NATIONAL SECURITY OR PRIVATE PROFITS? TRADE IN DUAL-USE COMMODITIES

by

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ABSTRACT

This paper develops a simple model of imperfectly competitive trade in commodities with both military and civilian applications, a.k.a. dual-use commodities. We consider the role of export barriers and foreign economic aid in encouraging peaceful rather than military application of dual-use commodities in importing countries. When governments conjecture the profit-shifting effect of their policies, Nash equilibrium policies combine export barriers and foreign aid.

JEL Codes: F1, F2, O3, L2
Key Words: dual-use commodities, national security, defense economics

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Whereas the paramount defense quandary of the Cold War concerned relations between superpowers, the dilemma for the twenty-first century promised to be the proliferation of weapons within developing and newly industrialized countries (South). Demand for high technology armaments has increased considerably in the South corresponding with their rapidly growing incomes. Asia's share of world military expenditures, for example, doubled in the past decade (Ball, 1994:79). By and large, the South remains a net defense and technology importer. Fueling this trend, "Northern" firms from the United States, Europe, and the former Soviet Union engage in keen competition for these Southern markets as defense spending declines at home. Policy makers in the North walk a delicate line as they attempt to promote their domestic high-tech industry through imports to the South while maintaining national and global security interests.

Compounding this policy problem is trade in high technology products that are neither clearly military nor clearly civilian as they are difficult to classify for policy purposes. The recent controversies, for example, over the Russian sales of cryogenic engines to India and the nuclear technology to Iran concern not only the exchange of sensitive commodities but also their *potential* end use. If used for peaceful purposes, these commodities pose no threat to Northern security. Rather trade contributes to both the capital and technology base of developing countries and to the profitability of R&D sectors in exporting nations. Yet a danger remains as this trade may erode Northern (and global) security if used in a destructive manner. Hence, the North has a stake in both the sale and the final application of dual-use commodities (DUCs).

DUCs tend to be products of high technology industries, including microelectronics, computers and super-computers, telecommunications, advanced materials, complex system engineering, communication satellites, high precision machine tools, optics, and biotechnology (Markusen and Yudken, 1992:121). Though statistical data on DUCs are limited, available evidence suggests that DUCs comprise a significant share of production and trade in these industries. Numerically controlled machine tools, including those subject to nonproliferation export barriers, for example, accounted for about 36 percent of total exports

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of machine tools, or about 12 percent of machine tool industry revenues in 1992 (OTA, 1994).

A conventional wisdom emerges from the standard defense literature -- where arms trade is in goods with no peaceful applications. Traditionally, arms trade models represent a political economy framework, where arms exports affect the social welfare via political (national security) and economic channels. Srinivasan's (1985) work, for example, considers Nash equilibrium expenditures on defense by governments that maximize a social welfare function that is additively separable in security and consumer utility. If on national security grounds a government wants to restrict exports of a commodity then an export tax is the first best policy, superior to the production tax or consumption subsidy.

The arms trade embargo is a focus of the paper by Levine, Sen and Smith (1994). In a dynamic general equilibrium model, forward-looking public firms compete imperfectly in supplying arms to a single buyer. Suppliers choose the arms output under Cournot-Nash conjectures to maximize intertemporal welfare that is a function of national security and export profits. The degree of cooperation and pre-commitment among suppliers, and expectations of suppliers and the buyer regarding future deliveries are crucial determinants of the supply of arms in the short and long runs. Within a similar framework, Levine and Smith (1995) model a Pareto optimal arms control regime whereby an arms cartel supplies importers who engage in an arms race among themselves. A possible war among buyers reduces the suppliers' welfare. An arms cartel tends to stabilize the arms race by increasing the price of arms. To compensate importers for the purchasing power loss resulting from the cartel pricing of arms, suppliers pay a sales tax and redistribute tax revenues to the buyers. Suppliers recognize importers' legitimate needs for security defined as the level of arms that minimizes the expected costs of an international war to suppliers. Perceptions about the legitimate security needs and the specific functional form of the security function determine the sustainability and optimality of the proposed regime relative to the unregulated competitive equilibrium.

Since a primary concern in the arms trade is the national security, the traditional arms literature tends to ignore the government's incentive to change the global distribution of arms

profits by promoting domestic arms exporters through the strategic trade policy. In the case of DUCs, however, the commercial significance of exports is high, and strategic trade considerations become important.[1] A sound policy-making with respect to such DUC-producing industries as aerospace, semiconductors and computers, for example, requires merging national security and strategic trade considerations. A standard result of the new trade theory is that when firms are imperfectly competitive government policies can shift profits from foreign to domestic firms and hence increase domestic welfare.[2] In addition to the negative externality on the national security associated with DUCs, social welfare analysis should include profit-shifting effects. Indeed this approach has been followed in the emerging literature on trade and environment.[3] Barrett's (1994) model, for example, incorporates a local pollution externality in the traditional strategic trade framework. Imperfectly competitive export industries generate a local pollution externality that lowers welfare and offsets profit gains from trade. In the Nash equilibrium, non-cooperating governments have a profit-shifting motive to use environmental standards as a strategic trade instrument.[4]

We model the DUC trade as a nexus of these arms, environmental and strategic trade policy models. Yet, a few distinguishing features remain. The effects of the DUC trade on North's welfare depend on the South's decision about the end use of a DUC. Hence, the North has an incentive to use demand-side policies to encourage the civilian application of DUCs in the South.[5] Such demand-side policies complement restraints on the supply of DUCs to the world market.[6] One contribution of this paper is that we explicitly model both supply-side and demand-side measures.[7]

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[1] Benson (1994) presents a similar argument.

