Economic Issues and Methodology in Arms Race Analysis

MICHAEL P. LEIDY
ROBERT W. STAIGER
Department of Economics
University of Michigan

This article reviews the recent contributions of economic analysis to the literature concerned with the process of national arms accumulation and the potential for arms control and disarmament. The role of formal model building as an aid to understanding the armament process is discussed. The existing economic literature in this area is organized and reviewed on the basis of the different modeling approaches that have been explored to date. Finally, strands of economic thought that have not yet been introduced into the arms race literature are explored, with the purpose of suggesting further applications of the economic approach to this important area of analysis.

The great variety of issues arising in arms race analyses indicates that the problem is multidimensional. Political, technological, psychological, sociological, historic, and economic elements are readily identifiable, but these are neither mutually exclusive nor exhaustive categories. Nevertheless, certain issues are commonly associated exclusively with a given discipline, and non-economists have no difficulty recognizing those issues in arms race analysis that belong presumably in the economics pigeonhole. Without considering the scope of other disciplines in the social sciences, the tendency to assign to economics only those problems that have been addressed traditionally by economists is ill consid-

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ered. The potential contribution of the economics profession to arms race analysis is constrained not by a body of traditional subject matter, but by the limits of positive economics methodology. While there exists an ongoing debate among economists concerning the limitations of economics methodology for understanding human action, there has emerged, perhaps, a consensus as to the defining characteristics of that methodology. "The combined assumptions of maximizing behavior, market equilibrium, and stable preferences . . . form the heart of the economic approach" (Becker, 1976). The nuances that compose the arms race problem fundamentally involve instances of constrained human choice. As such, the economic approach is well suited indeed.

A common criticism of the economic approach is that the nonrational domain of human behavior is conspicuously absent. Perhaps nonrational behavior is particularly evident in situations involving tension and conflict. Even the most zealous economic positivists acknowledge to some extent this limitation. With this caveat in mind, as well as the above methodological perspective, this article will summarize existing work and consider some new areas of study where economic analysis can be applied to understand various aspects of the arms race problem. The usefulness and limitations of efforts to model the arms race process will be addressed, followed by an abbreviated review of the arms race modeling literature, with a focus on economic contributions to this body of research and a brief survey of some of its policy implications. Finally, several areas of economic reasoning that have not yet been applied to the study of arms control and disarmament are briefly considered.

ARMS RACE MODELING OBJECTIVES AND LIMITATIONS

An understanding of the armament process among nations is valuable for at least two reasons. First, proper national defense decisions concerning military doctrine and weapons procurement must acknowledge the interconnectedness of current and future defense policy. If shortsighted military decision making is to be avoided, it is essential to understand the degree to which current military spending affects the future military spending of one's adversaries, and hence the military environment within which future defense decisions must be made. The study of arms races bears directly on this question. Second, an understanding of the armament process and its relationship to the likelihood of war may shed light

on our ability to control it and point the way to measures that could simultaneously reduce the economic burden of armaments and decrease the likelihood of nuclear disaster.

Building formal models of arms races is one way to gain an understanding of this process. Efforts at modeling the arms race represent an attempt to capture one or several of its salient features in a system of equations. Modeling provides a formal statement of hypothetical determinants of the armament process, and facilitates a systematic exploration of the implications of the hypothesis with respect to the behavior and characteristics of arms races. It also provides a framework for the rejection, on empirical grounds, of theories and hypotheses that are in some sense unsatisfactory. Ideally, alternative specifications of the armament process can be formulated and statistical tests employed to differentiate between the various models based on empirical criteria.

Unfortunately, differentiating between existing explanations of the armament process on empirical grounds is not very likely for several reasons. First, many of the existing arms race models contain an action-reaction process between an arming country and its adversaries. As observed by McGuire (1977) and Russett (1983) among others, even if the action-reaction process is an important component of arms races, the existing theory lacks sufficient richness to provide a firm theoretical basis for the choice of one measure of the armament process (e.g., number of warheads) over another (e.g., total megatonnage). Because it is not possible simultaneously to verify the presence of an action-reaction process and determine the appropriate measure for it, researchers are led to choose a measure on the basis of model performance, a practice that violates the methodology of classical hypothesis testing. As a result, empirical evidence is biased away from the rejection of hypotheses and is unlikely to provide a powerful means of discriminating between various specifications of the action-reaction process, or between models that incorporate an action-reaction component and those that do not. A second and equally important constraint on the empirical verification of arms race models involves the limited amount and quality of the published military statistics of many countries, a problem that is well documented in the literature (Russett, 1970; Holzman, 1980).

While these empirical difficulties imply that modeling efforts are unlikely to result in a unique, widely accepted view of the armament process by successful refutation of all competing hypotheses, they do not imply that modeling efforts in this area are futile. Valuable qualitative information pertaining to the nature of the armament process has been provided by past modeling efforts, even though a unified picture of arms

races has not evolved. Thus existing empirical constraints, although clearly important, have not denied arms race modeling the ability to contribute in a useful way to our understanding of the armament process. Confronted with the empirical limitations present in the arms race modeling literature, the most valuable role of modeling in this area is, perhaps, to organize and refine concepts and theories that have been advanced concerning the armament process, and to develop and present the qualitative implications of those ideas, both with respect to the dynamics of the arms race itself and with regard to the probable effects of various efforts at controlling the process. It is in this vein that the literature has most substantially contributed to date, and it is here that future contributions will most likely appear.

Even in this more qualitative role, however, efforts to discriminate between various specifications remain of utmost importance. The lack of direct empirical criteria allowing one to discriminate between arms race models suggests that indirect evidence must play an important role in providing guidance for model building in this area. Specifically, indirect empirical evidence suggesting the usefulness of particular assumptions in related modeling contexts can be introduced as evidence in favor of one arms race model and its assumptions over another. Moreover, because casual observation reveals that many features of the armament process are common to problems relatively well studied by economists, a special role is suggested for the perspective and experience of economic analysis in the evaluation of arms race models. Modeling assumptions and techniques fruitfully applied in those areas of economic analysis that share important characteristics with the arms race phenomenon may be particularly appropriate for application to arms race modeling. Careful and thoughtful application of such indirect evidence, together with the direct empirical evidence that is available, should provide a most useful guideline for model building and critical evaluation of arms race models. The next section reviews some of the contributions to the arms race modeling literature that have resulted from the application of economic thought to the analysis of the armament process.

