POLITICS AND THE ENVIRONMENT: NONLINEAR INSTABILITIES DOMINATE

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This analysis investigates a formal nonlinear systems model characterizing longitudinal change in the environment as a function of oscillating partisan control of the White House. It is assumed that one political party will tend to favor help for the environment despite some economic costs, whereas the other party will generally favor economic growth over environmental concerns. These policy changes affect the environment interactively with both public concern for particular environmental problems and the economic costs relating to environmental repair. This interaction with policy changes causes a disruption in the continuously evolving balance between the social factors that damage the environment and the environment's own ability to recover. The disruptive potential to the environment is considerably ameliorated with a reduction in the electoral cycling.

The relationship between presidential elections in the United States and the degradation of the environment is not thoroughly understood. In this analysis, the relationship is characterized as a nonlinear interaction between oscillating environmental policy positions due to changes in partisan control of the White House and two other critical inputs. These inputs are public concern for the environment and the economic costs of environmental cleanup.

Broadly, this addresses a contextual question relating to political structure. The current theoretical connection between the dual cycles of partisan control of the White House and public concern for certain issues finds direct correspondence with recent research on cycles in the public mood by Stimson (1991). The joint effect of electoral structure and political context on this cycling is an extension of a thematic approach to the study of political parties as pursued by Beck (1974), Huckfeldt (1983), and Sprague (1981), in which party activities are seen as agents influenced by the structure of various social constraints. These constraints, combined with normal party activities, often produce nonobvious by-products. I investigate this phenomenon here with regard to environmental policies. The results of the current investigation suggest that the interaction of the inputs just mentioned can lead to a surprisingly high potential for significant, and perhaps dangerous, volatility in the quality of the environment.

The relationship between democratic political structures and the environment is a relatively new area of research. It is easy to see how a rigidly communist or dictatorial society could inflict substantial environmental damage locally (or, in some instances, even globally), since public pressure for such governments to be environmentally conscientious is typically lacking.[1] But environmental damage occurs in democratic societies as well, and the level of this damage can be severe indeed, despite ostensibly "popular checks" against blatant abuse.

During the past 20 years, there has been an increasing global awareness of the immediacy of our planetary environmental worries. In part, this is evidenced by the existence of international meetings dealing with the environment, such as the June 1992 meeting in Rio de Janeiro of the United Nations Conference on Environment and Development. However, what has become increasingly obvious in international negotiations relating to the environment is that the dominant consideration of each of the participants is the likely impact on their own domestic politics. It is not well understood how the organizational structure of each society's politics may influence longitudinal change in national environmental policies and thus long-term change in environmental degradation. In short, understanding the domestic aspects of environmental policies goes well beyond obtaining recent survey data of the general public's attitudes. If serious damage is being done to the environment, understanding how governmental structure, particularly democratic political structure, contributes to the outcome is critical to our being able to minimize that damage in the future. The focus here is on an aspect of the electoral structure of presidential politics in the United States as an example of this relationship between democratic political structures and environmental damage.

Crucial to this discussion is the understanding that in democratic societies in general (and certainly in the United States), environmentalism is subject to the same fate of political trade-offs as is any other concern. The typical environmental trade-off is economic, as measured in terms of losses in gross domestic product or jobs. Indeed, this is the focus of a recent analysis of the economic consequences of global warming by Schelling (1992). In one respect, the current investigation is an attempt to extend the discussions between environmentalists and economists to a broader range of social scientists as well, including political scientists who are interested in democratic electoral politics.

This analysis proceeds by developing a model of change in environmental degradation that is structured by electoral change, public mood, and economic cost constraints. Simulations are then performed on the model that reveal its more basic dynamic properties by systematically changing one input at a time while holding all others constant. An analysis of some of the global properties of the model is then conducted over a continuous and realistically wide range of potential parameter values important to the process. Substantive conclusions are then drawn from this characterization of the political–environmental process.

THE EXTENSION FROM ECONOMICS TO POLITICS

Most of the social science literature on environmental degradation points to economic consequences of particular environmental change (e.g., global warming, ozone destruction, toxic contamination), including governmental responses to these changes. Particularly far-reaching in this regard is Schelling's (1992) analysis of global warming. (Other prominent examples of the environmental–economic connection include Darmstadter 1991, Moulton and Richards 1990, Nordhaus 1991a, 1991b, and Poterba 1991).

On a more political level, one focus of the extant literature has been on the bureaucratic or regulatory responses to competing political and environmental demands. Tobin's (1990) analysis of the regulatory failure associated with biological diversity is seminal in this regard. Also, Wood and Waterman have produced two pioneering pieces of research that seek to identify some of the political determinants of longitudinal changes in environmental regulatory practices (Wood 1988; Wood and Waterman 1991).

A difficulty in studying the interaction between politics and the environment is the current lack of data with regard to long-term environmental degradation. However, we are not at a total loss in this regard. Environmental modelers routinely develop models in the absence of data to explore the consequences of environmental changes to a broad range of interests, including ecosystem stability (R. May 1974), global warming (Energy Modeling Forum 1992), and other aspects of planetary transformation (see *New York Times*, Nat. Ed., 5 May 1992, pp. B5–7). In such cases, models are developed in anticipation of the data that are sure to arrive eventually.

