Strategies for Studying Causation in Complex Ecological-Political Systems

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This article shows that some commonly advocated methodological principles of modern political science are inappropriate for the study of complex ecological-political systems. It also provides conceptual tools for thinking about the causal roles of environmental and demographic factors, and it discusses various strategies for hypothesis and inference testing.

Introduction

Recent research has focused on the effects of demographic and environmental change on political stability (Goldstone, 1991; Homer-Dixon, 1991, 1994; Westing, 1986). This research suggests that rapid population growth and "environmental scarcities"—scarcities of renewable resources such as cropland, forests, and freshwater—can contribute to widespread violence and social conflict, especially in developing countries. The research also highlights important methodological issues that arise when studying complex ecological-political systems.

Such systems are characterized by a large number of physical and social variables linked by numerous interactive (i.e., multiplicative or synergistic), nonlinear, and reciprocal (i.e., feedback) causal relations. Examples include rural-urban migration and urban unrest in developing countries caused by scarcities of land and water in the countryside; the penetration and evisceration of Third World regimes by powerful coalitions of rent seekers profiting from the overexploition of natural resources; and the evolution of international institutions that address climate change.

This article identifies and describes some of the methodological issues generated by research on complex ecological-political systems, with specific reference to systems in which environmental scarcity contributes to violence. It shows that some commonly advocated methodological principles of modern political science are inappropriate for the study of these systems, and an alternative, methodologically "pluralistic" approach to this research is proposed. The article is therefore addressed to two audiences: scholars who are principally interested in the methodology of comparative political science (because many political systems,

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even those not incorporating physical variables, exhibit the kind of causal complexity discussed here) and those engaged in empirical analysis of links between environmental scarcity and violence.

Contemporary North American political scientists often advocate a quasi-experimental method of hypothesis testing and causal inference modeled after the natural sciences. By this method, researchers ideally use broad theories of political behavior to generate hypotheses about causal relations between variables that interest them. These should be key or "critical" hypotheses that are both testable and linked directly to core concepts and laws within the more general theories. The researchers then test the hypotheses—and, in turn, the more general theory—against empirical data.[1] Of key importance, according to this method, is the choice of data. Data should provide for variation of both the hypothesized independent and dependent variables while allowing for control of all other potentially confounding variables.

The problem of data choice is particularly acute in the field of comparative politics. Researchers must often rely upon selected case studies—of specific countries, for example—to test their hypotheses, but the procedures they use to choose cases can be contentious. Recently, some commentators have focused criticism on the procedure of selecting "on the dependent variable," in which cases are chosen that exhibit a particular value, or range of values, of the dependent variable. It is generally thought that this procedure gives biased estimates of the effect of the independent variable and cannot therefore be used to draw causal inferences or test hypotheses (Geddes, 1990; King, Keohane, & Verba, 1994).

However, other analysts have shown that selection of the cases on the dependent variable is the best testing procedure when the independent variable is hypothesized to be a necessary cause of the dependent variable (Dion, 1994; Most & Starr, 1989). The following pages show that there are additional circumstances where selection on both the dependent and independent variables is warranted. Specifically, research on the links between environmental scarcity and social conflict is often aided by explicit selection of cases in which environmental scarcity and conflict both occur. This is so because the subject matter is extraordinarily

1. For many years, political scientists generally thought that testing hinged on falsification: If data clearly contradicted a hypothesis, the theory from which the hypothesis had been deduced was "falsified" and therefore rejected. Knowledge cumulation progressed not by proof but by disproof. Although it was based on Karl Popper's interpretation of natural science, most methodological experts now acknowledge that falsificationism seriously misinterprets how natural science actually works. Years ago, for example, Quine (1953) showed decisively that theories are tested as a whole and that the discovery of evidence that contradicts a particular hypothesis deduced from a theory hardly ever results in the wholesale rejection of the theory. For a general critique of falsificationism and a defense of an alternative understanding of hypothesis testing, see Diesing (1991, especially pp. 248-254).

complex: The systems under study are characterized by an immense number of unknown variables and unknown causal connections between these variables, by interactions, feedbacks, and nonlinear relationships, and by high sensitivity to small perturbations. Such complexities and uncertainties make it virtually impossible to choose cases that control for potentially confounding variables.

