*}/dK^1 < 0$.

Part (b): Extend the decomposition of welfare effects in (8) to include the effect of changes in the countries' secure holdings of resources. Focusing on labor redistributions, invoking the envelope theorem and using the fact that $M^i = 0$ under autarky yield

$$\frac{dV_A^{i*}}{dL^i} = \mu(p_A^{i*}) \left[w(p_A^{i*}) + r(p_A^{i*}) K_0 \phi^i_{G^j} \frac{dG_A^{j*}}{dL^i}\right] \text{ for } i = 1, 2 \ (j \neq i), \tag{A.16}$$

[40] That $|J| > 0$ is shown in the Supplementary Appendix.

[41] In the expressions below, the top signs in "±" and "∓" apply when $k_2^i > k_1^i$ and the bottom signs apply when $k_2^i < k_1^i$.

where $p_A^{i*} = \widetilde{p}_A^*$ for initial distributions in $\mathcal{S}^0$. Then, part (b) of the lemma is established by invoking symmetry and applying part (a) of the lemma to (A.16) and an analogous expression for the welfare effects of a change in land. ‖

Lemma A.7 *A country's residual land/labor ratio, $k_X^i = k_X^i\left(\pi, B_F^i(G^j), G^j; \cdot\right)$, will change as follows along its free trade best-response function, $B_F^i(G^j)$, for $i \neq j$:*

$$\widehat{k}_X^i = \frac{\psi^i}{R^i s_K^i s_L^i} \frac{f_j' f_i}{f_j f_i'} \left[\left(\frac{\phi^i - \phi^j}{2\phi^i - \frac{f_i'' f_i}{f_i'^2}}\right)\theta_{LG}^i - s_L^i\right] dG^j. \tag{A.17}$$

(a) *If $G^i \leq G^j$, then $dk_X^i/dG^j|_{G^i = B_F^i(G^j)} < 0$;*

(b) *If $G^i > G^j$, then $dk_X^i/dG^j|_{G^i = B_F^i(G^j)} < 0$ almost always. A sufficient (but hardly necessary) condition is $\theta_{LG}^i < 2s_L^i$.*

Proof: Recall that, since free trade pins down product and, thus, factor prices, $dB_F^i/dG^j = -\phi_{G^iG^j}^i/\phi_{G^iG^i}^i$. Furthermore, observe that country i's FOC (9) implies (i) $r^i K_0 \phi_{G^i}^i = \psi^i$ and (ii) $r^i K_0 \phi_{G^j}^i = \psi^i \phi_{G^j}^i/\phi_{G^i}^i$. Then, these applications of (9) to (A.8) with (A.1)–(A.4) and the simplified expression for dB_F^i/dG^j gives (A.17). Part (a) follows immediately from (A.17). Part (b) also follows from (A.17), but noting that the expression is most likely to be positive when $\phi^i = 1$ which implies $\phi^j = 0$ and when $f_i''/f_i'^2 = 0$. ‖

Proof of Lemma 3.

Part (a): The result follows by the definition of π_A^i (which implies $M_F^{i*}(\pi_A^i) = 0$) and the observation that the strategic welfare effect—i.e., the second term in the RHS of (11)—is negative (positive) when $k_2^i > k_1^i$ ($k_1^i > k_2^i$).

Part (b): By Lemma 2(b) when $k_2^i > k_1^i$ ($k_1^i > k_2^i$), there exists a sufficiently high (low) price, $\overline{\overline{\pi}} > \pi_A^i$ ($\underline{\underline{\pi}} < \pi_A^i$)), such that $dG_F^{j*}/d\pi = 0 \ \forall \pi > \overline{\overline{\pi}}$ ($\forall \pi < \underline{\underline{\pi}}$). But then by (11) and the definition of π_A^i, which implies $M_F^{i*}(\pi) \lesseqgtr 0$ for $\pi \gtreqless \pi_A^i$, we must have that, if $k_2^i > k_1^i$ ($k_1^i > k_2^i$), then $dV_F^{i*}/d\pi > 0 \ \forall \pi \geq \overline{\overline{\pi}}$ ($dV_F^{i*}/d\pi < 0 \ \forall \pi \leq \underline{\underline{\pi}}$).

Part (c): By parts (a) and (b), there must exist a price, $\pi_{\min}^i \gtrless \pi_A^i$ when $k_2^i \gtrless k_1^i$, that minimizes country i's welfare while country i exports the land-intensive good. ‖

Proof of Proposition 4. Since we consider secure factor distributions in the *AES* subset of $\mathcal{S}^0$, it will necessarily be the case that $p_A^{i*} = \widetilde{p}_A^*$ for $i = 1, 2$, and thus $\pi_A^i = \widetilde{p}_A^*$. For clarity, suppose that $k_2^i > k_1^i$; however, keep in mind that analogous results obtain when $k_1^i > k_2^i$.