In the current absence of data, model simulations are used to understand the environmental consequences of human action. Indeed, the current separate worries regarding ozone holes and global warming are a response to just such model simulations. In part, simulations are useful because a society may want to *avoid* a particular consequence of human activity. Thus, data for catastrophic scenarios can, hopefully, never be collected if the simulations lead to policy changes that avoid the catastrophes. In fact, simulations of plausible models are the *only* path available to us to understand the consequences of a given course of action without actually performing the action and waiting to see if disaster strikes in, say, a hundred years.

Yet models and simulations are built upon an understanding of the basic inputs of a process. Fortunately, we know a great deal about democratic electoral processes in the United States. Relevant to the current investigation, we know how constituent pressures are aligned differentially with regard to the political parties and how governmental policies reflect these constituent pressures. Moreover, in the social sciences more broadly, there exists a long and rich tradition of exploiting models similar to the one developed here (with or without data) using simulations. This includes areas of research as diverse as political economy (Hibbs 1977), contextual theories of voter activity (Brown 1991; Huckfeldt 1983; Przeworski and Soares 1971; Przeworski and Sprague 1986), arms races (Richardson 1960; Ward 1984), and racial segregation (Schelling 1978). Thus we have a methodological tradition as well as sufficient substantive knowledge to begin investigating an area of research that we might call "political ecology."

THE MODEL

In constructing a model of longitudinal change in environmental degradation that will be heuristically useful for analysis with simulations, it is wise to follow two basic guidelines.[2] First, the model should be general. Thus, model complexities should be held to a minimum so that it is relatively easy to identify change in the model behavior caused by varying each input. Second, it should be easy to identify the type of input that each of the components of the model contributes. In this case, the types of inputs will be limited in a classical fashion to gains and losses.

We begin by constructing a model describing change in environmental damage. Beginning with the gains (i.e., increases in degradation), a straightforward approach is to assume that environmental damage will increase logistically. At first, pollution will increase exponentially as industries grow and populations consume more products that harm the environment. However, this cannot continue forever, even in the complete absence of environmental legislation. In a worst-case scenario, people would eventually die, perhaps of starvation if the polar ozone holes spread to temperate zones, leading to diminished agricultural production due to the higher levels of ultraviolet radiation. But in a less draconian fashion, one would expect that environmental damage has some upper limit beyond which a society will not willingly go. To ease the discussion of the model, the level of environmental damage, X, will be scaled to have an upper limit of unity. Thus, increases in environmental damage can be expressed as

$$dX/dt = rX(1 - X), \quad (1)$$

where r is a constant parameter of the model and represents what we can label as the "pollution growth rate" parameter.

Some readers may wonder whether it is correct to model environmental degradation as a smooth growth process, since it may seem as if occasional spurts of activity would make the "ride" more bumpy. As with all models, the model developed here contains some simplifications, and a degree of "smoothing" is a desired trait of all attempts at segregating systematic and stochastic components of longitudinal change. However, many spurts in environmental degradation may be accounted for by the complicated oscillatory components of the model in its more fully developed form.

It is necessary to include two separate loss terms in equation 1. First, governmental environmental policy can act to limit or repair environmental degradation. This occurs, for example, when governments clean up toxic waste dumps, prohibit lead in gasoline, or (perhaps in the future) orbit large mylar balloons to reflect some amount of solar radiation in the event of catastrophic global warming (see Schelling 1992). The amount of governmentally inspired reduction in environmental damage is likely to depend on the interaction between the amount of damage that exists, and the current level of public concern for that damage. Such connection of policy to longitudinal cycling in the public mood can be deduced from empirical work by Stimson (1991), MacKuen (1981), and others and has played a notable role in Rowland, Lee, and Goetze's (1990) theoretical specifications involving cycling catastrophe models of environmental change. The theoretical justification for a specification for this loss is explained more thoroughly below. The second loss term to include with equation 1 addresses the ability of the environment to repair itself over time. Pollutants tend to decay, be they chlorofluorocarbons or toxic wastes. Some have short half-lives, while others stay around considerably longer, but virtually all eventually decay.

Thus, we can now write the complete expression of change in environmental damage as

$$dX/dt = rX(1 - X) - pXY - kX. \quad (2)$$

Here, the variable Y is the current level of public concern for environmental damage, and the parameter p identifies the effectiveness of governmental policies in reducing current levels of damage as an interactive function of the level of damage and public concern for the environment. The parameter k is a decay parameter that reduces environmental damage based on some proportion of current levels of that damage. In this analysis, k is set equal to the expression, $-\ln(.5)/\text{halflife}$, where halflife is the number of years before one-half of the damage decays by itself.[3] This allows us to examine the model based on how long a particular pollutant is expected to stay around once it is released into the environment. For immediate purposes, the term halflife can be thought of as an average half-life for current and total environmental pollutants. Note that the entire expression in equation 2 limits the level of environmental damage to the range of zero to unity. This convenience further generalizes the model to an acceptable range suitable for numerical investigation.

The second major input into the environmental relationship identified is public concern for the environment. Again, we will have gains and losses in public concern. As with environmental damage, it is reasonable to place a logistically defined upper limit on public concern. In this case, public concern for the environment would increase as damage to the environment increases up to some limit (call it the "panic" limit).