ARMS RACE MODELING LITERATURE

It will be useful to divide the existing models of arms races into two categories. These consist of optimizing and nonoptimizing models. The nonoptimizing models, as the modifier suggests, do not apply the eco-

nomic approach to the analysis of the arms race process. Indeed few orthodox economists have contributed directly to this literature. Nevertheless, a juxtaposition of the nonoptimizing and optimizing models will serve to illustrate some important weaknesses of nonoptimizing models that are overcome by models with explicit choice-theoretic foundations.

NONOPTIMIZING APPROACH TO ARMS RACE MODELING

The work of Richardson (1960) initiated copious investigations into the arms race phenomenon using simple nonoptimizing models. Nonoptimizing models lack the choice-theoretic foundation that typically underlies economic models. Constrained optimizing behavior by a decision-making agent or agency is not employed to generate potentially refutable implications, although at times such behavior is implicit. Richardson-type models depict arms races as multi-agent interactive processes. In its standard form, a system of first-order, linear-nonhomogeneous differential equations with constant coefficients is proposed to describe the dynamic process of weapons accumulation. The time-dependent variables in a Richardson system are the weapon stocks of participating nations. The right-hand side of each Richardson equation is composed of three parts: a "defense" term indicating the effects on one's own missile acquisition of an opponent's acquisition of missiles; a "fatigue" term indicating the burden of maintaining a large missile stock; and a "grievance" term capturing all other effects on the acquisition of missiles. The underlying assumption of the Richardson framework is that these three factors have independent and additive effects on missile acquisition. This assumption allows the Richardson equations of motion to be written in their standard linear form.

The mathematical structure of the Richardson framework virtually directs the analyst by reflex action to consider the existence and stability of an equilibrium point. Much of the work done in the Richardson tradition exploits the simplicity of the mathematical structure to elicit the full implications of the model. For example, Okuguchi (1981) shows that the expected sign and relative size of entries in the coefficient matrix suggest that alliance formation, ceteris paribus, will tend to be stabilizing. According to Baugh (1978), the role of military aid flows and the details of alliance ties also have implications for the entries in the coefficient matrix, and as such for the stability of a rest point.

However, the implications forthcoming from the standard Richardson model are essentially empty. That is, while the model is rich in implications concerning the existence and stability of equilibria, nothing about the model explains the significance of either instability or the nonexistence of a steady state. Of course, there is a tendency to argue, as did Richardson, that an unstable arms race can only end in war. But this conclusion does not emerge directly from the model. Conditions affecting the likelihood of war and other important qualitative characteristics of the arms race do not enter the standard Richardson model explicitly.

Intriligator (1964, 1975) extends the nonoptimizing, Richardson-type model in two important papers. In his 1964 paper he introduces the role of strategy and constraints into the Richardson framework. The incorporation of strategic considerations adds important information concerning the nature of an equilibrium that is lacking in the standard Richardson model. For instance, if both nations in a two-country model are pursuing a strategy of deterrence, then the equilibrium is characterized by a perceived state of mutual deterrence. The inclusion of strategic information has thus enhanced our understanding of the character of the equilibrium.

Further, the introduction of institutional and/or resource constraints seems to obviate the concern over both the existence and stability of an equilibrium. If an equilibrium does not exist, then one is imposed by the constraint boundaries. If an equilibrium exists within the constraint set but is unstable, then it is nevertheless bounded by the origin from below and the intersection of the constraint curves from above. Therefore, an explosive arms race cannot exist as characterized by the time path of the vector of weapon stocks above an unstable equilibrium. There remains, however, the likelihood that an equilibrium existing at a relatively low level of weapon stocks is more attractive than one existing at or near the upper boundary of the constraint set. But whether or not this is the case is ambiguous as long as we remain in a nonoptimizing framework. Without including explicit information about social preferences and objectives, welfare statements are formally outside the scope of the model.

Nevertheless, while the mathematical structure of the Richardson framework points to the role of the coefficients in establishing the position of an equilibrium in weapons space, the standard model lacks sufficient richness or depth to indicate explicitly those factors that determine the size of these coefficients and so the position of the equilibrium. Because of this, if it is determined that, for example, an equilibrium at a lower level of weapon stocks is preferable, the standard Richarson model provides no policy alternatives that might, through either unilateral or multilateral action, achieve this end.

This shortcoming is addressed by Intriligator (1975) in an interesting and important extension of the Richardson model. Intriligator considers explicitly those factors that influence the decisions of defense planners. He postulates (1975: 340) that the decisions of defense planners "to acquire a weapon must be based on an evaluation of its effectiveness in the event of war." He proceeds to derive the Richardson coefficients as explicit functions of technical, timing, and strategic considerations that emerge from a dynamic model of a missile war. This extension deals directly with the underlying military decision process determining the size of the Richardson coefficients, and the result is a model that provides information as to the existence and stability of a rest point, its position, and, most important, the qualitative character of that equilibrium as well as the character of points in various directions around the equilibrium.

While Intriligator is able to introduce policy content into the Richardson coefficients, acknowledgment of the tradeoff between military and civilian objectives remains outside the model. Military goals are the single concern in this extension of the Richardson model. As a result, the predicted path of the arms race is in no way affected by the existence of resource constraints and their impact on the ability to pursue simultaneously both military and nonmilitary objectives. It is only by introducing competing military and civilian goals within an explicit choice-theoretic framework that one can carry out an analysis of the arms race that acknowledges in a noncapricious way the aspects of constrained social choice fundamental to the arms race phenomenon. Such an approach is embraced in the optimizing literature to which we now turn.

OPTIMIZING APPROACH TO ARMS RACE MODELING

The bulk of the work by economists in the area of arms race modeling is contained in a second body of arms race literature that can be characterized by its reliance on an optimizing framework within which modeling efforts are undertaken. Departing from the earlier modeling tradition exemplified by Richardson and others, the optimizing approach postulates an explicit form for the objective functions of each participating decision maker and derives the necessary conditions for maximizing behavior, the pursuit of which generates the arms race. The analysis of equilibria is then performed by deriving conditions for the existence (and stability) of an armaments vector that simultaneously satisfies the first-order conditions for all participating agents.