Part (a): By Lemma 3, there thus exists a price $\pi^{i\prime} > \pi^i_{\min}$, for $i = 1, 2$, such that $V_F^{i*}(\pi) < \widetilde{V}_A^{i*}$, $\forall \pi \in (\widetilde{p}_A^*, \pi^{i\prime})$. Now define $\pi'' = \min\{\pi^{1\prime}, \pi^{2\prime}\}$. It follows that $V_F^{i*}(\pi) < \widetilde{V}_A^{i*}$ for $i = 1, 2$, $\forall \pi \in (\widetilde{p}_A^*, \pi'')$.

Part (b): Starting at an arbitrary distribution in the AES subset of $\mathcal{S}^0$, transfer a small quantity of labor from country 2 to country 1 (i.e., $-dL^2 = dL^1 > 0$), so that the final distribution is in the AES subset of $\mathcal{S}^1$. Since in the case of free trade the strategic effect of such transfers vanishes (there is no effect on equilibrium arming), a welfare decomposition similar to that in (A.16) yields $dV_F^{1*}/dL^1 = -dV_F^{2*}/dL^1 = \mu(\pi)w(\pi)$. Thus, Lemma A.6(b) implies that $dV_F^{1*}/dL^1 < dV_A^{1*}/dL^1$ and $dV_F^{2*}/dL^1 > dV_A^{2*}/dL^1$. Since $\pi = \widetilde{\pi}_A^*$ implies $V_F^{i*} = V_A^{i*}$ initially, we will have $V_F^{1*} < V_A^{1*}$ and $V_F^{2*} > V_A^{2*}$ after the transfer. By continuity, there exists additional labor transfers with the just described preferences over trade regimes. ‖

B Supplementary Appendix (not for publication)

Theorem B.1 *An interior Nash equilibrium in pure strategies (security policies) exists under autarky. Furthermore, the equilibrium is unique if the technology for arms is sufficiently labor-intensive or the inputs to arms are not very close complements.*

Proof:

Existence: We establish existence of equilibrium in pure strategies, by showing that every country i's payoff function V_A^i is strictly quasi-concave in its strategy, G^i. To do so, it is sufficient to show either that V_A^i is strictly monotonic in G^i or that V_A^i is first strictly increasing and then strictly decreasing over the agent's strategy space.

Let $F(K_G^i, L_G^i)$ be the production function for guns that is dual to the unit cost function $\psi(w^i, r^i)$ and define $\overline{G}^i \equiv F(K^i, L^i)$ as the level of guns produced with the country's entire secure endowments of land and labor. Country i's strategy space is $[0, \overline{G}^i]$. For any $G^j \in [0, \overline{G}^j]$, if $G^i = \overline{G}^i$, country i ($\neq j$) will not be able to produce either of the consumption goods; therefore, $V_A^i(\overline{G}^i, G^j) < V_A^i(G^i, G^j)$ for any $G^i \in [0, \overline{G}^i)$ which implies that, under autarky, no country will use all of its resources to produce arms. Furthermore, since $\lim_{G^i \to 0} f'(G^i) = \infty$ by assumption, we must have $\partial V_A^i/\partial G^i > 0$ as $G^i \to 0$. By the continuity of V_A^i in G^i, there will exist a best response function for each country i, $B_A^i(G^j) \equiv \min\{G^i \in (0, \overline{G}^i) \mid \partial V_A^i/\partial G^i = 0\}$, with the property that $\partial V_A^i/\partial G^i > 0$ $\forall G^i < B_A^i(G^j)$. Thus, to establish strict quasi-concavity of V_A^i in G^i we need only to prove that $\partial V_A^i/\partial G^i < 0$, $\forall G^i > B_A^i(G^j)$.

Suppose, on the contrary, that $\partial V_A^i/\partial G^i \geq 0$. Since V_A^i must eventually fall to $V_A^i(\overline{G}^i, G^j)$, this supposition implies that V_A^i must attain a local minimum at some $G^i > B^i(G^j)$, which would imply that $\partial^2 V_A^i/(\partial G^i)^2 > 0$. We now establish that this is not possible. Recalling that $p_A^i = p_A^i(G^i, G^j)$ under autarky and that $\omega^i = \omega(p^i)$, we differentiate (9) with respect to G^i and apply (9) to the resulting expression to obtain[42]

$$\frac{\partial^2 V_A^i}{(\partial G^i)^2} = \overset{(-)}{\left[V_{G^iG^i}^i\right]}_{p^i=p_A^i} + \overset{(\pm)}{\left[V_{G^ip^i}^i\right]}_{p^i=p_A^i} \overset{(\mp)}{\left(\frac{\partial p_A^i}{\partial G^i}\right)} < 0. \tag{B.1}$$

By Lemma A.3(a), the first term in the RHS of the above expression is negative regardless of the ranking of factor intensities. Furthermore, by Lemmas A.3(c) and A.4(b), the product of the expressions in the second term will also be negative. It follows that $\partial^2 V_A^i/(\partial G^i)^2 < 0$ at any G^i where $\partial V_A^i/\partial G^i = 0$ regardless of the ranking of factor intensities. This proves $B_A^i(G^j)$ is unique and establishes the existence of a pure-strategy equilibrium.