However, the public does not typically react to current levels of environmental damage in an instantaneous fashion. There is usually a lag in public concern as people wait until the environmental damage begins to affect them directly. Since the direct effects of environmental damage are usually due to pollutants introduced into the environment some time previously, the public is actually responding to an earlier level of environmental damage. Indeed, this lag can be as short as a few years or as long as many decades, depending on the particular type of environmental damage being considered. For example, it took a few decades for environmental pressure to build substantially with regard to the poisoning of the Great Lakes, yet concern for the ozone holes and global warming increased more quickly once the connections between these phenomena and human behavior were identified. For modeling purposes, we can say that there will be an average lag in public concern. Thus, public concern will increase as a function of previous levels of environmental damage up to some limit. As with environmental change in equation 2, it is convenient to set this limit at unity.

Decreases in public concern for the environment are most likely to be due to the costs of cleanup. If people are going to have to pay substantially higher gasoline taxes or taxes of another type, concern to clean up the environment is likely to diminish, on average. Thus the total expression for change in public concern for the environment can be written as

$$dY/dt = X_{\text{old}}(1 - Y) - Z. \quad (3)$$

Here X_{old} is the lagged value of the level of environmental damage, and Z is the cost associated with cleaning up the environment. Growth in public concern for the environment continues as long as concern is not yet near its limit and costs are relatively low. Once concern is near its limit or costs are high, costs will tend to dominate the dynamics in equation 3 and concern for the environment will begin to diminish.

The costs of cleaning up the environment will vary as well. There will be gain and loss characteristics of the change in costs. With regard to the gains, costs will tend to increase as *both* concern for the environment and actual environmental damage rise. Concern for the environment will spur politicians to address environmental issues, but politicians will allocate money for the environment only when there are clearly definable problems that can be addressed. Yet there are limits to the funds available for all governmental projects. For numerical purposes, we can scale the variable for costs such that the upper limit for governmental spending on the environment is unity. Thus, spending for the environment will increase in the direction of this limit as long as there is increasing public concern for the environment and sufficient current environmental damage.

Longitudinal decreases in governmental spending on the environment are likely to be due to the magnitude of the current burden of environmental spending. Environmental spending will tend to increase as long as costs are low. As costs increase (and especially when costs approach their limit), public concern for the environment will tend to diminish (perhaps some environmental problems may appear resolved), and overall spending will tend to decline. Thus, the equation describing longitudinal change in spending for the environment can be expressed as

$$dZ/dt = XY(1 - Z) - Z. \quad \mathbf{(4)}$$

In combination, equations 2–4 constitute a nonlinear system of three interconnected differential equations. The three state variables—environmental damage, public concern for the environment, and spending for the environment—interact longitudinally in a continuous fashion. As the system is currently specified, interactive cycling among all of the state variables is possible, as I shall demonstrate. However, to capture a more complete characterization of the cycling between public concern for the environment and electoral activity (a generalized empirical reality described more fully in Stimson 1991), this system requires a modification.

The modification is to allow the system to vary according to the partisan politics originating from the White House. This modification can be accomplished using parameter p in equation 2. The analysis has two levels of sophistication. As a first approximation to modeling the interaction between politics and the environment, parameter p oscillates between two different values, depending on the ideological perspective of the current president. When a conservative president occupies the White House, that president's supporters are not likely to include those environmentalists who want large increases in governmental spending on the environment, and thus parameter p is likely to have a relatively low value. However, a more liberal president will be more closely tied to the desires of environmentally active constituents. In such a situation, the value of parameter p is likely to be relatively high. Thus we will need to vary the value of parameter p in a systematic fashion in order to see how the change in presidential perspective affects overall environmental damage, given the other elements in the model.[4]

Oscillating the value of the parameter p between two discrete values is considered a first approximation to modeling the interaction between politics and the environment because many environmental policy changes that occur across administrations may happen more gradually. Discrete changes are examined first in order to identify causally the behavioral characteristics associated with specific components of the model in its simplest form. Later in this analysis, the model is extended to include gradual changes in the parameter p that would reflect less sudden policy alterations that may be more typical of many situations.

But let us be clear at the outset about what is being captured by the parameter p. There are two ways of thinking about the parameter. The first is that the government actually cleans up the environmental mess that it and others made. However, a second motivation underlying parameter p reveals a more subtle reasoning.[5] Governments sometimes do clean up toxic disasters. But, perhaps more commonly, governments actively reduce environmental degradation by phasing out dirty technology in favor of newer and cleaner technology. Examples of this can be found in the construction of power plants, the use of catalytic converters on cars, the removal of lead from paint, and many other areas. Industry initially resists such conversions to cleaner technology, but once the conversion is made, the situation is relatively permanent. The reason for the permanence is cost. Industry does not want to invest in new infrastructure twice—once to clean things up and a second time (if allowed) to get dirty again.

The desire of industry to stay clean once it is forced to invest in cleaner technology does not nullify the reasoning behind the specification using parameter p. The reason is that society is always changing, and industry is always growing. Thus, there will constantly be new products and new industries that will be producing new sources of environmental degradation. The parameter p captures the government's overall ability to keep on top of this ever-expanding and constantly changing problem. It is not just that government sometimes cleans up environmental damage. Government also inhibits, through a variety of mechanisms, the development of new environmental problems. Thus, a high value for the parameter p reflects a government that is actively engaged in developing and maintaining a cleaner environment through a variety of means. The phasing out of old, dirty technology and the gradual introduction of cleaner technology is just one such means. The parameter p captures the summary effect of the total efforts.