The general approach in this literature can be captured in several steps. The first step is to identify the relevant decision-making agents responsible for national military procurement and to postulate objective functions for each of them. The arguments of the objective function are specified, and in particular, an index of security must be constructed that is normally a function of own and adversary missile stocks. Next, an implicit or explicit assumption is made concerning each country's expectations about adversary reaction to a change in its missile stock. Finally, constraint equations, which outline the budget constraints that decision makers face and the technical factors limiting the rate of accumulation of missile stocks, complete the optimizing model.

This general approach represents an advance over the rather ad hoc formulations associated with the Richardson tradition. The action-reaction evolution of weapon stocks that emerges from these models is a result of optimizing decisions made in the presence of limited resources and competing military and nonmilitary objectives. Not only is the arms race phenomenon shown to be consistent with the behavior of (noncooperative) optimizing agents, but the underlying parameters are seen to emerge in a natural way as functions of the technical, strategic, and behavioral coefficients of the model. Thus the prior determination of certain behavioral and technical parameters leads, through the maximizing behavior of decision-making agents, to an endogenous determination of the form and content of the arms race equations, as opposed to the exogenously determined formulation in the nonoptimizing tradition of Richardson. Indeed, Richardson's original linear formulation falls out as a special case of such models, and the behavioral and technical assumptions sufficient to generate equations of the form Richardson postulated can be assessed within the optimizing framework.

Three major issues in this literature warrant brief discussion. The first concerns the designation of the process by which national military procurement decisions are made. Almost without exception, optimizing models of arms races have been derived under the implicit or explicit assumption that each participating country in an arms race can be treated as a single rational actor maximizing a well-defined utility function (see for example, Lambelet, 1973; Chatterjee, 1974; and Brito and Intriligator, 1977). That is, each nation engaged in the arms race is treated as if it were ruled by an omnipotent social planner who acts to maximize a social welfare function, which is increasing in both private consumption and national security, subject to a national budget constraint. In addition, it is important to note that in all of the existing optimizing literature, nations are treated symetrically with respect to both the description of the na-

tional decision-making process (e.g., the single-rational-actor approach) and the functional form of the objective functions and constraints that dictate the behavior of the relevant decision makers.

A lone exception to the "single rational actor" approach is provided by Brito and Intriligator (1981), who reject this traditional formulation in favor of a model of bureaucratic decision making. In their model, which still treats countries in an essentially symmetric manner, a nation's defense expenditures are determined by the interaction of three classes of agents: two bureaus competing for budgetary allocations; an allocative authority that sets budgets for the two bureaus; and a review authority to whom the bureaus can appeal budgetary decisions made by the allocative authority. These together are involved in the allocation of resources between private expenditures and public expenditures, and further between public defense and nondefense expenditures. Each of the three classes of agents is assumed to act so as to maximize an explicit objective function subject to appropriate budgetary constraints. It is the interaction of these three classes of decision makers, and their interaction with the decision makers of other nations, that determines military procurement in each country, and hence the nature of the arms race.

Surprisingly, although the postulated objectives of each class of agents taken separately seem to be consistent with the aims of society, Brito and Intriligator are able to demonstrate the possibility of a somewhat perverse effect of arms limitation treaties that is absent from the results generated by single-rational-actor models. The fact that assumptions concerning the process of rational decision making can make crucial differences in the expected effects of efforts to control the arms race suggests that the designation of the decision-making process is a critical step in the modeling effort.

The second major issue in this literature concerns the way in which "missiles" (defense expenditures) enter the objective functions of decision-making agents. This issue reduces to the construction of a security index that captures the perceived relationship between missiles and the commodity—national security—from which their demand is derived. Beginning from the observation that missile stocks can provide second- and/or first-strike capabilities, much of the optimizing literature employs simple security indices that seem intuitively to be related to one or both of these military criteria (see, for example, Brubaker, 1973). Measures such as the ratio of own to adversary missile stocks, as well as the absolute difference between own and adversary missile stocks, have been employed to capture the second-strike capabilities of a nation's nuclear arsenal, and are entered directly into the objective functions as measures

of national security. Where first-strike (e.g., preemptive) capabilities are of concern, similar measures can be used to reflect the number of surviving missiles after a first strike has been launched.

Other, more sophisticated measures have also been proposed. For example, Dumas (1979) constructs a different security index by introducing the notion that larger world missile stocks lead to higher probabilities of accidental war. Not surprisingly, the difference between his security index and other more traditional measures has important implications for the analysis of the arms race. Brito (1972) employs yet a different measure—a general class of security indices that incorporates several of the security measures discussed above. This security index is constructed to reflect the notion that weapon stocks are inputs into the production of military potential, and depicts decreasing but nonnegative returns to own missile investment.

As is evident from the above discussion, without some sort of framework within which to derive the perceived relationship between national security and missile stocks, a wealth of indices can be put forth and defended on vaguely intuitive grounds. The ad hoc nature of these measures makes it difficult to discriminate between them, and is certain to limit the usefulness of models that employ them. In addition, the measures are deficient in that they do not describe the process by which nations choose a particular index level as acceptable—for example, what particular ratio value we consider acceptable for deterrence, or how the desired level might change as a function of various parameters of the model.

The approach taken in Brito and Intriligator (1974), for example, is an attempt to rectify this situation. They formulate a process by which the military authorities might try to justify defense budget and military force levels to political authorities. A model of hypothetical missile warfare—as in Intriligator (1975)—is constructed that incorporates information on strategic, technical, timing and social/psychological factors and is employed by the military authorities to calculate missile requirements for a given military objective (e.g., deterrence). Using this model, expected payoffs in the event of war that are associated with various combinations of initial missile stocks are employed to determine the properties of a general security index. This general index is then entered directly into a social utility function. Like the more ad hoc security indices of previous studies, the index thus constructed will be a function of own and adversary missile stocks. But unlike the ad hoc measures, this approach recognizes the impact of strategic and technical factors, as well as military doctrine, on the resulting missile requirements. Note that this approach claims neither to model accurately an actual missile war nor to predict

deterrent outcomes. It only attempts to describe a model that military authorities might employ to justify defense expenditures. Thus the model represents a hypothetical or perceived relationship between missiles and national security that is advanced by the military authority for the calculation of missile requirements.