[2] See a collection of papers on the strategic trade policy in Grossman (1994).

[3] For a survey of the literature on trade and environment see Dean (1992).

[4] However, as with most strategic trade policies, the optimal environmental policy is not robust to the assumption on the mode of competition (Cournot and Bertrand).

[5] For example, the Center for Strategic and International Studies (1994) argues in favor of "...(a) increased multilateral efforts to coordinate among all significant suppliers a set of barriers uniform in both scope and implementation (a supply-side effort); and (b) new initiatives to ease the demand for weapons of mass destruction (a demand-side effort)."

[6] The dual-use trade is regulated by national export codes and a number of international agreements, including the Non-Proliferation Treaty, the Biological and Toxin Weapons Convention, the Missile Technology Control Regime, and the Australia Group.

[7] For the descriptive analysis of export barriers on dual-use trade see NAS *et al* (1987), Bertsch (1988), Stemmed (1990), Markusen and Yudken (1992), McDaniel (1993), Crawford (1993), Branscomb (1993), OTA

This paper provides a simple analysis of social policy when trade is in DUCs. We develop a partial equilibrium model where a monopolist in each of two Northern countries (East and West) competes to export a DUC to a third country (South). In contrast to the arms trade literature that assumes the public provision of arms, we realistically treat DUCs as privately produced goods. The DUC has harmful implications for the security of the North, if and only if it is used in a non-civilian manner by the South. Thus, the Northern governments have conflicting incentives to promote exports for positive economic profits and yet to offset security damages.

We begin the equilibrium analysis by considering optimal policies under the traditional arms trade assumption whereby the Northern governments conjecture fixed foreign production. In contrast to the arms trade literature, the North's security damage depends on the South's decision about the end-use of the DUC. Thus, the marginal rate of substitution between DUC's civilian and military applications becomes an important determinant of North's optimal policies, along with incomes, technologies, security preferences, etc., that the arms trade literature emphasizes.

Next, we consider the implications of adding strategic trade policy assumptions to the DUC trade model. We assume that the Northern governments recognize their influence over domestic and foreign production of the DUC. We find that such strategically optimal policies include a combination of the foreign aid and export barriers. Governments choose to offer the foreign aid under Cournot and Bertrand competition. This result is surprising as the strategic trade policy is typically not robust to assumptions on the mode of competition. The foreign aid is a consistently optimal strategic trade policy, because it raises both the equilibrium quantity and price by expanding demand.

The rest of the paper is organized as follows. A non-technical description of the model is given in section one. The subsequent sub-sections discuss the dual-use decision of the DUC-importing country, profit maximization problem of the DUC-exporting firms and policy choice by the DUC-exporting governments. We analyze optimal decisions under the Bertrand-Nash assumptions in section two. The last section concludes the paper.

(1994) and CSIS (1994).

I. THE MODEL

We begin with a simple three-country model. A developed North, consisting of two countries East (E) and West (W), specializes in the production a DUC (y) for export to a developing South (S).[8] Assume that the DUC is a homogenous good. Production technologies in the East and West are identical, and resources are fully employed. As DUC industries are typically characterized by imperfect competition, we assume, without a loss of generality, that the DUC is produced by monopolists in the East and West.

The South uses the imported DUC as an input into production of two goods: a civilian good (x) and a military good (z).[9] A rocket engine, for example, can be used as an input in either a weapons delivery system or a commercial satellite launcher. While the civilian use of the DUC by the South does not affect the Northern well-being, the military application reduces the Northern security and thus Northern welfare. Thus, the international externality associated with the DUC depends on its end-use rather than its purchase.

Governments in the North maximize social welfare as a weighted average of economic benefits and security damages from the DUC trade using two policy tools: an administrative export barrier and a civilian production subsidy in the form of Southern foreign aid.[10] Export barrier represents private administrative and compliance costs imposed on Northern firms for DUC export licenses. From an economic perspective, these costs are a pure waste of resources, and do not generate an off-setting government revenue. Northern foreign economic aid to the South is conditional on the civilian use of imported DUC by the South.

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[8] Under consideration are strategic interactions among the DUC-exporting countries and DUC-importing country. Limiting the number of importers to a single country precludes analysis of factors that affect South's security.

[9] The model does not deal with the possibility of the DUC resale by the South. In practice, DUCs are sometimes acquired by an intermediary country for resale to another country that cannot purchase the DUC directly due to national security restrictions of the exporting country.

[10] The welfare trade-off between national security (foreign policy, in general) and commercial costs and benefits of policies represents a major policy challenge (see OTA, 1994; Crawford, 1993). The exogenous weights in the social welfare function may be interpreted as the lobbying power of different interest groups. The Northern governments attempt to balance national security and economic interests within their countries. Firms in the North are lobbying for economic gains whereas national interest and international security groups are lobbying for non-proliferation and the restraint of an economic interest. Alternatively, the weights may represent preferences of a dictator.

We model this aid as a per-unit civilian production subsidy paid by Northern governments to Southern firms.[11]

The Northern (Eastern and Western) governments and Northern (Eastern and Western) firms behave strategically and non-cooperatively. The Northern governments commit to production subsidies (s^E and s^W) and export barriers (t^E and t^W). After the policy announcement, the Northern firms engage in Cournot competition with each other in the style of Brander and Spencer (1985) and choose the optimal quantity of the DUC to produce. The Southern government, consumers and firms react predictably to Northern governments and firms' actions and do not attempt to influence their decisions. The South solves a general equilibrium problem of producing civilian and military commodities (x and z) with the imported DUC as an input. All agents have complete and perfect information and act to maximize their individual interests. The rules of the game are common knowledge.