There is very substantial empirical evidence suggesting that varying the value of the parameter p (both discretely and gradually) is a useful approach to modeling the interaction between politics and the environment. Since public concern for the environment began to heighten in the 1970s, there have been marked contrasts across administrations with regard to environmental concerns. Wood and Waterman have demonstrated that agency leadership is the critical factor in determining the direction of administrative environmental activities (Wood 1988; Wood and Waterman 1991). This affects dramatic and sudden shifts in agency funding and contributes to the long-term effectiveness of regulatory activity. Indeed, political appointments have greater influence over environmental activity than legislation, budget variations, or even actions by Congress. In sum, administratively orchestrated politics determines whether or not an environmental agency will be an effective advocate of environmental concerns.

Two heuristic examples are useful here. In the early Reagan years, a determined (and generally successful) effort was made to curtail quickly the scope, enforcement, budget, and effectiveness of environmental regulation. (For the detailed story of these efforts, which included the very effective appointment of an antienvironmentalist attorney, Ann Burford [née Gorsuch], see Harris and Milkis 1989; Vig and Kraft 1984; Waterman 1989; Wood 1988; and Wood and Waterman 1991.) However, such visible efforts are not needed in order to subdue an agency. Late in the Bush administration, it was reported that the Justice Department systematically but quietly blocked the prosecution of environmental crimes, thereby fatally derailing the efforts of the Environmental Protection Agency to enforce its own regulatory activity (*New York Times*, Nat. Ed., 30 October 1992, p. A13).

Thus, there is no one way to measure an administration's concern or lack of concern for the environment. If an administration wants to undermine environmental regulatory activity, there are many ways to do it. Moreover, the same is true if an administration seeks to be broadly supportive of environmental concerns. It is for this reason that parameter p is specified as a summary estimate of all current environmentally related activity that reverses total levels of degradation, assuming that each administration will use whatever means are currently at its disposal to achieve its desired goals.

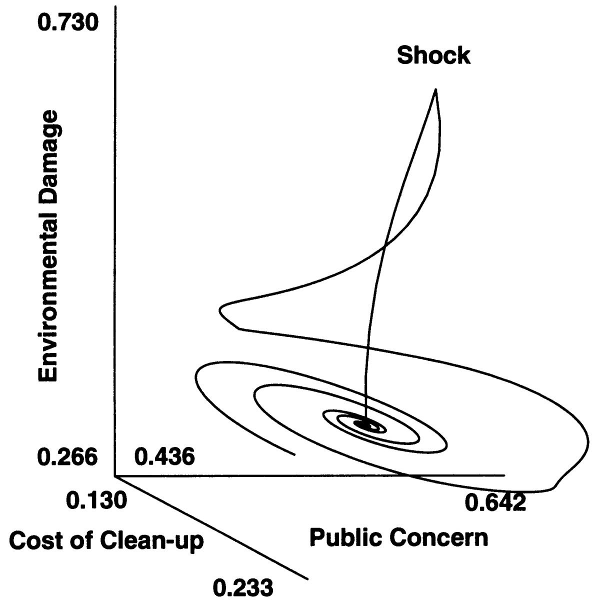
THE NUMERICAL EXPERIMENTS

As is typical of nearly all such nonlinear and interconnected systems of equations, it is not possible to uncouple the separate state variables in order to evaluate the system's behavior using techniques of indefinite integration. Moreover, linearizing techniques are both cumbersome and not very useful in the current situation. Rather, to learn from the system outlined, it is best to approach the system numerically with Hamming's maxim constantly in mind: "The purpose of computing is insight, not numbers" (Hamming 1973, 3).

The strategy of the current approach to analyzing the system is similar to the way one would approach any empirical problem. First, a baseline description of the system is established. From this baseline description, the general behavior of the system in its simplest form is identified. Subsequently, experiments are performed in which one change is made to the system at a time, thereby gaining an understanding of the effect of that one influence on the overall model.[6] In this way, the model in its baseline characterization acts as the controlling specification with regard to the component that is being varied.

FIGURE 1

Phase-Portrait Representation of Environmental Damage, Public Concern, and Environmental Cleanup Costs: Sample Trajectory with Six-Year Public Lag and *No* Partisan Policy Differences



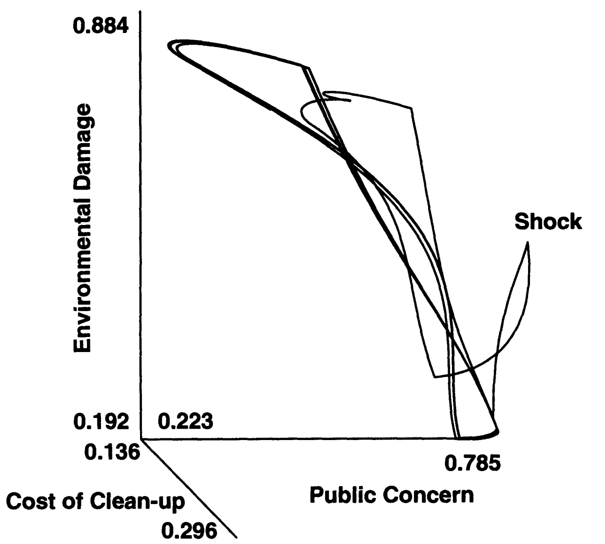
Note: All trajectories spiral to a single global attractor, thus moderating environmental damage, despite short-term catastrophes.