A final major issue in the optimizing literature on arms race modeling concerns the postulated reactions of an adversary to changes in one's own missile stocks. The most common assumption is of Cournot behavior with respect to missile stocks. This means that each country behaves as if the remaining countries will not modify their missile stocks in response to a change in its own missile stocks. While this allows the relatively tractable Cournot-Nash equilibrium concept to be applied, it does imply an extreme myopia among nations concerning the probable reactions of their adversaries.

An alternative to the myopic behavior implied by the Cournot assumption is the assumption of Stackelberg behavior. Brito (1972) postulates that each country employs information about current arms levels and rates of change in arms levels in both countries to predict future arms levels in the adversary country, and that this projection, which is continuously revised, is used to plan own current military investment. Thus, in contrast to the Cournot world, a country may incorporate into its armament decisions the expected reaction of its adversaries to any missile-stock change it considers.

A final alternative suggested in this literature is a solution concept proposed by Scarf (1969) and presented in Kalman (1971). The Scarf solution differs from that of Nash in that countries can combine in arbitrary coalitions and modify their strategies through joint action, and one coalition can respond to actions of another so as to deter attempts by the coalition to initiate change. Although this solution concept appears to have some desirable features and may represent a reasonable description of the interactions of arms race participants, it has not, aside from Kalman's brief treatment, been employed in the arms race literature.

POLICY IMPLICATIONS OF ARMS RACE MODELS

This section gives a brief survey of some of the policy implications of the arms race modeling literature, focusing on the contributions of economists. The discussion is not meant to be in any way exhaustive, but rather to sketch the kinds of issues that have been explored within the framework

of existing arms race models. The major policy results of this literature can be separated into two categories.

One group of results concerns factors that influence the likelihood of the existence of a stable equilibrium arms vector. Although this question is of primary concern in many of the arms race modeling efforts in the literature, explicit motivation for the policy relevance of the issue is largely absent. Yet the import of this question is not immediately obvious. Certainly the fact that a stable arms vector exists does not by itself imply that the arms race will end in a manner that is in any sense satisfactory. For instance, to prove that a stable equilibrium arms vector exists is not to prove that the arming nations will avoid war long enough to arrive at that equilibrium. And even to arrive at a stable equilibrium is not to ensure that war is not unlikely to break out. In fact, many of these models have nothing to say about the probability of war, either at various points during an arms race or once the equilibrium is reached. Models that do address the relationship between weapon stocks and the probability of war can be used to show that, in the presences of resource constraints, equilibrium weapon stocks and a high probability of war are perfectly compatible (see, for example, Chatterjee, 1974, and Lambelet, 1975).

Still, it seems that the conditions under which equilibria will exist and be stable provide potentially important information for at least three reasons. First, it may be argued that while the existence of a stable equilibrium arms vector is not sufficient nor perhaps even necessary for the avoidance of war, the knowledge that the arms race is of finite duration is worth something; it places bounds on the resource drain associated with the armament process, and to the extent that the period over which the arms race extends is typified by heightened international hostilities, it may diminish the probability of war by reducing the duration of this dangerous period.

Second, successful negotiation of an arms reduction treaty may be less likely in the atmosphere of international tension that accompanies an ongoing arms race than during the relative international calm that might be expected once a stable equilibrium arms vector had been reached. Hence, even if the particular equilibrium point toward which the arms race tended was not in itself desirable, once there, a more desirable situation might be more easily orchestrated.

Third, the existence of a stable equilibrium arms vector highlights the connection between various military choices and the character of the arms race itself, and suggests the possibility of manipulating the parameters that determine the position of the equilibrium to bring about desirable changes in the character of the race. Hence, the question of the exis-

tence of stable equilibria does seem to have policy relevance, although the lack of motivation in much of this literature necessitates a certain amount of speculation as to exactly how that relevance is to be defined.

A general result of the early Richardson modeling literature is that a stable equilibrium will exist whenever the economic constraints associated with large missile stocks—captured by the fatigue term—outweigh the desire to acquire new missiles in response to growing adversary missile stocks. These results, which seem to capture in a simple form the forces underlying most of the findings in this area, are given a sorely needed degree of policy content by later authors who introduce into their models technical, strategic, and behavioral factors.

Brito (1972) finds, for example, that an equilibrium arms vector will exist as long as there are positive costs associated with the maintenance of missile stocks, but that its stability depends on more questionable assumptions concerning the strategic interactions of arming nations. Intriligator (1975) concludes that the existence of a stable equilibrium arms vector depends crucially on the military objectives—for instance, deterrence or attack—of the arming nations. He also finds a relationship between certain technical factors—such as hardness of missile silos and the stability of equilibria. Siljak (1976) explores the relationship between the formation of alliances and the stability of the arms race and finds that the formation of neutral countries or alliances cannot undermine and is likely to increase the stability of an equilibrium armaments vector. While these results represent only a portion of the findings concerning the likelihood of the existence of stable equilibria, they provide a clear indication of the breadth of military policies that bear on this important question.

A second body of findings concerns the effects of various noncooperative and cooperative policies on the position and character of equilibrium arms vectors—that is, the size of the equilibrium missile stocks and the probability of war associated with them. Here again, a sampling of the results derived in the literature will attest to the diversity of policies that can affect the nature of the arms race. Intriligator (1975), for example, derives the equilibrium level of missile stocks as an explicit function of such factors as the degree of missile hardening, accuracy, and yield, as well as the length of warning time and effectiveness of civil defense programs in the arming countries. Thus many of a nation's military decisions concerning strategy and technology are shown to bear directly on the size of missile stocks toward which the arms race will tend.