There is another characteristic of the environment-conflict research program worth noting. The program does not aim to determine the range of factors that explains the current value of the dependent variable (incidence of violent conflict); rather, it seeks to determine if a specific independent variable (environmental scarcity) can be an important cause of changes in the dependent variable.

This is not a goal generally thought to guide social-scientific inquiry. Usually, researchers want to explain or understand the current causes of certain types of social events. They are interested in the factors that currently influence the value of a specific dependent variable, *Y*. They therefore ask: What factors cause or explain changes in the value of *Y*? But researchers studying the links between environmental scarcity and conflict have a different goal. They are not interested in the whole range of factors that currently cause changes in the value of the dependent variable (conflict); instead, they want to know whether, and how, a hypothesized independent variable in particular (environmental scarcity) can cause conflict. Their key question is therefore different: Can variable *X*, in particular, cause changes in the value of variable *Y*? Their emphasis consequently shifts from explaining the current incidence of the dependent variable (*Y*) to understanding the current and potential causal role of a specific hypothesized independent variable (*X*) and the nature of the causal relationship between the two variables.[2]

This shift in focus is not uncommon. It is reasonable, for example, when two conditions hold: first, the value of a variable in a complex system is changing significantly or is thought likely to change significantly in the future and, second, researchers want to know if this change will affect other variables that interest them. In cases where the value of the hypothesized independent variable has changed little or only slowly in the past, standard statistical procedures reveal little relationship

2. Dessler (1992) similarly distinguishes between a focus on outcomes and a focus on causal factors:

> The analyst interested in some phenomenon might treat it as an outcome or feature of some process or structure and search for conditions associated with its appearance. Alternatively, the researcher might choose a factor known or thought to play a role in causing the phenomenon and analyze the tendencies of this factor in isolation. Both categories of analysis link factors to outcomes, but convey different information about this link. Whereas the first category (focus on *outcome*) tells us what configuration of conditions lead to some specified observed outcome in the world, the second one (focus on *factor*) tells us what outcomes tend to be brought about by the workings of a specified factor, whether these outcomes are actually produced. (p. 8)

Dessler derives his distinction from Mill (1859).

between this variable and other variables. If researchers are interested in the potential causal role of the independent variable, they need to study past cases selected specifically to accentuate its variance.

The above two conditions apply in environment-conflict research: Evidence suggests that environmental scarcity is getting rapidly worse in many parts of the world, and the incidence of violent conflict around the world is of concern to many political science researchers. Therefore, these researchers might reasonably ask the following questions:

1. Can environmental scarcity contribute to violent conflict?
2. If yes, how can it contribute to conflict?
3. Is this contribution interesting?

Identifying how environmental scarcity can contribute to conflict—that is, answering the second question—means identifying scarcity's possible causal roles. Identifying its causal roles helps answer the third question; for example, environmental scarcity's contribution to a given conflict is interesting if it is identified as a powerful and independent cause.

Clearly, all three of the above questions can only be properly answered with empirical evidence derived from careful research. But two difficult and interrelated issues immediately arise. The first is empirical: What are environmental scarcity's possible causal roles? For example, researchers commonly distinguish among three: Environmental scarcity might be a *trigger* that releases accumulated nonenvironmental social pressures; an *aggravator* of already existing conflicts; or an *underlying stressor* that is causally distant yet powerful. The second issue returns us to the methodological problem introduced above: How do we test our hypotheses about the current and potential causal role of environmental scarcity as a contributor to violent conflict? Researchers argue over the relative merits of quantitative and case-study analysis, over how many and what types of case studies should be used, and over the circumstances that require rejection or modification of hypotheses. These two issues are addressed below.

Identification of a Causal Role

Debate about whether and how environmental scarcity contributes to conflict often centers on the specific causal role of this factor.[3] There are

3. Although widely used by social scientists, the concept of causation is far more imprecise than is usually acknowledged. For insightful analysis, see Humphreys (1989), Salmon (1984), Van Inwagen (1980), and Beauchamp and Rosenberg (1981). In addition, there are serious philosophical debates about whether and how causal claims in the social sciences differ from those in the natural sciences. These debates are particularly pertinent to environment-conflict research, because many causal claims in this field mix natural and social variables. See Fodor (1975), Schiffer (1991), and Rosenberg (1980).