Uniqueness: Having already established that guns production is bounded (i.e., $B_A^i(G^j) \in (0, \overline{G}^i)$ for $i = 1, 2$ ($j \neq i$), we can now establish uniqueness of equilibrium by showing that, at any equilibrium point, the determinant of the Jacobian of the net marginal payoffs in (9) is positive—i.e., $|J| = \frac{\partial^2 V_A^1}{(\partial G^1)^2}\frac{\partial^2 V_A^2}{(\partial G^2)^2} - \frac{\partial^2 V_A^1}{\partial G^1 \partial G^2}\frac{\partial^2 V_A^2}{\partial G^2 \partial G^1} > 0$ (Kolstad and Mathiesen, 1987).

Consider an equilibrium point where $G_A^{1*} = B_A^1(G_A^{2*})$ and $G_A^{2*} = B_A^1(G_A^{1*})$. From the expression for $|J|$, it can be seen that, if the product of the slopes of the two countries' best response functions, $\left(\partial B_A^1/\partial G^2\right)\left(\partial B_A^2/\partial G^1\right)$, is less than 1 at (G_A^{1*}, G_A^{2*}), then $|J| > 0$, implying that this equilibrium is unique. The slope of country i's best-response function can be written as

$$\frac{\partial B_A^i}{\partial G^j} = -\frac{\partial^2 V_A^i/\partial G^i \partial G^j}{\partial^2 V_A^i/(\partial G^i)^2} = -\frac{\left[V_{G^iG^j}^i\right]_{p^i=p_A^i} + \overset{(\pm)}{\left[V_{G^ip^i}^i\right]}_{p^i=p_A^i} \overset{(\pm)}{\left(\frac{\partial p_A^i}{\partial G^j}\right)}}{\left[V_{G^iG^i}^i\right]_{p^i=p_A^i} + \left[V_{G^ip^i}^i\right]_{p^i=p_A^i} \left(\frac{\partial p_A^i}{\partial G^i}\right)}. \tag{B.2}$$

Since $\partial^2 V_A^i/(\partial G^i)^2 < 0$ as shown in (B.1), the sign of $\partial B_A^i/\partial G^j$ is determined by the sign of $\partial^2 V_A^i/\partial G^i \partial G^j$ shown in the numerator of (B.2). Now, by Lemmas A.3(c) and A.4(b), the second term of the numerator of the RHS of this expression is always positive. By Lemma A.3(b), the first term in the numerator is positive if $B_A^i(G^j) > G^j$ (also see equation (A.11)), in which case G^i is a strategic complement for G^j. However, if $B_A^i(G^j) < G^j$, then the first term is negative. Thus, when $B_A^i(G^j)$ is sufficiently smaller than G^j, G^i can become a strategic substitute for G^j. Furthermore, since $\phi^1_{G^1G^2} = -\phi^2_{G^2G^1}$ (see (A.4)),

[42] In this expression and below, the top signs in "±" and "∓" apply when $k_2^i > k_1^i$ and the bottom signs apply when $k_2^i < k_1^i$.

it follows from (A.11) that sign $\left[V^1_{G^1G^2}\right]_{p^1=p^1_A} = -\text{sign}\left[V^2_{G^2G^1}\right]_{p^2=p^2_A}$. Therefore, we have two possibilities to consider. Either (i) $\partial B^i_A/\partial G^j > 0$ and $\partial B^j_A/\partial G^i \leq 0$ for $i = 1, 2$ ($j \neq i$); or, (ii) $\partial B^i_A/\partial G^j > 0$ for $i = 1, 2$ ($j \neq i$). It is easy to check that, in case (i), $\left(\partial B^1_A/\partial G^2\right)\left(\partial B^2_A/\partial G^1\right) < 1$ and therefore $|J| > 0$. Turning to case (ii), we now establish the existence of (sufficient) conditions that ensure $\left(\partial B^1_A/\partial G^2\right)\left(\partial B^2_A/\partial G^1\right) < 1$ and thus $|J| > 0$.[43]