Dumas (1979) explores the effects of a unilateral reduction in armaments on the nature of the arms race, and finds that unilateral arms reduction initiated by one country should, if the other country acts rationally in

its own self-interests, result in an equilibrium arms vector that involves fewer missiles and greater security for both countries. Intriligator and Brito (1976) examine the likely effects of various arms reduction and disarmament programs and find that, while limited unilateral or bilateral arms reduction may be desirable, bilateral disarmament agreements are clearly undesirable, as they move the equilibrium point in a manner that leads to the greatest probability of war. The high probability of war associated with bilateral disarmament arises as a result of what Brito and Intriligator call an inevitable movement through the "regions of initiation," both in moving to a disarmed position and, if hostilities resume, in rearming from the disarmed state. These are regions in which either or both sides have missile stocks that are sufficient for a preemptive strike but not sufficient to deter the other side from striking. Thus they lead to a high probability of war because the incentive to strike first is overwhelming.

Of course, arms race models that focus on domestic stimuli carry with them the implication that treaties addressing external factors will not have the desired effect. An example is provided by Brito and Intriligator (1981), who extend the examination of arms reduction treaties to a world of bureaucratic decision making, and conclude that arms treaties are likely to lead to an accelerated qualitative arms competition, which could ultimately result in lower levels of security and higher levels of military expenditure than were associated with the pretreaty equilibrium position. Thus models of this type suggest the necessity, if not the sufficiency, of domestic changes if the arms buildup is to be controlled.

The list of findings could continue, but the point seems clear. The various models in this literature provide a useful vehicle for examining the policy implications of a wide variety of alternative hypotheses concerning the nature of the arms race. The result is a body of important and often self-reinforcing findings that hold the promise of concrete contributions to future arms control and disarmament debates.

NEW DIRECTIONS FOR RESEARCH

In this section, areas of economic reasoning that have not yet been applied to the study of arms control and disarmament are briefly considered. Nothing approaching a rigorous development of the possible applications of economic theory is presented. Rather, the discussion is tentative and is meant to identify existing areas of economic thought that might, by analogy, be applied to issues of arms control. The potential of

this line of inquiry has been demonstrated in the past, for example, by the meaningful contributions of oligopoly theory to the analysis of arms control and disarmament issues. It seems reasonable that other areas of economic theory may also hold the promise of significant contributions to the existing body of arms control analysis.

EXTENSIONS FROM OLIGOPOLY THEORY

Given that the structure of arms race phenomena is normally described by a small number of participating nations, it is perhaps natural that the theory of oligopoly has contributed so significantly to the study of arms races. A particularly promising direction for future arms control research may therefore be the continued application of recent advances in oligopoly theory. Two broad categories concerning the application of oligopoly theory to armament issues may be identified: those implications of oligopoly structure that bear on the conduct of the oligopolists, and those implications of oligopoly structure that bear on the performance of the oligopoly.

With regard to the relationship between structure and conduct, several advances in oligopoly theory immediately suggest themselves for application to an analysis of the arms race. The first concerns the way in which interactions between the oligopolists are modeled. The theory of oligopoly that the arms race literature has utilized is founded on the notion of Cournot, or occasionally Stackelberg, behavior. Such behavioral assumptions are decidedly nonstrategic in that oligopolists are not allowed to make and communicate prior commitments to reaction functions—that is, to threaten retaliation—so as to influence the subsequent decisions of their rivals. Even a Stackelberg leader does not influence its followers with a commitment to some reaction function but only attempts to influence their decision by self-interestedly committing to some activity that the leader knows they will take as given. Yet the importance of strategic behavior in enabling models to achieve satisfactory solutions to problems involving individual interaction is becoming increasingly clear (Thompson and Faith, 1981), and existing empirical evidence is often compatible with models that allow for strategic behavior in oligopolistic situations (Laitner, 1980). This suggests that models that allow strategic behavior might be usefully introduced into the arms race modeling effort.

A framework within which strategic behavior has been introduced into the economic theory of oligopoly is the conjectural variation approach. The notion here is that each oligopolist makes a conjecture about its rivals'

reaction functions—these are the conjectural variations—and announces an output decision based on these conjectures. After simultaneous announcements by all oligopolists, plans are revised, and the process is repeated until the output bundle satisfies the objective of all parties. The outcome of this process is a Nash equilibrium conditional on the conjectures of each oligopolist.

As might be expected, this process leads to a multiplicity of equilibria (among which are included the Cournot and Stackelberg solutions), and it is because of this that strategic issues arise. Several attempts have been made in the literature to reduce the degree of indeterminancy in the conjectural variations solution, and they have helped to define the role of strategic behavior under conditions of oligopoly. Breshnahan (1981) introduces the notion of consistency of conjectures to narrow the possible equilibria to, under certain assumptions, a unique equilibrium point. His notion of consistency is simply that the conjectural variations and their respective reaction functions be equated. It requires that each oligopolist be able to recover the others' reaction functions, a task that, Breshnahan argued, should not be difficult provided the oligopolists can observe movements in the equilibrium that result from shocks exogenous to the oligopoly.

Two points deserve mention here. First, this notion clearly defines a critical role for strategic behavior, as it is the set of chosen reaction functions—that is, the structure of retaliation—that ultimately determines which of the multiplicity of equilibria will obtain. And second, Breshnahan's argument that a "natural experiment" can easily be performed to obtain information on the reaction functions of one's rivals is probably better suited to the industry framework within which it was made than to nations engaged in an arms race.

Laitner (1980) suggests a different approach to the indeterminacy of the conjectural-variations oligopoly solution. He imposes a rationality condition on the conjectures of each oligopolist. The condition rules out conjectures about a rival's reaction to one's own action that would not rationally be carried out by the rival in the event that the action were indeed to take place. While this approach does not succeed in isolating a unique equilibrium solution for the conjectural variation problem, it may be more appealing for application in the context of arms-race modeling, since it seems at once to capture both the inevitable uncertainty concerning a rival nation's true reaction function, and the emphasis placed on the "rationality" or credibility of various forms of threatened retaliation in an arms competition. Regardless of which notion is used, however, strategic behavior will play an important role in determining the equilibrium

outcome, either through the strategic adoption of an advantageous reaction function whose existence will be transmitted to rivals via the results of "natural experiments," or through the strategic construction of an advantageous rational response set via the selective restriction of one's options.