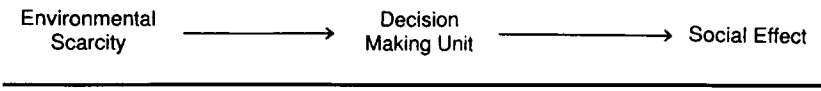

Figure 1: The Decision-Making Unit

two useful ways of thinking about this issue: We can focus on how environmental scarcity influences rational actors, or we can focus on the nature of the hypothesized relationship between the cause (environmental scarcity) and its effect (conflict). Although not mutually exclusive, these two approaches are discussed separately.

THE RATIONAL ACTOR APPROACH

Dessler (1994) provides an account of the rational actor model. Figure 1 shows that environmental scarcity influences the decision-making unit (DMU), which might be an individual, a group, or an organization. The DMU, in turn, chooses to act in such a way as to produce a social effect. The DMU might choose, for example, to migrate, to change its resource consumption behavior, or to attack another group to obtain more resources.

Dessler (1994) disaggregates the DMU and its environment into four components, each of which influences the ultimate choice that the DMU makes. First, the DMU confronts an "opportunity structure," which is an external and objective set of constraints and pressures that determines its set of feasible actions. Second, the DMU's cognitive processes and circumstantial factors in the DMU's environment influence the perceptual salience of opportunities and obstacles in its environment. Third, the DMU has certain relevant beliefs about the causal consequences of its various possible actions. And fourth, the DMU has preferences regarding the various outcomes that it believes will arise from its actions.

Dessler (1994) argues that environmental factors can affect all of these components, either singly or in combination. Environmental scarcity can obviously influence the set of feasible actions: Severe land degradation, for example, might close off certain agricultural and economic options for the DMU. Environmental scarcity can also influence the salience of perceived options or obstacles: A sudden drought might make obvious the long-term deterioration of the agricultural economy. Dessler argues that environmental factors can also have multiple and complex influences on the DMU's beliefs and preferences. In Dessler's opinion, attention to these various effects of environmental factors on decision makers allows nuanced analysis of the causal role that the environment plays in contributing to conflict.

THE CAUSAL RELATIONSHIP APPROACH

The other approach to analyzing the causal role of environmental factors focuses on the nature of the relationship between the cause and its effect. The following seven variables can be used to characterize this causal relationship: necessity, strength, proximity, exogeneity, multicausality, interactivity, and nonlinearity.

Necessity is a dichotomous variable: Something is either a necessary cause of a given type of event, or it is not. Environmental scarcity is clearly not a necessary cause of violent conflict, because much violence occurs in situations of resource abundance. Unlike necessity, the *strength* of a cause can vary along a continuum or scale, from weak to "sufficient."[4] Causal *proximity* can similarly vary along a scale from distant to proximate. We commonly think of proximity in terms of causal distance in time or space. But proximity is really a function of the number of intervening causal steps or variables between the cause and its effect: The larger the number of intervening variables, the lower the causal proximity.[5] The characteristics of proximity and causal strength are sometimes conflated, because a distant cause is often assumed to be weak. But intervening variables do not necessarily weaken the link between a cause and its effect.

The causal independence of a variable, or its *exogeneity*, can also vary along a scale from fully endogenous to fully exogenous. Many analysts assume that environmental scarcity is no more than a fully endogenous intervening variable linking political, economic, and social factors to conflict (see the first diagram in Figure 2; Smil, 1994). By this view, environmental scarcity may be an important indicator that political and economic development has gone awry, but it does not merit, in and of itself, intensive research and policy attention. Instead, we should devote our resources to the more fundamental political and economic factors.

There are, however, three reasons why this view is not entirely correct (as illustrated in the second and third diagrams in Figure 2). First, environmental scarcity can be an important force behind changes in the politics and economics governing resource use. Scarcity can cause powerful actors to strengthen an inequitable distribution of resources in their favor. Second, ecosystem vulnerability is often an important variable contributing to environmental scarcity, and this vulnerability is, at least in part, an external physical factor that is not a function of human social

4. See Most and Starr (1989, pp. 52-54), for a discussion of necessity and sufficiency. The strength of a cause can be measured by the *probability* of the cause producing a given effect; if the probability is 1.0, then the cause is sufficient.