To proceed, use (A.8) and (A.13), applying (9), to obtain

$$\frac{\partial p^i_A}{\partial G^i} = -\frac{p^i_A \psi^i \theta^i_{LG}}{\Delta^i\, |\lambda^i|\, R^i s^i_K s^i_L} \quad \text{and} \quad \frac{\partial p^i_A}{\partial G^j} = \frac{p^i_A \psi^i}{\Delta^i\, |\lambda^i|\, R^i s^i_K s^i_L}\left(-\frac{\phi^i_{G^j}}{\phi^i_{G^i}}\right) s^i_L.$$

The above expressions together with (A.10), (A.11), and (A.12) can be substituted into (B.2) to obtain $\partial B^i_A/\partial G^j = -(\phi^i_{G^j}/\phi^i_{G^i})\Gamma^i_A$, where

$$\Gamma^i_A = \left[-\frac{\phi^i_{G^iG^j}\Delta^i}{\phi^i_{G^j}} + \frac{\psi^i\theta^i_{LG}s^i_L}{|\lambda^i|\,|\theta^i|\,R^i s^i_K s^i_L}\right] \Bigg/ \left[-\frac{\phi^i_{G^iG^i}\Delta^i}{\phi^i_{G^i}} + \frac{\psi^i(\theta^i_{LG})^2}{|\lambda^i|\,|\theta^i|\,R^i s^i_K s^i_L}\right]. \tag{B.3}$$

From equations (A.1) and (A.2), we have $(\phi^1_{G^2}/\phi^1_{G^1})(\phi^2_{G^1}/\phi^2_{G^2}) = 1$, implying $\left(\partial B^1_A/\partial G^2\right) \cdot \left(\partial B^2_A/\partial G^1\right) = \Gamma^1_A\Gamma^2_A$; therefore, if $\Gamma^i_A \in (0, 1)$ for $i = 1, 2$, then $|J| > 0$. In case (ii), both the numerator and the denominator of Γ^i_A are positive, so $\Gamma^i_A > 0$. Now define $\eta^i \equiv G^i[-\phi^i_{G^iG^i}/\phi^i_{G^i} + \phi^i_{G^iG^j}/\phi^i_{G^j}]$. From (A.1)–(A.4), $\eta^i = G^i[f'_i/f_i - f''_i/f'_i] > 0$. Then, subtracting the numerator of Γ^i_A from its denominator while using the definition of Δ^i shown below (A.13) gives the following:

$$\frac{\eta^i}{G^i}\left(\sigma^i_D + \frac{\delta^i_K + \delta^i_L}{|\lambda^i|\,|\theta^i|}\right) + \frac{\psi^i\theta^i_{LG}}{|\lambda^i|\,|\theta^i|\,R^i s^i_K s^i_L}\left(\theta^i_{LG} + \theta^i_{KG}\sigma^i_G\eta^i - s^i_L\right). \tag{B.4}$$

Clearly, a sufficient condition for $\Gamma^i_A < 1$ is that (B.4) is positive, which is almost always true. In particular, since the first term and the coefficient in front of the second term are unambiguously positive, a sufficient (but hardly necessary) condition for $\Gamma^i_A < 1$ is $\theta^i_{LG} + \theta^i_{KG}\sigma^i_G\eta^i - s^i_L \geq 0$ or equivalently $\theta^i_{LG}(1 - s^i_L) + \theta^i_{KG}(\sigma^i_G\eta^i - s^i_L) \geq 0$. This condition is satisfied under a wide range of circumstances,[44] including: (i) $\sigma^i_G\eta^i \geq s^i_L$, which requires arms inputs not to be close complements; and (ii) $\theta^i_{LG} \geq s^i_L$ (or, by (A.9), $k^i > k^i_G$), which requires the guns sector to be sufficiently labor-intensive, regardless of the degree of substitutability between inputs in arms. Either condition, along with the boundary

[43] Note that, in case (ii), $|J| > 0$ is also the condition for local stability of equilibrium.

[44] If, for example, the production function for guns is Cobb-Douglas and the CSF assumes the Tullock form (i.e., $f(G^i) = (G^i)^\gamma$, $\forall\gamma \in (0, 1]$), then $\sigma^i_G = 1$ and $\eta^i = 1$, thus implying that the sufficient condition simplifies to $1 - s^i_L \geq 0$, which is always satisfied.

conditions established above, ensures uniqueness of equilibrium. ||

Theorem B.2 *If the world price, technology, the distribution of secure endowments and the degree of land insecurity are such that (i) free trade in consumption goods leads to international factor price equalization, and (ii) the production of arms does not exhaust either country's secure land endowment, an interior pure strategy, Nash equilibrium in security policies will exist, and will be unique and symmetric.*

Proof: The proofs for existence and uniqueness of equilibrium, which build on parts (a) and (b) of Lemma A.3, are similar to those in the case of autarky (see above), and are thus omitted here. See the main text for a discussion of the logic underlying the symmetry results. ||