Figure 1 presents a phase portrait representation of a sample trajectory for the model.[7] This figure is used here as the baseline characterization of the system's behavior. The three axes represent the three state variables in the system: environmental damage, public concern for the environment, and environmental cleanup costs. In Figure 1, the parameter p is held constant with a value of 1 and is therefore not varied between two values.[8] This represents a situation in which there are no policy differences between the parties and all presidents behave similarly with regard to favorably promoting environmental policies. Moreover, the lag in public awareness with regard to concern for the environment is held at a moderate value of 6 years for this simulation.

Note that the trajectory spirals into a stable equilibrium point from its initial condition. Moreover, this equilibrium point reflects a relatively low level of overall environmental damage, as would be expected in a situation in which both parties favorably support environmental policies. After the trajectory's arrival in the proximity of the equilibrium point, a large shock is added to the system to see how quickly the trajectory would return to the neighborhood of its equilibrium. This shock represents what would happen to the system following a short-term ecological disaster. Note that the return trip is relatively rapid.

FIGURE 2

System Phase Portrait: Sample Trajectory with Six-Year Public Lag *and* Partisan Policy Differences



Note: With a public lag of six years and political party differences, a stable orbit develops that leads to large—and potentially disastrous—changes in environmental damage, as well as cleanup costs.

Thus, the system as represented in Figure 1 (i.e., in the absence of partisan policy differences and with a moderate lag in the public's perception of environmental damage), supports (at equilibrium) a stable low level of environmental damage with moderate levels of public concern and relatively low financial costs. The swings encountered while arriving at that point may seem a bit rough, particularly following a major shock to the environment. But the eventual arrival at a pleasant and sustainable equilibrium does not take long. All this makes sense and would be expected from a properly functioning representation of this process under the given conditions.

Partisan differences in environmental policies are added to the system in Figure 2, that being the only difference. Thus, in Figure 2, the parameter p was allowed to oscillate between 0 and 1 every eight years. This represents a situation in which each party would hold substantial differences in environmental policies and the two parties would rotate control of the White House every eight years.[9] A value of 0 for parameter p would reflect an administration that, say, strongly supports economic growth over environmental protection. Thus, governmental actions to decrease further damage to the environment would be minimal at best. A value of 1 for parameter p would reflect an administration that actively promoted proenvironment policies.

In the situation given in Figure 2, note that a large stable orbit develops in the system. Moreover, even the ecological shock to the system disturbs the trajectory from this stable orbit only briefly. Thus, in the long run, the model is quite sensitive to environmental policy variations between the parties that rotate control of the White House.

From an environmental and cost point of view, the model's behavior as represented in Figure 2 is not good news. The problem is the large magnitude of the cycling and the consequent high level of governmental financial costs. When, say, a pro-jobs president is elected, the environmental policies of his or her predecessor may have reduced the level of environmental damage. Moreover, with environmental damage more or less under control, the public's concern for the environment can begin to diminish. This leads to a relaxation of proenvironmental legislation and regulatory activity with its consequent eventual increase in environmental damage. At this point, the public desires change, a new party occupies the White House, and the process of reducing damage to the environment repeats.

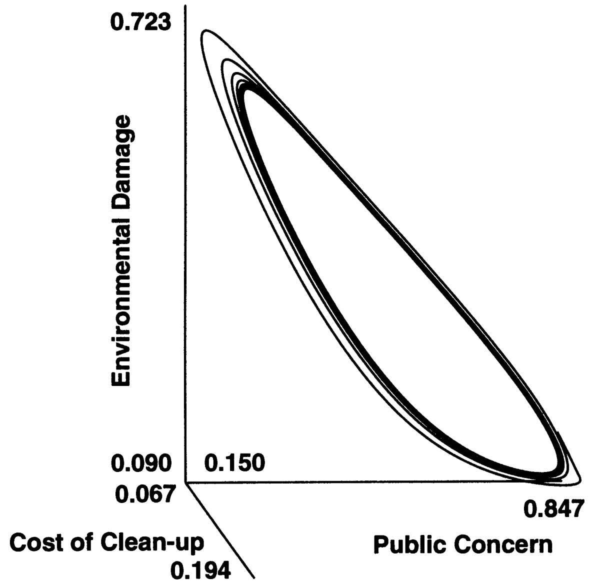
One major problem identifiable in Figure 2 is that the overall costs of this cycle appear to be much greater than the relatively moderate and stable costs represented in Figure 1. From an environmental point of view, the repeated and high levels of damage are the problem. But from a financial point of view, the cycle itself, with its large and costly swings into the expensive programs needed for environmental recovery, is the most damaging. Indeed, from both points of view, it might seem a better choice to reduce such long-term costs as well as environmental damage by avoiding the cycling.