The choice of the equilibrium analysis in this paper highlights the distinguishing features of the DUC trade. Strategic trade policy and profit-shifting considerations are important in the imperfectly competitive DUC trade. However, as the arms trade, trade in DUCs may affect the national security of exporting nations. Thus, it is appropriate for a model of DUC trade to integrate the security externality framework of the arms trade literature and the strategic trade policy approach. We achieve this by comparing two types of equilibria -- security and strategic optima -- that correspondingly concur with the traditional assumptions of the arms trade and strategic trade policy literatures on the Northern governments' conjectures.[12]

At the security optimum, each Northern government recognizes the domestic firm's response to domestic policy changes while taking the foreign firm's output as given. Thus, the governments fail to account for the effect of their policies on the transfer of the foreign

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[11] The foreign aid is an effective policy tool, provided the civilian and military commodities in the South are gross substitutes. This assumption holds automatically in a two-good case. In practice, the effectiveness of the foreign economic aid (i.e., a positive economic sanction) depends on historical, political and economic factors. For a review of the literature on economic sanctions see van Bergeijik (1994). The effectiveness of export barriers may vary depending on the type of the DUC, the capabilities of the DUC-importing country, the availability the DUC from other suppliers, and the degree of international cooperation, monitoring and enforcement effort (see OTA, 1994).

[12] Barrett's paper considers different conjectures of governments. Under the first conjecture the domestic policy does not influence both domestic and foreign production, whereas under the second conjecture both domestic and foreign production respond to changes in the domestic policy.

rent to the domestic imperfectly competitive firm, i.e., the profit-shifting effect. In contrast, at the strategic optimum, each Northern government knows that both domestic and foreign firms respond to changes in the domestic policy. This conjecture allows the Northern governments to take into account the profit-shifting effect of their policies. We find both security and strategic optima as subgame-perfect Nash equilibria in pure strategies by backward induction. Then, we compare the security and strategic optima and assess policy implications.

A. DUC Importer: The Dual-Use Decision

We begin with South's response to actions by the Northern governments and firms. The South chooses between civilian and military uses of the imported DUC. The outcomes of the earlier stages of the game, the DUC price and production subsidies are taken by the South as given. Solving for the general equilibrium in the South, we derive South's demand for the imported DUC.

Perfectly competitive firms in the South produce military and civilian goods (x and z respectively) using a DUC (y) and labor (l) as inputs and receiving production subsidies (s^E and s^W) per unit of civilian output from the North.[13] The South also produces an exportable good (q) using one unit of labor input per unit of output. All production functions are well-behaved. Labor is a numeraire good, and its supply L is fixed. The respective profit-maximization problems of civilian, military and exporting firms in the South are as follows:

$$\max \pi^S_x = (p^x + s^E + s^W)\, x - p^y y - l \qquad \text{s.t.} \qquad F^x(x, y, l) = 0$$

$$\max \pi^S_z = p^z z - p^y y - l \qquad \text{s.t.} \qquad F^z(z, y, l) = 0$$

$$\max \pi^S_q = p^q q - l \qquad \text{s.t.} \qquad F^q(q, l) = 0$$

where F^i, $i = \{x, y, z\}$, denote transformation functions. Labor and DUC constraints are

[13] A simplifying assumption of the perfect competition allows one to focus on the DUC trade aspects rather than the market structure in the South. An alternative assumption of public firms in the South does not over-turn the results.

$$l^x + l^y + l^z = L$$

$$y^x + y^z = y$$

South's national interests include military and commercial priorities with weights (w^S) and (1-w^S) respectively. The Southern government maximizes additively separable social welfare function W^S weighted between homothetic and twice continuously differentiable utility functions $u^z(z)$ and $u^x(x)$ subject to the budget constraint.[14] The South's welfare maximization problem is

$$\max_{x,\,z} \; W^S = w^S u^z(z) + (1 - w^S) u^x(x) \quad \text{s.t. } p^x x + p^z z = L - q$$

The trade balance equation is given by

$$q = p^y y$$

A general equilibrium is reached with market clearing prices $p^x = P^x(p^y, s^E, s^W, w^S, L)$ and $p^z = P^z(p^y, s^E, s^W, w^S, L)$. The inverse DUC import demand is $p^y = P^y(y, s^E, s^W, w^S, L)$ is downward-sloping and increasing in production subsidies (i.e., $p^y_y < 0$, $p^y_t > 0$, where subscripts denote partial derivatives).

B. DUC Producers' Decision

Prior to South's decisions, the Northern DUC producers choose the optimal supply of the DUC. We now proceed to the analysis of Cournot competition between DUC producers. Each Northern firm takes the Northern governments' export barriers and the rival's output of the DUC as given. Additionally, firms hold rational beliefs about South's import demand for the DUC. Maximizing their profits, the Northern firms choose an optimal quantity of the DUC to be produced.