5. Goertz (1994) notes that causal proximity is influenced by theoretical and pragmatic concerns, because it is usually possible to specify the variables and links in the causal process with greater and greater detail and thereby reduce proximity, especially by dropping down to lower levels of analysis.

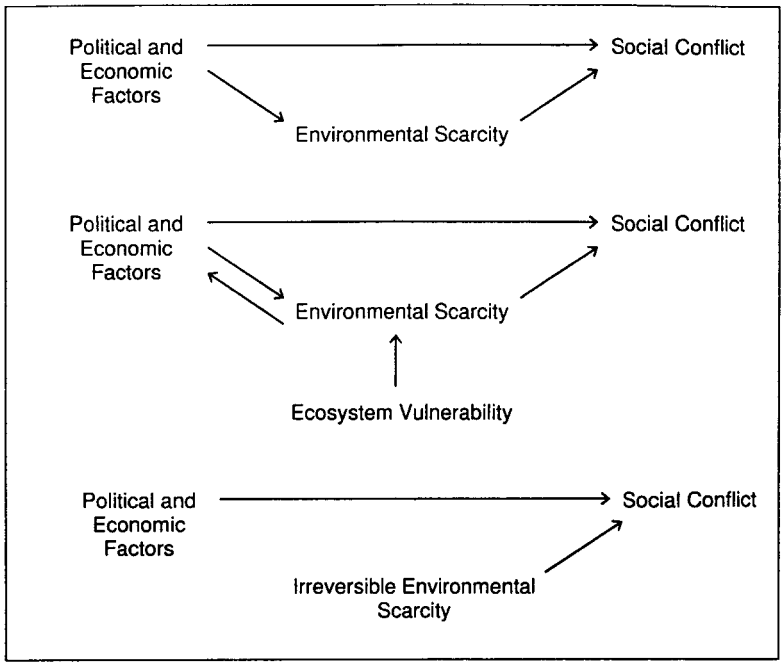

Figure 2: Three Views of the Role That Environmental Scarcity Plays in Violent Conflict

institutions or behavior. Third, in many parts of the world, environmental degradation has crossed a threshold of irreversibility. Even if enlightened social change removes the original political, economic, and cultural causes of the degradation, it will be a continuing burden on society. In other words, once irreversible, environmental degradation becomes an exogenous variable.[6]

The degree of *multicausality* of the processes producing social conflict also varies. If environmental scarcity contributes to conflict, it almost always operates with other political, economic, and cultural causes. Analysts who are skeptical about environmental scarcity as a cause of conflict often conflate the characteristics of multicausality and causal strength by assuming that if many factors are involved, each must be relatively weak.[7]

Interactivity is a dichotomous variable: The relationship between two causes of an event can be either interactive or additive. Interaction is a common feature of environmental-social systems. In an interactive system

6. See Homer-Dixon (1994, pp. 35-36). When environmental degradation becomes irreversible, it takes on the character of a "barrier" cause—that is, a cause that constrains opportunities and precludes options. See Goertz (1994, pp. 90-113).

7. In contrast, "environmental determinists" tend to assume that few factors operate and that the environmental ones are powerful.

of causes of a specific social event, none of the causes is sufficient, but all are necessary; thus causal strength and interactivity are linked, because no single cause can produce the event itself. But beyond this statement, it is meaningless to claim that a given cause in an interactive system is stronger—or should be given more weight in the analysis—than another.[8]

Finally, the degree of *nonlinearity* of the mathematical function describing the relation between a cause and an effect can vary from high to low. A system with highly nonlinear functions can exhibit unanticipated "threshold effects" and chaotic behavior in response to small perturbations. This is a key characteristic of many environmental-social systems.

Academic and lay discussions of environment-conflict linkages are usually larded with imprecise causal verbs such as *aggravate*, *amplify*, and *trigger*. These fuzzy, *folk* concepts are useful in everyday explanations of physical and social events, but they are not always helpful for research. However, by using the above distinctions, these terms can be clarified.