Once strategic considerations are introduced into arms race analysis, a variety of interesting issues can be addressed concerning the effects of various conjectures, reaction functions, and self-imposed constraints on the existence and position of a stable equilibrium arms vector. An example of conjectural variations analysis in a context quite similar to an arms race is provided by Thursby and Jensen (1983), who explore the implications of a class of conjectures (neither consistent nor rational) on the equilibrium tarrif vector in a tariff war between two countries. The conjectural variations approach provides a valuable framework within which to study the effects of retaliation on tarrif equilibria, and the findings of Thursby and Jensen suggest that increases in the magnitude of expected retaliation will under certain conditions result in lower equilibrium tariffs for both countries. The analogy between their modeling efforts and arms race modeling is clear, and the conjectural variations approach seems likely to provide an equally valuable framework for the evaluation of various forms of strategic behavior in arms competition.

Another recent topic of research related to the conduct of oligopolies that might have interesting applications to arms control issues is the notion that noncooperative actions over a sufficiently long period could yield the same outcome as cooperative actions in a single period. Shapiro (1980), for example, presents a pair of strategies to be followed by noncooperating duopolists that, starting from a Cournot equilibrium, would lead the duopolists to converge to a Pareto optimum with respect to their objective functions. The strategies are differential equations that tell the producers exactly what to do at each instant in time, and allow the user to test the rationality of a rival in a way that minimizes exposure to loss in the event of irrational responses. Further, the strategies are self-reinforcing in that the values of the objective functions of each party increase monotonically as they move from the Cournot to a Pareto solution point.

To the extent that this line of reasoning can be applied to nations engaged in an arms race (and similar ideas have been suggested in the arms race context by Dumas, 1979), it has important implications for the possibility of resolving arms competition in a Pareto efficient manner without having to rely on cooperative arms treaties. The application would be limited, however, to those activities where a rival's true response is readily discernible and has a well-defined effect on one's own national

security. Thus, the same sorts of verification issues that occur with cooperative treaty agreements will also be present here. Still, if nothing else, the idea represents a simple and powerful way to establish the rationality of one's rival, and possibly to lay the groundwork for more substantial cooperative agreements in the future.

Turning next to those implications of oligopoly structure that bear on the performance of the oligopoly, two additional applications suggest themselves. The first is to exploit the considerable body of research concerning the relationship between market structure and R&D expenditures to analyze the effects of nuclear proliferation on the nature of the qualitative arms race (national military R&D expenditures). Some work has been done concerning the effects of proliferation on the character of the arms race (see, for example, Brito and Intriligator, 1977; Intriligator and Brito, 1978; Okuguchi, 1981; and Intriligator and Brito, 1981), but the analogy between proliferation and a changing market structure has not yet been examined.

Dasgupta and Stiglitz (1980) analyze the relationship between market structure and R&D in a framework that might reasonably be adapted to the nuclear proliferation problem. They conclude, among other things, that increased competition in the present product market (an increase in the number of firms selling the product) leads to the likelihood of lower R&D expenditures in the industry, due essentially to the decreased opportunity for profit in the postinvention market, and that increased competition in R&D itself (an increase in the number of firms involved in R&D) leads to greater R&D expenditures. The analogy between their work and the question of nuclear proliferation is far from complete, but to the extent that arming nations do engage in qualitative arms competition in part to reap the benefits stemming from a dominant strategic position, it seems that such benefits would be a declining function of nuclear weapons proliferation, and consequently that a negative relationship between proliferation and world military R&D expenditures would exist. Similarly, a positive relationship between the proliferation of nuclear weapons research activity and world military R&D expenditures might be expected to hold. This kind of result could have important implications for the desirability of arms exportation and other policies that would bear on both the number of countries with nuclear weapons capabilities, and the number of countries with nuclear weapons research capabilities. While this is all purely speculative, it seems intuitively likely that this kind of framework could yield important insights into the nuclear proliferation issue.

A second issue that might be usefully explored within this market structure framework is that of alliance formation. The analogy between horizontal mergers and the formation of alliances could be exploited in order to borrow from the framework and results of the existing body of industrial organization literature concerning horizontal merger activity and its effect on market performance. As one possible example of the way in which the analogy between alliance formation and horizontal merger might be exploited, consider the analysis of horizontal mergers in Salant, Switzer, and Reynolds (1983). These authors explore the effects of horizontal mergers on the profits of the merging companies and find the possibility of decreased postmerger profits as a result of Cournot interactions between the newly formed merger and the other firms in the market. This leads the authors to describe a model that would distinguish profitable mergers from unprofitable ones, and thus predict which mergers would be likely to occur and remain stable in an equilibrium.

A framework of this sort seems well suited to the examination of various alliance issues in the arms race literature and, to the extent that the analogy could be exploited, would lead to a model of alliance formation that would enrich the existing analysis concerning the effects of alliances on the stability of arms race equilibria. The framework could be particularly useful in facilitating the exploration of an issue that has not yet been systematically addressed in the arms literature, namely, the impact of alliance formation on the position of equilibrium arms vectors. The fact that Salant et al. are able to describe the equilibrium output effects that Cournot interaction would produce as a result of merger activity suggests that this framework would also allow the calculation of equilibrium missile stocks as a function of alliance formation. This would represent a valuable addition to the existing body of knowledge concerning the importance of alliance formation in arms competition.

ASYMMETRIES

Next, we note that both optimizing and nonoptimizing Richardson-type arms race models have treated the agents in an essentially symmetric manner. However, the East-West arms race is fundamentally an asymmetric process. The political and economic institutional arrangements that constrain decision makers in both camps are vastly different, and these differences probably should be embodied in arms race models. The literature on the role of internal stimuli affecting the arms accumulation

process indicates that some theorists have relied exclusively on domestic institutional arrangements to explain the arms buildup (see for example, Kurth, 1972). Those employing the economic approach, however, have either ignored existing asymmetries or have treated them in an ad hoc fashion as an afterthought. No attempt appears to have been made to incorporate rigorously into a constrained optimization model the important differences that characterize the East-West political-economic dichotomy. It is likely that both the objective functions and the constraint equations will differ across blocs if these differences are incorporated into an interactive duopoly-type theoretical framework. Such models will yield implications for the impact of changed political and economic parameters that do not appear explicitly in existing constrained optimization models of the arms race.