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[14] The utility of the military good z is equivalent to the national security, and hence z is a public good. In this simple model with government being a single consumer there is no difference between a public and private

Denote the quantities of the DUC produced by the East and West as y^E and y^W respectively, the production cost function $C^i(y^i)$, and the total revenue function $R^i(y^E, y^W)$ where $i = \{E, W\}$. Production costs are monotonically increasing in the DUC output, i.e., $\frac{\partial C^i}{\partial y^i} = C^i_i > 0$, where partial derivatives are represented by subscripts. Assuming East and West's DUCs are (strategic) substitutes, each firm's revenue and marginal revenue are decreasing in the rival's output, i.e., $\frac{\partial R^i}{\partial y^j} = R^i_j < 0$, and $R^i_{ij} < 0$, where $i \neq j$. Firms incur per-unit administrative costs t^i due to the export barrier. Profit functions π^i, where $i = \{E, W\}$, are strictly concave and twice continuously differentiable. Firms maximize their profits given by

$$\max_{y^i} \ \pi^i = R^i(y^E, y^W, s^E, s^W, w^S, L) - C^i(y^i) - t^i y^i$$

with the corresponding first-order condition

$$\pi^i_i = R^i_i - C^i_i - t^i = 0 \qquad (1)$$

The marginal profit's own effect dominates the cross effect by assumption. The second-order and stability conditions are given by

$$\pi^i_{ii} = R^i_{ii} - C^i_{ii} < 0$$
$$\pi^E_{EE}\,\pi^W_{WW} - \pi^E_{EW}\,\pi^W_{WE} > 0$$

Solving the system (1) yields the Cournot-Nash equilibria $y^i = Y^i(s^E, s^W, t^E, t^W, w^S, L)$ where $i = \{E, W\}$.

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good. In a more complicated framework with multiple consumers, the demand for z will depend on the marginal rate of substitution between the private good x and the public good z of all consumers.

C. Optimal Government Policy of DUC Exporters

We now consider the initial announcement of policies by the Northern governments. The Northern governments choose export barriers (t^i where $t^i \geq 0$) and production subsidies (s^i where $s^i \geq 0$) by maximizing their social welfare (W^i). The governments have rational beliefs about the Northern firms' and South's reactions, and take each other's policies as given.

The national interests of country i, where $i = \{E, W\}$, include security and commercial priorities with the corresponding weights (w^i and $1\text{-}w^i$). The social welfare function (W^i) represents a difference between the net commercial benefit (B^i) from the DUC exports and security damage (D^i) from the military use of the DUC by the South. Assume that the social welfare function is strictly quasi-concave and twice continuously differentiable. The net commercial benefits are equal to profits from the DUC exports less the value of production subsidy paid to the South. The security damage is given by a function (g^i) that is twice continuously differentiable and monotonically increasing in the quantity of the military good. Thus, the social welfare function of a Northern country i, where $i = \{E, W\}$ is

$$\max_{t^i,\, s^i} \quad W^i = B^i - D^i = (1 - w^i)(\pi^i - s^i x) - w^i g^i(z) \tag{2}$$

To emphasize various aspects of the DUC trade problem, we contrast two solutions: security and strategic optima.[15] The security optimum follows the traditional assumption of the arms trade literature that the Northern governments take the foreign DUC output as given. We then relax this assumption in accordance with the strategic trade policy approach. The strategic optimum occurs when the Northern governments recognize that both domestic and foreign productions respond to a change in the domestic policy.

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[15] This follows the methodological approach of Barrett (1994) who compares alternative government strategies for setting environmental standards in imperfectly competitive industries.

The Security Optimum

We begin our equilibrium analysis by considering the security optimum in which the Northern governments move simultaneously and credibly precommit to export barriers and foreign aid policies. The security optimum conforms to the traditional assumptions of the arms trade literature. Srinivasan (1985), Levine, Sen and Smith (1994), and Levine and Smith (1995), for example, consider a Nash equilibrium supply of arms where domestic governments take the foreign production as given. Similarly, in this paper each Northern government treats the foreign DUC production and government policy as fixed and assumes that the domestic firm adjusts its production decisions in response to the domestic policy. The government does not internalize the behavioral reaction of the foreign firm to changes in the domestic policy. Thus, the security optimum policies are not strategic, as the Northern governments fail to consider the profit-shifting effect of their policies. However, since the Northern governments know the damage to their security from the DUC trade, they account for the security externality in their decisions.

Government i chooses optimal policies by solving unconstrained welfare maximization problem, equation (2), and taking the foreign output as given with the corresponding first-order conditions

$$W^i_t + W^i_i \frac{\partial y^i}{\partial t^i} = 0 \tag{3}$$

$$W^i_t + W^i_i \frac{\partial y^i}{\partial s^i} = 0 \tag{4}$$

The security optimum export barriers and production subsidies, denoted by $\tilde{t}^i$ and $\tilde{s}^i$ respectively, are solutions to equations (3) and (4). At the security optimum, the marginal commercial losses due to larger export barriers (larger production subsidies) are equal to the marginal increase in security. Suppose that national interest priorities are such that the security optimum policies are non-negative.

With the strict quasi-concavity of the objective function, the Hessian matrix is negative definite. Hence, the following second-order conditions are satisfied

$$W^i_{tt} < 0,\ W^i_{ss} < 0 \text{ and } \Omega \equiv W^i_{tt} W^i_{ss} - W^i_{ts} W^i_{st} > 0 \qquad (5)$$

where Ω denotes the determinant of the Hessian matrix. For stability we assume that the marginal welfare's own effect dominates the cross effect of export barriers and production subsidies. For example, with respect to export barriers

$$W^i_{ii}\, W^i_{tt} - W^i_{it} W^i_{ti} > 0 \text{ and } W^i_{ii}\, W^j_{jt}\, W^j_{tj} - W^i_{ij} W^j_{ji} W^j_{tt} + W^i_{ij}\, W^j_{jj}\, W^j_{tt} > 0$$

Generally, the security optimum export barriers and production subsidies ($\tilde{t}^i$ and $\tilde{s}^i$ respectively) depend on the damage functions, incomes, preferences, technologies, and national interest priorities. The higher priority the Northern governments give to security in their social welfare, they more weight they put on a marginal increase in security compared to a marginal reduction in commercial benefits (from tightening export controls or increasing subsidies); thus, the governments choose relatively tighter export barriers and larger production subsidies.