A claim that an environmental factor amplifies the effect of other causes of conflict implies that the factor interacts with the other causes to multiply their impact. In contrast, a claim that the factor aggravates the impact of the other causes seems to suggest that the factor's effect is added to that of others. A trigger of conflict is always a proximate cause and usually an unnecessary and insufficient one too. The term also implies that the system responds nonlinearly to the factor in question; that is, the factor triggers a disproportionately large response by pushing the system beyond a critical threshold. Stochastic and extreme environmental events—such as cyclones, floods, and droughts—can be important triggers of conflict. They can provide challenger groups with opportunities for action against a state whose buffering capacity has been gradually eroded by civil war, corruption, economic mismanagement, rapid population growth, or deteriorating stocks of renewable resources.[9]

8. Such a claim is like the assertion that the 3 in the product term $2 \times 3 = 6$ contributes more to the 6 than the 2 does. The error of treating an interactive relationship between variables as an additive one is common in debates about the relative contribution of nature and nurture to such human characteristics as height and intelligence; commentators often claim that some proportion of measured height or intelligence, say, 60%, is a consequence of nature, whereas the remainder, additively, is a result of nurture. As Sober (1988) points out, such a claim is meaningless when applied at the "local" level—that is, at the level of the individual person or event. At the level of the population of persons or events, however, the claim might be a meaningful interpretation of the results of an analysis of variance, if it means that a certain proportion of the variance in the population can be explained by the factor in question. At the local level, the only time it is appropriate to differentially weight the causal contribution of variables in an interactive relationship is when they have different rates of change over time. Holdren (1991, especially pp. 243-244) provides a mathematical method for estimating the relative causal importance of variables in such situations.

9. Such opportunistic exploitation of drought in Africa is discussed by Wallensteen (1986).

Aggravator, amplifier, and trigger models are popular with skeptics, because they seem to relegate environmental scarcities to the status of secondary causes of conflict. Although these models are often valuable, they offer inaccurate and incomplete explanations of interesting cases. Research shows that environmental stresses can be important contributors to conflict even if causally distant and even if the system is interactive and highly complex (Homer-Dixon, 1994).

Hypothesis Testing

All empirical research must begin with hypotheses. These often take the form of if-then statements about causal relations, or, at least, correlations between types of events.[10] The *if* in the if-then statement identifies the independent variable, whereas the *then* identifies the dependent variable. The if also states any *scope conditions*, which are additional circumstances, perhaps intervening between the independent and dependent variables, that must be true if the whole if-then statement is to be valid.

Development of hypotheses is not a simple process. Researchers usually start with very simple causal or correlational hypotheses, perhaps, but not necessarily, derived from a general theory. They use each hypothesis to interrogate available evidence by asking the question: What does the evidence say about the hypothesized correlation or causal process? Evidence that flatly contradicts the hypothesis—often called a *null finding*—is valuable, but other kinds of evidence are valuable too. This includes evidence that supports the hypothesis and evidence that is equivocal but suggests the alteration of category boundaries, introduction of intervening variables, or addition of new causal linkages. On the basis of all this evidence, not just of null findings, researchers refine their hypotheses as their work progresses.

Over time, the boundaries of the independent and dependent variables are more precisely defined (which often involves generating additional categories of these variables), and the understanding of the scope conditions becomes more textured. This process is neither purely deductive (from hypotheses to evidence) nor inductive (from evidence to hypotheses), but rather it is an iterative cycle between increasingly sophisticated hypotheses and an increasingly comprehended empirical world (George & McKeown, 1995, especially p. 24). If, eventually, the hypotheses become sufficiently refined, and if they are linked by a definable set of binding assumptions or concepts, then we can reasonably speak of a *theory* that explains the set of events under study.

10. A statement of the form, If *X*, then *Y*, implies that the antecedent *X* is a sufficient cause or condition for the consequent *Y*. When *X* is hypothesized to be a necessary cause, then the statement should be of the form, Only if *X*, then *Y*. When *X* is proposed as a necessary and sufficient cause, then the statement should be, If and only if *X*, *then* *Y*.