But differing party policies with regard to the environment is not the only thing that can cause large magnitude and costly swings with this system. Indeed, even in the complete absence of political differences, the system is sensitive to the length of the lag in the public's perception of environmental damage. This sensitivity is demonstrated in Figure 3. The only thing changed is the length of the lag in public concern regarding environmental damage. Policy differences between the political parties are not included in the computation of the trajectory in this figure. Here, the lag between environmental damage (e.g., the release of pollutants) and the public becoming concerned about the damage is 15 years. The result of this increased lag is that the system develops a large stable orbit. This is a substantial characteristic change from the stable equilibrium that dominated the trajectory in Figure 1. It is clear in Figure 3 that the trajectory slowly converges to an orbit in which there are large changes in environmental damage, public concern, and economic costs. This is despite a political situation in which both political parties pursue similar environmental policies![10]

When political policy changes occur together with an increased lag in the public's concern for environmental damage, the oscillations continue, but with more abrupt changes in direction and a much more complicated orbital form. Figure 4 combines both the longer 15-year lag as well as 8-year policy changes in the White House. From the phase-plane perspective, the orbit in Figure 4 seems to "flap" at lower levels of environmental damage, somewhat mimicking the

FIGURE 3

System Phase Portrait: Sample Trajectory with 15-Year Public Lag and *No* Partisan Policy Differences

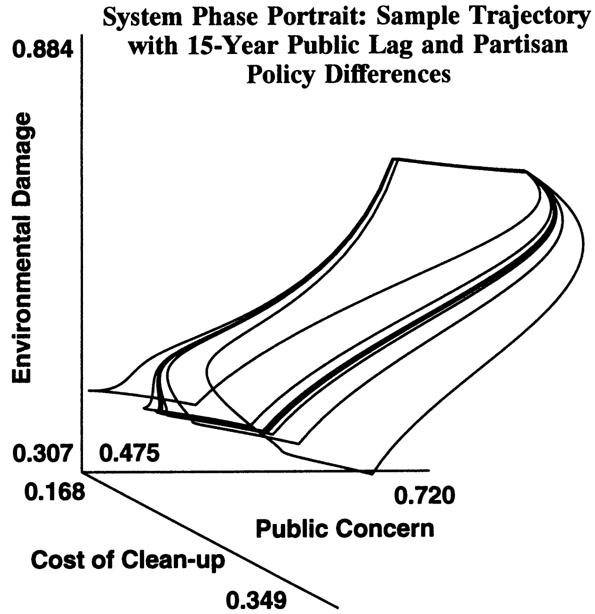


Note: An increased lag in public concern produces large swings in environmental damage, despite no political party policy differences.

swings of a pendulum. From this figure, it is clear that directional changes in environmental damage can be much more radical than those associated with Figure 3. Of course, these changes are associated with substantial changes in costs. But the costs often

FIGURE 4

System Phase Portrait: Sample Trajectory with 15-Year Public Lag and Partisan Policy Differences



Note: The combination of an increased lag in public concern for environmental damage and political policy changes produces a "flapping" oscillatory orbit.

vary in this figure out of phase with changes in the other variables.

This temporal disconnectedness between costs and actual damage is directly tied to the interactive influence of the long lag in the public's awareness and the discontinuities inherent with the political policy differences. Moreover, this type of lagged cycling may be common. Notably, such cycling has been observed between the public mood and partisanship by Stimson, using a large body of survey data (1991, 93–94).

In terms of a goal of maintaining a healthy environment, this latter situation could be quite dangerous. The overall impact on the environment is one of rapid departures from previous states and thus an increase in the longitudinal volatility of environmental quality. In some respects, this situation may partially reflect the general characteristics of the contemporary state of much environmental management in the United States today.

GRADUAL POLICY CHANGES

In its present form, the model presented here assumes that governmental policy changes with regard to the environment are sudden. In some—perhaps many—situations, this may not be an unreasonable assumption. Wood and Waterman have offered empirical evidence suggesting that national environmental policy changes are primarily influenced by the nature of top political appointments rather than by legislation, changing budgets, or Congress (Wood 1988; Wood and Waterman 1991). Moreover, these policy leaders can display a remarkable ability to produce a wide range of change very quickly.[11]

However, not all policies—environmental or other—will change suddenly. Indeed, more gradual changes across a broad range of policies may likely be closer to the norm of regulatory politics. At first, this may seem like a good thing. Gradual changes enable governments to come to grips with the consequences of previous policies and thereby to fine-tune subsequent policy developments. Thus we would expect increased predictability and a reduction in environmental instability when policy changes are more gradual. This, in turn, promises a reduction in the overall level of environmental damage. Surprisingly, these intuitions may be largely false. Indeed, gradual changes in policy need not eliminate dangerous and large-scale oscillations in environmental damage, and they can also end up hindering our overall ability to manage the environment.

To show why we are not necessarily better off with gradual policy changes with regard to the environment, it is necessary to reformulate the model to include gradual, rather than sudden, changes. Thus, we need a new equation in the system. This equation will structure change in the parameter p, the government policy response to environmental damage. A high value for p suggests that the party in power is strongly engaged in reducing environmental damage through regulatory and other activities, whereas a low value for p indicates the opposite. Previously, the model has allowed p to flip from one value to another, thereby reflecting discrete changes in policy preferences across administrations.