Proposition 1. *The more biased are national priorities toward security, the larger are export barriers and production subsidies at the security optimum.*

Proof. Totally differentiating first-order conditions (4) and (5) yields

$$W^i_{tt} dt^i + W^i_{ts} ds^i = - W^i_{tw} dw^i \text{ and } W^i_{st} dt^i + W^i_{ss} ds^i = - W^i_{sw} dw^i$$

Using Cramer's rule, we find comparative statics

$$\frac{\partial t^i}{\partial w^i} = \frac{-W^i_{tw} W^i_{ss} + W^i_{ts} W^i_{sw}}{\Omega} > 0$$

By the second-order conditions (5) the denominator is positive and $W^i_{ss} < 0$. Using the assumptions and equations (3) and (4) it can be shown that $W^i_{tw} > 0$, $W^i_{ts} > 0$ and $W^i_{sw} > 0$; hence, the numerator is positive.[16] Likewise[17]

$$\frac{\partial s^i}{\partial w^i} = \frac{-W^i_{tt} W^i_{sw} + W^i_{tw} W^i_{st}}{\Omega} > 0$$

The comparative static increase in export barriers in response to a rise in the relative importance of security priorities is typical for arms trade models (Srinivasan 1985, Levine, Sen and Smith 1994, Levine and Smith 1995). These models, however, do not analyze the use of the foreign aid as a policy instrument. An increase in the foreign aid following a rise in security concerns is an intuitive result as the foreign aid effectively reduces security damages as well as increases export profits in this model. However, if the foreign aid is politically infeasible, the security optimal export barrier corresponds to the optimal export tax in the arms trade literature.

The Strategic Optimum

Next we consider the strategic optimum, at which the Northern governments' conjectures are consistent with the strategic trade policy literature. The Northern governments recognize that changes in the domestic policy affect the foreign production and shift profits between imperfectly competitive Northern firms. Thus, in contrast to the security

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[16] By the second-order conditions (5) the denominator Ω is positive, and $W^i_{ss} < 0$. Differentiating equation (1) gives $-W^i_{tw} = -(y^i + s^i x_t - g^i_z z_t) < 0$, since $x_t < 0$ and $z_t < 0$, $g^i_z > 0$ by definition, and $y^i + s^i x_t < 0$ from equation (3). Differentiating equation (4) yields $W^i_{ts} = (1 - w^i)(\pi^i_{ts} - s^i x_{ts} - x_t) - w^i g^i_z z_{ts} > 0$ since $\pi^i_{ts} = 0$, $x_t < 0$, and by assumption $x_{ts} = 0$, $z_{ts} = 0$. Differentiating equation (4) gives $W^i_{sw} = -(p^y_s - s^i x_s - x) - g^i_z z_s > 0$ since $p^y_s > 0$, $x_s > 0$, $z_s < 0$ (since x and z are gross substitutes in a two-good case), $x \geq 0$, and $p^y_s - s^i x_s - x < 0$ from equation (4). Hence, the numerator is positive.

[17] By the second-order conditions (5) the denominator Ω is positive, and $W^i_{tt} < 0$. Differentiating equation (1) gives $W^i_{tw} = -(p^y_t - s^i x_t - x) - g^i_z z_t > 0$, since $p^y_t > 0$, $x_t > 0$, $z_t < 0$ (since x and z are gross substitutes in a two-good case), $x \geq 0$, and $p^y_s - s^i x_s - x < 0$ from equation (4). Differentiating equation (3) gives $W^i_{tw} = y^i + s^i x_t - g^i_z z_t > 0$ since $x_t < 0$, $z_t < 0$, $g^i_z > 0$ by assumption, and $y^i + s^i x_t > 0$ from equation (3). Differentiating equation (3) gives $W^i_{st} = W^i_{ts} = (1 - w^i)(\pi^i_{ts} - s^i x_{ts} - x_t) - w^i g^i_z z_{ts} > 0$ since $\pi^i_{ts} = 0$, $x_t < 0$, and by assumption $x_{ts} = 0$, $z_{ts} = 0$. Hence, the numerator is positive.

optimum, the strategic optimum policies take into account not only the security damage, but also the profit-shifting effect of government policies.

The government i maximizes its social welfare taking the policy choice of the government j, where $i, j = \{E, W\}$, and $i \neq j$, and the reaction functions of firms i and j as given. The Northern governments simultaneously maximize equation (2) subject to constraints (1)

$$\max_{t^i,\, s^i} \quad W^i = B^i - D^i \qquad \text{subject to} \qquad \pi^E_E = R^E_E - C^E_y - t^E = 0$$
$$\pi^W_W = R^W_W - C^W_y - t^W = 0$$

The first-order conditions are given by

$$W^i_t + W^i_i \frac{\partial y^i}{\partial t^i} + W^i_j \frac{\partial y^j}{\partial y^i} \frac{\partial y^i}{\partial t^i} = 0 \qquad (6)$$

$$W^i_s + W^i_i \frac{\partial y^i}{\partial s^i} + W^i_j \frac{\partial y^j}{\partial y^i} \frac{\partial y^i}{\partial s^i} = 0 \qquad (7)$$

where $i = \{E, W\}$, and $W^i_i = \frac{\partial W^i}{\partial y^i}$ and $W^i_j = \frac{\partial W^i}{\partial y^j}$. In equation (6) the first term represents a *direct effect* of a change in export barriers on the social welfare of country i. If lower export barriers are adopted by the domestic government, the net commercial benefits and security damages simultaneously increase for a given quantity of the domestic exports. The second term is an *output effect* reflecting the change in the domestic output in response to the change in the domestic export barriers. With lower export barriers, the administrative costs are lower, and, as a result, the optimal level of the domestic output and market share increases. The third term is a *profit-shifting effect* induced by the change in the foreign output in response to the change in the domestic output. As the domestic firm's output increases due to lower (domestic) export barriers, the rival firm's output and profits fall, and, as a result, the domestic social welfare rises. Production subsidies have similar welfare effects as summarized in equation (7).