In environment-conflict research, a number of methods are available to test hypotheses against empirical evidence. Three deserve close attention, of which the first two are conventional, quasi-experimental methods in political science. First, researchers can undertake a *correlational analysis* of large amounts of quantitative data on the relative frequencies of environmental scarcity and conflict across many societies and over time. Such an approach involves statistical estimation of the probability of obtaining a given correlation observed in the data if, in actuality, there is no correlation in the real world between the variables in question.[11] Second, researchers can undertake a *controlled-case comparison*, in which cases are selected that vary on the independent variable, environmental scarcity, but that are essentially the same for all other variables that might affect the incidence of conflict. Researchers aim to select cases that control for all variables except environmental scarcity so that scarcity's effect on conflict can be isolated.[12] If sufficiently similar cases are not available, researchers can instead undertake thought experiments using counterfactual analysis in which researchers ask, What would have happened if the independent variable changed its value but all other factors remained constant?[13]

Finally, researchers can undertake *process tracing* of the causal processes in a selection of cases where environmental scarcity apparently contributes to conflict. Here, in violation of the strict canons of conventional political science, cases are selected explicitly on both the independent and the dependent variables. The aim is to determine if the independent and dependent variables are causally linked and, if they are, to induce from a close study of many such cases the common patterns of causality and the key intermediate variables that characterize these links.[14] Process tracing often involves dropping down one or more levels of analysis to develop a more finely textured and detailed understanding of the causal steps between the independent and the dependent variables.[15] In process tracing, George and McKeown (1985) write:

11. Of course, as often noted, correlation does not prove causation; so a correlational analysis by itself does not adequately answer the three key questions posed in the introduction of this article.

12. A similar approach is *crucial case* analysis, in which hypotheses deduced from a theory are tested against a case that would appear to be better explained, prima facie, by an alternative, competing theory. See Eckstein (1975).

13. For a thorough discussion of counterfactual analysis, see Fearon (1991).

14. Controlled-case comparison and process tracing are both discussed in George and McKeown (1985, pp. 24-43).

15. To the extent that these causal linkages are specified by the researcher's hypotheses, process tracing increases the number of empirical observations that can be used to test the hypotheses. This is one way of dealing with the problem of an inadequate number of observations for the number of causal variables hypothesized—the "small-*N* problem"—that many analysts believe bedevils comparative case-study methodology. See King et al. (1994, pp. 226-227).

> [T]he process of constructing an explanation is much like the construction of a web or network. The researcher assembles bits and pieces of evidence into a pattern; whether a piece is to be changed or added depends on whether the change fits with what already has been constructed, and whether it strengthens the web's structure. Does the modification of the explanation create internal inconsistencies in the theory? Does the modification of the explanation create more new puzzles than it solves? If yes is the answer to these questions, the modification is rejected. Modifications that are consistent and produce smaller, more localized, and less frequent research puzzles are to be valued. The growth of the web orients the search for new pieces, just as the growth of a jig-saw puzzle guides the search for pieces that will fit together with what is already assembled. (p. 36)[16]

A central claim of this article is that the stage of research strongly influences the method of hypothesis testing a researcher can use to best advantage. During early research in a new field, especially if the subject matter is highly complex, hypotheses are liable to be too crude to support testing that involves quantitative analysis of large numbers of cases. Similarly, it may be inefficient for a researcher to spend a great deal of time examining cases in which the cause of interest does not occur, as would be required by a methodology of controlled comparison. Initially, at least, the researcher can often use research resources to best advantage by examining cases that appear, prima facie, to demonstrate the causal relations hypothesized—that is, by selecting on the independent and dependent variables. This narrow focus allows the researcher to efficiently identify conceptual errors and basic empirical weaknesses in the early hypotheses. Later, as the hypotheses become more refined and as understanding of scope conditions becomes more textured, the hypotheses can be subjected to much more rigorous analysis.

The issue of selecting on the independent and dependent variables is contentious within environment-conflict research. Early pioneering

16. Process tracing provides a particular type of explanation of the independent variable, which Kaplan (1964) calls the "pattern" model of explanation. Kaplan writes, "According to the pattern model . . . something is explained when it is so related to a set of other elements that together they constitute a unified system. We understand something by identifying it as a specific part in an organized whole." Kaplan notes that the pattern model of explanation is distinct from the "deductive" model: "Very roughly, we know the reason for something either when we can fit it into a known pattern, or else when we can deduce it from other known truths" (pp. 332-335). Kaplan's deductive model corresponds to Hempel's (1965) "deductive-nomological" or "covering-law" model of explanation, whereby a phenomenon is said to be explained if its occurrence can be shown to be logically expected, given certain general laws. However, Hempel similarly distinguishes between covering-law explanations and what he calls "genetic" explanations, which, he argues, are generally a better form of explanation for social events. A genetic explanation "presents the phenomenon under study as the final stage of a developmental sequence, and accordingly accounts for the phenomenon by describing the successive stages of that sequence" (p. 447). Thagard (1992, pp. 118-126) makes an analogous distinction between deductive, schematic, and causal modes of explanation.