We now want to vary p continuously, rather than discretely. That is, the value for parameter p must change continuously in the direction of a desired partisan goal for that parameter. For example, a Democratic administration may desire p to have a high value, whereas a Republican administration may prefer it at a lower value. These desired values are partisan goals, to which the value of the parameter p should asymptotically approach, depending on which party is in power at a given point in time. Algebraically, this is accomplished by introducing into the system the equation

$$dp/dt = ep(g_{\text{Dem}} + g_{\text{Rep}} - p). \quad (5)$$

In equation 5, g_{Dem} and g_{Rep} are the partisan goals for the parameter p. Only one such goal can operate at a time, since only one party at a time can control the presidency. Thus, when a Democratic administration is in power, g_{Dem} is set to its ideal value and g_{Rep} is set to zero, the reverse being true when a Republican administration is in power. Thus, all of the terms in parentheses in equation 5 act in combination as a logistic directional control for the evolving value of parameter p. For example, when a Democratic administration is in power, the value of p changes in the direction of g_{Dem}. Change slows down when p approaches g_{Dem} as a limit. The parameter e identifies the rate (proportional to the current value of p) at which this movement in the value of p takes place. All of this changes p from a constant parameter to a variable parameter. The entire model is now a four-equation system, which is collected and summarized as follows:

$$dX/dt = rX(1 - X) - pXY - kX$$

$$dY/dt = X_{\text{old}}(1 - Y) - Z$$

$$dZ/dt = XY(1 - Z) - Z$$

$$dp/dt = ep(g_{\text{Dem}} + g_{\text{Rep}} - p)$$

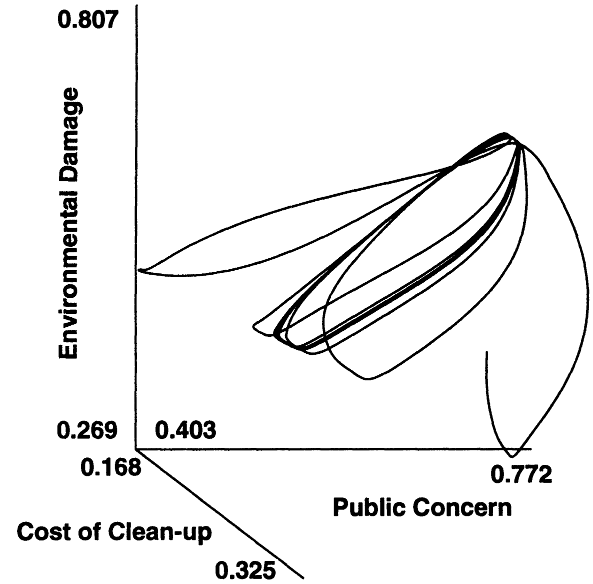
Again, the variables and parameters are

X	environmental damage
Y	public concern for the environment
Z	economic costs of environmental clean-up
p	governmental policy response to environmental damage (a variable parameter)
g_{Dem}	ideal Democratic policy response goal
g_{Rep}	ideal Republican policy response goal
r	pollution growth rate parameter
k	natural pollution decay rate
e	parameter determining speed of government policy changes toward partisan goals

Our first test to see the effect of this change in determining the value of parameter p on the overall behavior of the model will be to duplicate all of the other conditions used to create Figure 4, which included partisan policy differences as well as a 15-year lag in public concern for environmental damage. This new simulation is presented in Figure 5. The values of parameters r and e are set equal to 1, and the Democratic and Republican ideal policy response goals (g_{Dem} and g_{Rep}) are set equal to 1 and 0, respectively. Thus the situation is very similar to that of Figure 4, except that the value of parameter p is allowed to move continuously and gradually between two oscillating limits. From Figure 5, the primary effect of this change on the overall model is to round off the sharp edges of the trajectory that were previously the result of sudden policy changes. Large-magnitude oscillations in environmental damage still occur, and the flapping oscillation pattern of Figure 4 reappears, albeit in the form of rounded loops rather than more sharply angular movements.

FIGURE 5

System Phase Portrait: Sample Trajectory with 15-Year Public Lag, Partisan Policy Differences, and Gradual Partisan Policy Changes



Note: The combination of an increased lag in public concern for environmental damage and gradual political party policy changes can produce smoothed versions of the flapping oscillation observed in Figure 4. Here, $r = 1$ and $e = 1$. Democratic and Republican ideal policy response goals are 1 and 0, respectively. This corresponds to position A in Figure 6.

A natural observation relating to Figure 5 is that we are looking at only one value for the parameter e. Recall that the value of parameter e controls the rate at which government policy changes toward the partisan goals emanating from the White House. High values for this parameter corresponds to rapid movement toward these goals. Very high values can produce movement that mimics that associated with sudden shifts in policies, as portrayed in Figure 4. Very low values make movement between the two goals sluggish at best.

At this point in the analysis, we need a way to portray the overall behavior of the model through a continuous and realistically suitable range of values for the parameters *e* and *r* without paging through a countless series of trajectory phase portraits. This is important because we do not yet have a hundred or so years of data from which to estimate these parameters. One counterargument to the current analysis would be that the particular values used for these two parameters are not likely to be the exact values that the system will actually have once it is estimated, given an appropriately long collection of time-series data. Other parameter values may produce less dangerous systemic behavior. Moreover, it is likely that these parameter values will migrate over time (i.e., not remain constant) to keep pace with evolutionary changes in our social and political cultures. Thus, it is important to describe the general topology of the environmental playing field on which the values of these parameters are placed so that one can generalize about the overall characteristics of the system. As will become obvious, one can find little solace in the idea that it may be better to wait to collect the data before worrying about the intricacies of the political–environmental connection. Indeed, in terms of environmental risk and a desire to engineer an effective collection of environmental policies, it may be difficult to imagine a less hospitable general setting.