Equations (6) and (7) can be solved for policies that are defined as the *strategic optimum* export barriers $\hat{t}^i$ and production subsidy $\hat{s}^i$, where $i = \{E, W\}$. The strategic optimum is the Nash equilibrium strategy of the Northern governments incorporating the behavioral response of domestic and foreign firms to changes in the domestic policy.

Each Northern government sets its domestic export barrier at a level where the marginal net commercial loss is less than the marginal net security improvement from tightening export barriers (an increase in t^i), i.e., $W^i_{t^i} + W^i_{i}\frac{\partial y^i}{\partial t^i} > 0$ (see Appendix 2). This implies that at the strategic optimum export barriers are weaker than those at the security optimum, $\hat{t}^i < \tilde{t}^i$. The strategically optimal policy $\hat{s}^i$ is chosen at a level where the marginal net commercial loss is greater than the marginal net security improvement from an increase in s^i, i.e., $W^i_{s^i} + W^i_{i}\frac{\partial y^i}{\partial s^i} < 0$. This implies that at the strategic optimum production subsidies are larger than those at the security optimum, $\hat{s}^i > \tilde{s}^i \geq 0$.

Proposition 2. *At the (Cournot-Nash) strategic optimum export barriers are lower and production subsidies are larger than those at the security optimum.*

Proof. See Appendix 2.

When the domestic government chooses lower export barriers combined with larger subsidies, the domestic firm increases its DUC exports relative to the foreign firm, and profits are shifted from the foreign to the domestic country. There is 'under-provision' of export barriers and 'over-provision' of subsidies at the strategic optimum compared to the security optimum. The over-provision of subsidies occurs because larger subsidies increase the demand for the DUC and also improve the security of the DUC-exporting countries.

Proposition 3. *At the (Cournot-Nash) strategic optimum production subsidies are positive.*

Proof. By the non-negativity of security optimum subsidies and proposition 2, $\hat{s}^i > \tilde{s}^i \geq 0$.

Graphically, the security and strategic optima can be represented by the intersection points of the Northern governments' downward-sloping reaction functions (Figures 1 and 2). Downward-sloping reaction functions imply that as one Northern government increases its export barriers (production subsidies), it is optimal for another government to reduce its export barriers (production subsidies).

The reaction functions corresponding to the strategic optimum are shifted farther out than those corresponding to the strategic optimum. As a result, the strategic optimum export barriers (point A in Figure 1) are lower than the security optimum ones (point B in Figure 1). In contrast, the strategic optimum production subsidies (point A in Figure 2) are larger than the security optimum ones (point B in Figure 2).

Security benefits associated with export barriers and production subsidies are a public good for the North. When a Northern country acts out of self-interest and maximizes its individual welfare, it fails to take into account the marginal security benefits of its policies for the other Northern country. Therefore, the strategic and security optima are Pareto sub-optimal from the joint Northern welfare (and security) perspective.

In addition, there may be efficiency losses due to free-riding in the provision of public benefits of security using export barriers and production subsidies (Olson and Zeckhauser, 1966).[18] This implies unequal burden-sharing with a tendency for those allies that place higher value on their security to bear a disproportionately higher share of the burden associated with export barriers and production subsidies. Free-riding also leads to the sub-optimal provision of export barriers and production subsidies.

II. OPTIMAL POLICY UNDER BERTRAND COMPETITION

Under Bertrand competition, the Northern firms simultaneously choose their price schedules by solving the following optimization problem

$$\max_{p^i} \ \pi^i = R^i(p^E, p^W, s^E, s^W, w^S, L) - C^i(p^i) - t^i y^i(p^i)$$

[18] For a survey of the literature on the economic analysis of alliances see Sandler (1993).

The Northern governments choose export barriers and production subsidies by maximizing the difference between their net commercial benefits and security damages. The strategic optimum is defined by the following first-order conditions

$$W^i_{t^i} + W^i_{t^i}\frac{\partial p^i}{\partial t^i} + W^i_{p^j}\frac{\partial p^j}{\partial p^i}\frac{\partial p^i}{\partial t^i} = 0 \qquad (8)$$

$$W^i_{s^i} + W^i_{t^i}\frac{\partial p^i}{\partial s^i} + W^i_{p^j}\frac{\partial p^j}{\partial p^i}\frac{\partial p^i}{\partial s^i} = 0 \qquad (9)$$

At the (Bertrand-Nash) strategic optimum export barriers and subsidies are larger than those at the security optimum. When the Northern governments behave strategically, they can increase their social welfare through an additional channel: the *profit-shifting* effect (the second and third terms in equations (8) and (9) respectively), besides the direct effect (the first term in equations (8) and (9)) and the *price* effect (the second term in equations (8) and (9)). The profit-shifting effect is positive for an increase in t^i and s^i, and as a result, strategically behaving governments choose larger export barriers and production subsidies.

Proposition 4. *At the (Bertrand-Nash) strategic optimum export barriers and production subsidies are larger than those at the security optimum.*

Proof: See Appendix 3.