		Violent Conflict	
		Yes	No
Environmental Scarcity	Yes	1	2
	No	3	4

Figure 3: Environmental Scarcity and Violent Conflict Matrix

work focused explicitly and intentionally on cases where the hypothesized causal link between environmental scarcity and conflict appeared to exist (Homer-Dixon, 1994). Given prevailing methodological thought within political science, it could be claimed that this approach biased the work's results in favor of positive findings.

The criticism would take the following form. If environmental scarcity is the independent variable and violent conflict is the dependent variable, and if each variable, crudely, has two possible values, then we have four possible outcomes, as illustrated in the matrix in Figure 3. All cases (say, countries) are located in one of the four quadrants of the matrix. If environmental scarcity is a necessary cause of conflict, there are no cases in Quadrant 3, but there may be cases in any of the other three. If scarcity is a sufficient cause of conflict, there are no cases in Quadrant 2, but, again, there may be cases in the others. If scarcity is both necessary and sufficient, there are cases only in Quadrants 1 and 4.

A correlational analysis attempts to determine if the distribution of cases across the four quadrants is significantly different from a distribution that could be expected by chance alone. A distribution that is significantly different provides evidence that environmental scarcity and conflict are correlated. A controlled case comparison varies cases on the independent variable, environmental scarcity, without regard to values of the dependent variable; of particular interest are any null cases in Quadrant 2 in which all the preconditions of the hypotheses connecting environmental scarcity with conflict hold, yet conflict does not occur. Finally, process tracing focuses on cases selected just from Quadrant 1. This is the method used in much environment-conflict research to date.

Critics might contend that process tracing somehow avoids a fair test of hypotheses. However, in the early stages of research, process tracing is often the best, and sometimes the only, way to begin. It can show, for

particular cases, whether the proposed independent variable is a cause of the dependent variable. It answers the important questions identified above: Are there any cases in Quadrant 1 in which the independent variable is causally linked, in a significant and interesting way, to the dependent variable? If so, how does this causation work?

More important, in highly complex systems such as ecological-political systems, it is likely that the proposed independent variable is not a sufficient cause of the dependent variable. Rather, as noted, multiple factors, including the hypothesized independent variable, interact to produce the effect in question. If a hypothesis is to be valid for such a system, therefore, it has to be more than a simple statement of X causes Y or X is correlated with Y. The hypothesis requires, in addition, numerous and detailed scope conditions; it must take the form, for example, of X causes Y, when A, B, and C are true.[17] Adding the right scope conditions should increase the causal strength of the whole set of independent variables and scope conditions taken together. As the causal strength of the whole set increases, and if the whole set is taken as the independent variable, cases in Quadrant 2 should move to Quadrant 4. If enough conditions are specified, it might be possible to identify a set that is a "jointly sufficient" cause of Y. In this case, Quadrant 2 should be empty.

Without including adequate scope conditions, a statistical analysis of the distribution of cases across the quadrants in Figure 3 probably reveals little correlation, even though there might be important and interesting causal links between environmental scarcity and conflict. Yet careful process tracing, involving close examination of the causal process operating in the cases in Quadrant 1, helps identify the relevant scope conditions.

Highly complex systems also present problems for controlled case comparisons. Such an approach, which, ideally, varies cases on the independent variable, is appropriate only if the researchers can be sure that all other variables that might affect the incidence of conflict are controlled. Then they can see what happens with the sole difference of variation in the independent variable.