In what respects might the economic constraints facing decision makers in the representative democracies of the West differ from those in the communist oligarchies of the Soviet bloc? We might suspect that many political decision makers in the West have an electoral incentive to supply desired government services (including defense services) while avoiding contemporaneous tax financing. Such a real election constraint does not exist in the East. Crain and Ekelund have studied the tendency of democratic governments to run perennial budgetary deficits. Using a model of political competition, they argue that even if deficit financing is known to represent an equivalent stream of future taxes (Barro, 1974), "there is a fundamental factor which may tend to enhance the willingness of voter-taxpayers to accept deficit financing of government output over increases in current tax prices" (Crain and Ekelund, 1978: 821) This political-institutional phenomenon suggests that the economic constraints facing decision makers in democratic states are functionally dependent upon political variables. If, for example, the option of deficit financing were constitutionally eliminated by a balanced budget amendment in the United States, then, ceteris paribus, we would expect to see a lower level of federal government spending. That is, the elimination of the deficit-financing option will act to increase the perceived tax prices of all government goods and services and so reduce the quantities demanded. Assuming the tax price elasticity of demand for defense goods and services is nonzero, there will be political pressure to cut defense spending as well as nondefense spending.

As a further indication of the way in which political-economic asymmetries might be incorporated fruitfully into economic models of the arms race, consider the following. Suppose that political constraints in democratic states direct decision makers to pursue the goal of deterrence

maximization as an imperfect substitute for the more general objective of national security maximization. The commodity "national security" can be thought of as being composed of three elements: defensive capabilities, offensive capabilities, and deterrence capabilities. Of course, most weapon systems can assume all of these roles simultaneously. Nevertheless, we can often categorize a weapon system according to which of these elements of national security it enhances most. For example, an antiballistic missile system is generally regarded as essentially defensive in character, although it is not so exclusively. With these distinctions in mind, we would expect the composition of the respective arsenals of a deterrence maximizer and a national security maximizer to differ substantially, even while facing both with identical budget constraints. If strategic nuclear weapons such as ICBMs and SLBMs initially provide least-cost units of deterrence, then it is likely that such weapons will be more prominent in the arsenal of a deterrence maximizer than in that of a national security maximizer.

Further, although the arsenal of a deterrence maximizer may tend to emphasize strategic nuclear weapons, this model need not imply the absence of conventional weapons. If we postulate eventually diminishing returns to deterrence, then at some point the marginal deterrence of conventional weapons per dollar will equal the marginal deterrence of strategic nuclear weapons per dollar and so both nuclear and conventional weapons will appear in the arsenal. This indicates that this model is consistent with real-world observations.

Uncovering a bias toward nuclear weapons is not an insignificant qualitative detail, yet it emerges from a simple adjustment of one nation's objective function. It is not our intention to argue that democratic nations do indeed act as deterrence maximizers. Rather, the above illustrates how important details may be uncovered if appropriate asymmetries are recognized. Thus the consequences of political-economic asymmetries, as the examples above begin to suggest, can be quite dramatic, and so some attention to the differences that characterize the principles in the East-West arms race may be usefully incorporated into duopoly-type interactive models.

EXPECTATIONS AND OPPORTUNITY COSTS

Another area where further investigation is desirable involves the opportunity costs associated with arms races and international tension. We do not have in mind the crowding out of private investment and consump-

tion by defense spending, which is addressed by Benoit (1962, 1968), and Barro (1981), among others. Rather, the high levels of risk and uncertainty associated with international tension, including the real possibility of a nuclear confrontation, may have numerous economic consequences. Slemrod (1982) has argued that the perceived threat of nuclear war adversely affects saving and investment rates which, in turn, have implications for economic growth. Arms races and international tension affect economic variables by influencing expectations. The extent of their impact on expectations has not been adequately explored. It is likely that such economic variables as the term structure of interest rates, the mix of investment between long- and short-lived assets, asset prices, the velocity of money, and currency exchange rates are all influenced by arms races and international tension.

Further, arms races and international tension may significantly influence commodity trade and financial capital flows. In the case of commodity trade flows, political instability will elevate the expected transactions cost and so act to inhibit trade. Financial flows will also likely exhibit some sensitivity to international tension and the threat of war. Financial capital, which otherwise might have flowed between nations, will be redirected as fears of an asset freeze or uncompensated expropriations intensify. These intangible barriers to trade preclude the mutual gains from free and informed trade that otherwise would have occurred. Thus extensive opportunity costs associated with international tension and arms races may exist in addition to the crowding-out effects of defense spending. The opportunity costs of international tension, ideally measured, would express the difference between world economic welfare in our current state and that attained in a world fully at peace with itself.

GROWTH ISSUES

At this point, a critical issue regarding economic growth should be mentioned. The existing action-reaction models of arms races have left unclarified an important ambiguity. Equilibrium in these models is characterized by a single vector in weapons space, not an equilibrium time path. If the action-reaction process is unstable and an equilibrium is imposed by the intersection of constraint curves, then again we have the implication that no forces exist that will change this level of weapon stocks. Does this mean that arms races are necessarily transitory, that they are guaranteed to approach a limit imposed either by intersecting reaction or

constraint curves? This appears to be the implication of these static action-reaction models. But will this implication remain if economic growth enters the model? Certainly we know that economic growth will cause the constraint curves to shift outward in weapons space over time. If the constraint curves alone are preventing further weapons accumulation, then economic growth provides the additional resources required to resume an arms race. Whether or not economic growth will shift the reaction curves is unclear, and is likely to depend upon the precise formulation of the model. In any case, the failure of most existing arms race models to incorporate economic growth is responsible for some dubious interpretations of the equilibrium position in such models (although Senger, 1975, presents an initial investigation of this issue). The role of economic growth in the interactive arms race models warrants further investigation.