At the (Bertrand-Nash) strategic optimum export barriers are larger, since an increase in export barriers simultaneously reduces security damages and increases domestic profits by limiting the incentive to undercut the foreign firm in price (Eaton and Grossman, 1986).

Proposition 5. *At the (Bertrand-Nash) strategic optimum export barriers and production subsidies are positive.*

Proof: By the non-negativity of security optimum policies and proposition 4, $\hat{t}^i > \bar{t}^i \geq 0$ and $\hat{s}^i > \bar{s}^i \geq 0$.

III. CONCLUSION

This paper focuses on optimal dual-use trade policies that can limit weapons proliferation without harming economic growth. The dual-use trade can potentially damage exporting nations' security if the dual-use commodity contributes to the military rather than civilian production in the importing nation. Since the security damage depends on the importer's end-use decision, demand-side policies complement supply-side instruments in the case of the dual-use trade. Moreover, governments can pursue these policies in a strategic trade manner, since the dual-use trade tends to be dominated by imperfectly competitive industries.

By considering strategic trade and aid policies in the presence of a negative security externality, we extend the traditional arms trade literature. We find that export barriers and the foreign aid are complementary policies and, somewhat surprisingly, the positive level of foreign aid is optimal both under Cournot and Bertrand modes of competition.

As in Barrett's (1994) model, the Northern governments choose too much aid and too weak export barriers compared to the levels where the marginal economic gains exactly offset security losses in the absence of profit-shifting. Non-strategic export barriers discussed in the arms trade literature are higher than those under the strategic trade assumption.

With agents acting non-cooperatively, the equilibrium outcome corresponds to that of the traditional prisoners' dilemma game. Non-cooperative policies are sub-optimal from the standpoint of the joint exporters' welfare maximization. As security damages are global, nations have an incentive to free ride and lower their export barriers and foreign aid.

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Appendix 1

The terms of trade effects of a change in the DUC export barriers and production subsidies are given by

$$\frac{dp^Y}{dt^i} = \frac{\partial p^Y}{\partial y^i}\frac{\partial y^i}{\partial t^i} + \frac{\partial p^Y}{\partial y^j}\frac{\partial y^j}{\partial y^i}\frac{\partial y^i}{\partial t^i}$$

$$\frac{dp^Y}{ds^i} = \frac{\partial p^Y}{\partial y^i}\frac{\partial y^i}{\partial s^i} + \frac{\partial p^Y}{\partial y^j}\frac{\partial y^j}{\partial y^i}\frac{\partial y^i}{\partial s^i}$$

The terms of trade effects are ambiguous. If the change in the domestic terms of trade induced by the change in the domestic output (the first term in the above equations) exceeds the effect of the induced change in the foreign output (the second term in the above equations), then the domestic terms of trade improve (worsen) when export barriers (production subsidies) increase.

Appendix 2

Proof of Proposition 2

The first order condition for export barriers is given by

$$W^i_t + W^i_i \frac{\partial y^i}{\partial t^i} + W^i_j \frac{\partial y^j}{\partial y^i} \frac{\partial y^i}{\partial t^i} = W^i_t + W^i_i \frac{\partial y^i}{\partial t^i} + B^i_j \frac{\partial y^i}{\partial t^i} \frac{\partial y^i}{\partial t^i} - D^i_j \frac{\partial y^i}{\partial t^i} \frac{\partial y^i}{\partial t^i} = 0 \qquad \text{(i)}$$

Since $R^i_j < 0$ by the assumption of close substitutes, $\pi^i_j < 0$, $\frac{\partial p^y}{\partial y^j} < 0$, and $\frac{\partial x}{\partial p^y} \frac{\partial p^y}{\partial y^i} = \frac{\partial x}{\partial p^y} \frac{\partial p^y}{\partial y^j}$, then $B^i_j = (1 - w^i)(\pi^i_j - s^i \frac{\partial x}{\partial p^y} \frac{\partial p^y}{\partial y^j}) < 0$. Since $g^i_z > 0$, $\frac{\partial z}{\partial p^y} < 0$, then $D^i_j = w^i g^i_z \frac{\partial z}{\partial p^y} \frac{\partial p^y}{\partial y^j} > 0$. Totally differentiating (1) for firm j and (3) for country j for a given s^j:

$$W^j_{it} dt^j + W^j_{ij} dy^j = 0 \qquad \text{(ii)}$$

$$W^j_{ji} dy^i + W^j_{jj} dy^j + W^j_{jt} dt^j = 0 \qquad \text{(iii)}$$

Combining (ii) and (iii) and rearranging gives:

$$\frac{dy^j}{dy^i} = (- W^j_{ji} W^j_{it}) / (W^j_{jj} W^j_{it} - W^j_{ji} W^j_{ij}) \qquad \text{(iv)}$$

$W^j_{it} < 0$ by the second order conditions (5). The denominator of (v) is positive by stability conditions. $W^j_{ji} < 0$ since $R^i_{ij} < 0$. This implies that $\frac{dy^j}{dy^i} < 0$. Totally differentiating (1) for firm i and (3) for country i for a given s^i:

$$W^i_{it} dy^i + W^i_{ij} dy^j + W^i_{it} dt^i = 0 \qquad \text{(v)}$$

Rearranging (v) and substituting (iv) yields $\frac{dy^i}{dt^i} = [W^i_{it}(W^j_{jj}W^j_{ii} - W^j_{ji}W^j_{ij})] / [W^i_{ii}W^j_{jt}W^j_{ij} + W^j_{ji}W^j_{ii}W^i_{ij} - W^i_{ii}W^j_{jj}W^j_{ii}]$. If export barriers are binding,

$$W^i_{ii} < 0 \qquad \text{(vii)}$$

The numerator is negative by (vii) and (2). The denominator is positive by (3). This implies that $\frac{dy^i}{dt^i} < 0$. Substituting in (i) and rearranging yields $W^i_t + W^i_i\frac{\partial y^i}{\partial t^i} > 0$. (Similarly it can be shown that $W^i_s + W^i_i\frac{\partial y^i}{\partial s^i} < 0$.)