Unfortunately, however, with ecological-political systems, researchers can never be sure that everything relevant is controlled. As indicated above, these systems include countless unknown variables and causal connections; analysts may not even be aware of the existence of many variables and causal linkages, let alone how they operate. Moreover, the relationships between their variables are often nonlinear,

17. The conjunction in this statement could also be *or*. Thus, an exhaustive statement of the conditions would be of the form X causes Y when conditions A and/or B and/or C . . . and/or N are true. The relationship between X and these conditions is interactive. Ragin (1987, pp. 23-30) discusses the methodological implications of such "multiple conjunctural" causation in which multiple causes interact in different combinations to produce effects of interest to researchers.

reciprocal, and interactive (Broecker, 1987; Chen & Fiering, 1989; Ludwig, Hilborn, & Walters, 1993; Smil, 1993, especially chapter 5; Wiman, 1991), which makes the systems highly sensitive to small perturbations by relatively peripheral variables. It is therefore often impossible to identify cases similar enough that key independent variables can be isolated. Unknown and ill-understood differences between cases selected to vary only on a specified independent variable may have a great influence on the occurrence of conflict. Consequently, a close study of the incidence of conflict in cases that do not exhibit severe environmental scarcity may not reveal anything about whether and how environmental scarcity contributes to conflict.[18]

One possible response to this problem of lack of adequate control is to carefully compare positive cases in Quadrant 1 with any null cases that appear in Quadrant 2.[19] Such a comparison might help identify hidden factors and processes that influence links between environmental scarcity and conflict. However, once again, the high uncertainty about the character of the systems under investigation means that it is not sensible for researchers to conduct such a comparison before they have a good idea of how environment-conflict linkages work. Early in a research program, a focus on cases in Quadrant 1 using process tracing is an efficient use of resources. If, instead, researchers spend much of their time examining null cases in Quadrant 2, they will probably waste resources following red herrings and bad leads.

Close study of Quadrant 1 cases using process tracing allows the researcher to determine key scope conditions and intermediate processes and variables. Eventually, on examining cases in Quadrant 2, the researcher can ask whether these scope conditions and intermediate variables were present, and if not, why not. If these factors were present, the researcher can then determine what other factors prevented environmental scarcity from causing conflict. This staged approach permits progressive refinement of hypotheses and their scope conditions.

In summary, when researchers investigate highly complex causal systems, such as ecological-political systems, the choice of methodology to test hypotheses should be partly determined by the stage of research. In early stages, more attention should be given to the process tracing of causal links in cases where the hypothesized causal links appear to exist. As hypotheses are refined, an expanded range of methodologies can be used, including correlational analysis and controlled case comparison. Truly robust hypotheses—that is, hypotheses that reflect the complexity of the system under examination and that have a high probability of validity—are necessarily a product of later stages of research. They are

18. The problems of control in case study research are highlighted in George and McKeown (1985, p. 27; see also Fearon [1991], p. 174, n. 11).

19. Marc Levy (1995) advocates this strategy.

the product of an iterative process of engagement with empirical data, using a range of quantitative and case-based tests.

Conclusions

Experts on methodology in political science often advocate an approach to hypothesis testing and causal inference that is modeled after the natural sciences. This orthodoxy stresses quasi-experimental research designs—including large-scale statistical analysis and controlled-case comparisons—that supposedly permit control of confounding variables, allow for variance on selected dependent and independent variables, and permit the disaggregation of the relative causal "weight" of different independent variables. The study of ecological-political systems highlights some weaknesses of this approach.

First, political scientists, and social scientists in general, tend to use folk concepts of causation that often do not further our understanding of complex social systems. A more precise and differentiated grasp of the possible causal roles of environmental scarcity as a contributor to conflict should inform methodological decisions about how to test environment-conflict hypotheses. In particular, researchers must be aware of the multivariate and highly interactive nature of ecological-political systems: These characteristics often render moot questions about the weighting, or relative strength, of specific causal variables.

Second, these systems are very opaque to researchers, in that they are extremely complex, ill-understood, and sensitive to small perturbations—characteristics that can together overwhelm both statistical and controlled-comparison methods. Consequently, in early stages of research involving ecological-political systems, process tracing is the best method to develop, refine, and test hypotheses. As research progresses and hypotheses become more sophisticated, researchers can fruitfully use a broader range of methodologies. In general, analysts should remember that political science is, at best, a soft science; a pluralistic approach to research methodologies is therefore often justified.

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