BARGAINING THEORY

Another area that deserves mention is the theory of bargaining. With respect to bargaining issues in arms treaty negotiations, there may be several aspects of bargaining theory as developed in the economic literature that would be worth pursuing. First, there is a growing literature on the effects of reputation—the subjective expectations of bargainers about the behavior of their opponents—in a bargaining situation. In particular, the reputation an agent brings to the bargaining table has been advanced as a factor that ultimately contributes to the resolution of the indeterminacy inherent in the bargaining outcome. Formal models of the effect of reputation on the outcomes of games are provided, for example, in Kreps and Wilson (1982), while experimental evidence for its existence is provided in Roth and Schoumaker (1983).

The notion that bargaining outcomes are influenced not only by the strategic options and preferences of the bargainers but also by their expectations is important for the negotiation of arms treaties. Not only does the cultivation of an advantageous bargaining reputation take on new strategic importance (Rosenthal and Landau, 1979) but the likelihood of agreement is substantially affected by activities that foster common expectations among all bargaining parties. Thus, for example, the political volatility of a bargaining nation would tend to decrease the likelihood of an arms agreement because the uncertainty of reputations would increase the probability of discongruous expectations among the bargaining par-

ties. The systematic incorporation of these ideas into the analysis of arms issues should lead to a richer discussion of the possibility of cooperative arms agreements and of the form that those agreements might take.

The importance of reputation is not, however, limited to negotiated cooperative agreements. It was noted that one strategic activity that arises in the conjectural variations framework is the choice of a particular reaction function in an effort to affect the subsequent behavior of one's rivals. Where uncertainty about reaction functions exists, strategic signaling to convey a preferred reputation concerning retaliations may be undertaken in an effort to affect the conjecture of one's rivals. In this way reputation could play an important role in determining the nature of arms competition.

The models presented in Kreps and Wilson seem suited to the analysis of the effects of reputation in gaming situations analogous to arms races. As their models demonstrate, reputation can play an important role when uncertainty is present about the true objective functions of the gaming parties. Their models demonstrate the long-term rationality of short-term irrational actions in the context of a monopolist attempting to deter entry by developing its reputation. In that context, the short-term irrational behavior associated with a price war can be long-term rational behavior for a firm if its reputation as a "tough guy," cultivated as a result of that price war, yields sufficiently large gains in the future. A strong analogy exists between that context and one of the posturing of arming nations, absorbing the short-term losses associated with an arms race in an effort to cultivate reputations that will yield future benefits. To the extent that this analogy can indeed be exploited, the implications of a Kreps and Wilson-type analysis of the arms race would be that it is perceived by the participants as a long-term rational process that is driven by short-term irrational actions. This would provide a striking alternative to the result of Dumas (1979) that the arms race is a long-term irrational process that is driven by what are perceived as short-term rational actions.

A related body of literature concerns the optimal design of bargaining strategies. Vickrey (1978), for example, has discussed the possibility of applying demand-revealing processes to the efficient settlement of international disputes. Chatterjee (1982) however, states and proves an impossibility theorem concerning the existence of bargaining procedures that satisfy certain desirable criteria and are efficient in the sense that they induce a truthful revelation of preferences over the bargaining issue. Riley and Zeckhauser (1983) examine the desirability of haggling versus holding firm in bargaining situations, and demonstrate the superiority of

the holding firm strategy. And Fudenberg and Tirole (1983) examine the effects of certain bargaining parameters on such aspects of the solution as the probability of impasse and the likelihood of concessions.

With the exception of Vickrey, all of these analyses are carried out in the context of firm or market behavior, but these or similar frameworks appear to be readily adaptable to the arms negotiation context. For example, the driving force behind the results of Riley and Zeckhauser—that haggling is costly because it encourages bargaining partners to refuse a hard bargain in the hope of getting an easier one—should apply whether the hardness of the bargain is measured by the steepness of the selling price or the number of missiles one must concede. The findings and frameworks presented by these authors and others like them to the extent that they can be generalized to this setting, would prove extremely useful in the study of the proper design of arms treaties and bargaining strategies.

PENALTY SYSTEMS

A final line of economic inquiry that might be usefully adapted to the arms literature falls in the area of the design of penalty systems. Landsberger and Meilijson (1982), for example, view penalty systems as a means of regulating the generation of costly externalities, and in the context of income-tax evasion, derive a penalty scheme with desirable efficiency properties. Such systematic exploration of desirable properties associated with certain characteristics of penalty schemes could be usefully incorporated into the existing literature on the design and efficacy of economic sanctions for treaty violations. For example, the results of Landsberger and Meilijson indicate that a penalty system which involves a constant probability of detection is less effective in inducing the desired behavior than a penalty system that involves a properly constructed dynamic, state-dependent detection scheme. This detection scheme would involve subjecting individuals to varying degrees of detection probability as a function of their recent record of violations.

To the extent that these results are applicable to the arms control context, they would have important implications for the issue of verification. A treaty that incorporated these results in its verification mechanism would have the appealing property that intrusive means of verification necessary for high-probability detection of treaty violations need only be implemented sequentially as a nation's recent treaty violations mounted.

The application of this kind of result and the economic reasoning that provided it seems likely to contribute significantly to the existing literature concerning treaty enforcement.

CONCLUSION

The underlying determinants of a nation's perceived military requirements are numerous, and the way in which they combine to dictate military expenditures extremely complex. As some factors lend themselves more readily than others to modeling efforts, building mathematical models of the armament process can at best yield only a partial understanding of this important phenomenon. Still, when viewed from this perspective, modeling efforts provide a potentially powerful tool with which to gain insight into some of the important aspects of arms races and the armament process.

Within this more limited role, the arms race modeling literature has gained a great deal from the efforts of various authors to introduce strands of economic thought and methodology into the analysis of the armament process, both in terms of a greatly enriched understanding of the impact of national policy on the character of the arms race, and in terms of a more fully developed and coherent framework within which to carry out the analysis. At the same time, it seems that the existing contributions of economic thought to the arms race modeling literature represent only the tip of the iceberg. Much of what the economic approach has to offer this literature remains unexploited. As such, the continued application of economic thought and methodology to arms race analysis represents a promising route through which to gain a deeper understanding of the arms race problem.

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