Appendix 3

Proof of Proposition 4

The first order condition for export barriers is given by

$$W^i_t + W^i_i \frac{\partial p^i}{\partial t^i} + B^i_j \frac{\partial p^j}{\partial p^i} \frac{\partial p^i}{\partial t^i} - D^i_j \frac{\partial p^j}{\partial p^i} \frac{\partial p^i}{\partial t^i} = 0 \qquad \text{(i)'}$$

Since $\pi^i_j > 0$ by the assumption of close substitutes and $\frac{\partial x}{\partial p^i} = \frac{\partial x}{\partial p^j} < 0$, then $B^i_j = (1\text{-}w^i)(\pi^i_j - s^i \frac{\partial x}{\partial p^j}) > 0$. Since $g^i_z > 0$, and $\frac{\partial z}{\partial p^i} < 0$, then $D^i_j = w^i g^i_z \frac{\partial z}{\partial p^i} < 0$. Totally differentiating the first-order conditions for firm j and country j for a given s^i yields:

$$W^j_{it} dt^i + W^j_{ij} dp^j = 0 \qquad \text{(ii)'}$$

$$W^j_{ji} dp^i + W^j_{jj} dp^j + W^j_{jt} dt^i = 0 \qquad \text{(iii)'}$$

Combining (ii)' and (iii)' and rearranging gives:

$$\frac{\partial p^j}{\partial p^i} = (- W^j_{ji} W^j_{it}) / (W^j_{jj} W^j_{it} - W^j_{jt} W^j_{ij}) \qquad \text{(iv)'}$$

$\frac{\partial p^j}{\partial p^i} > 0$ by the second-order and stability conditions. Totally differentiating the first-order condition for firm i and country i for a given s^i gives:

$$W^i_{it} dp^i + W^i_{ij} dp^j + W^i_{it} dt^i = 0 \qquad \text{(v)'}$$

Rearranging (v)' and substituting (iv)' yields $\frac{\partial p^i}{\partial t^i} = [W^i_{it}(W^j_{ji}W^j_{tt} - W^j_{jt}W^j_{tj})]/[W^i_{ii}W^j_{jt}W^j_{tj} + W^j_{ji}W^j_{tt}W^i_{ij}{}^j_{tt}] > 0$ by stability conditions. Substituting in (i)' and rearranging gives $W^i_t + W^i_i\frac{\partial p^i}{\partial t^i} < 0$. (Similarly it can be shown that $W^i_t + W^i_i\frac{\partial p^i}{\partial s^i} < 0$.)

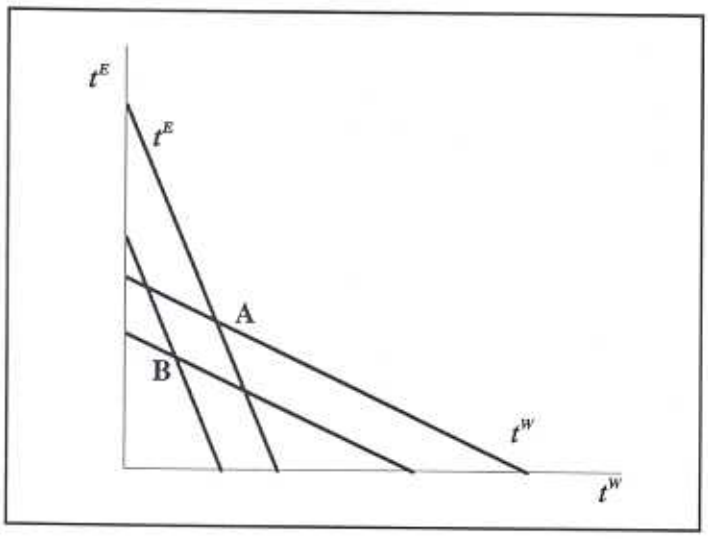

Figure 1. Export Barriers: Security and Strategic Optima.

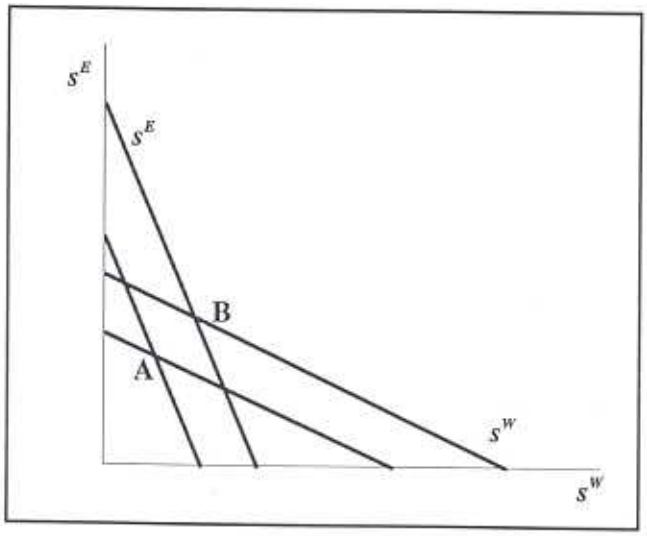

Figure 2. Production Subsidies: Security and Strategic Optima.