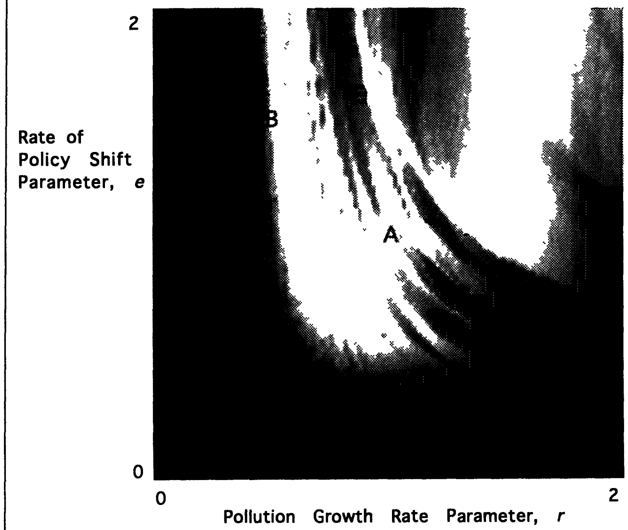
To do this, a new measure is needed that will capture two aspects of the overall behavior of the model. The first is the sum of the absolute value of total change in environmental degradation. Small values of this aspect indicate that change is slight and thus probably more manageable from a regulatory perspective. On the other hand, large values of total change indicate dangerous levels of environmental volatility. The second aspect of our new measure must indicate how much directional change characterizes the model's behavior. This is captured by counting the total number of changes in sign in the model's four derivatives for a fixed period of time.

The new measure is calculated by weighting the total magnitude of change in the environment by the total number of sign changes in the system's derivatives. This measure is an estimate of overall environmental turbulence. High levels of environmental turbulence indicate large magnitudes of overall environmental damage combined with frequent oscillations in the direction of change. Low levels of this measure indicate relative stability in environmental damage, both in terms of the total magnitude of change and the direction of movement. The measure is comparable across trajectories as long as the length of time for all trajectories is held constant.

Figure 6 is a portrait of the measure of environmental turbulence across a continuous range of values from 0 to 2 for the parameters *e* and *r* (the pollution-growth-rate parameter).[12] The environmental turbulence measure is being shown on the third dimension of the figure by the shading. Brighter shades in the portrait indicate high levels of environmental turbulence whereas darker shades indicate lower levels of turbulence. The letter "A" on the figure indicates the location of the parameters used to construct the trajectory presented in Figure 5.

FIGURE 6

Portrait of Environmental Turbulence for the Entire System Based on Continuous Ranges of Potential Values for Two Parameters



Note: This is a portrait of the total magnitude of change in the environment weighted by the number of sign changes in the system's derivatives. Brighter shades indicate large-magnitude changes in the quality of the environment combined with many shifts in the direction of change for the variables (i.e., high levels of environmental turbulence).

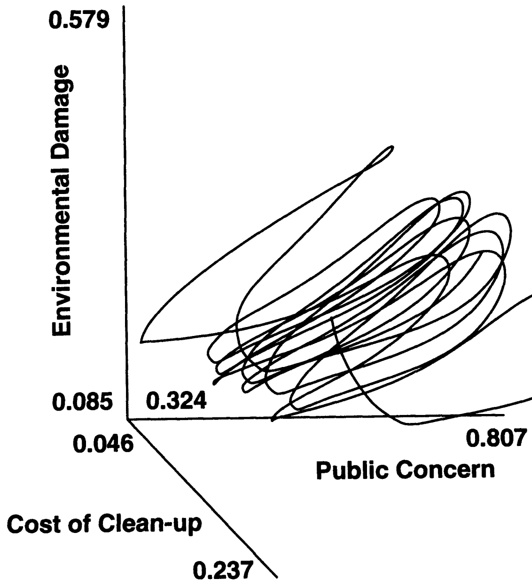
In Figure 6, note that continuous change in the values of the parameters does not produce gradual changes in the measure of environmental turbulence. Indeed, the portrait in Figure 6 is filled with closely interwoven variations in shading, indicating rapidly changing levels of turbulence. That is, turbulence does not increase smoothly as, say, industries increase their level of pollutant discharge. Nor is the change in turbulence gradual if the government pollution reduction rate changes evenly. Moreover, the only areas in Figure 6 in which darker shades dominate in a significantly continuous fashion are for situations with very sluggish rates of partisan policy change (i.e., very low levels for the parameter *e*) or under conditions of very low levels of environmental damage, neither of which seem realistically to describe current regulatory or environmental conditions.

In order to manage the environment, one must be able to predict what will happen when changes are made. The results of Figure 6 suggest that this may not be easy or even possible, given current measurement inadequacies. Attempts to manage the environment within a setting of significant differences in partisan approaches can lead to large-scale and highly volatile environmental changes, many of which may not be easily reversible from an ecological point of view.

As bad as this sounds, the situation is worse. There are large areas in the parameter spaces of parameters *e* and *r* for which the determination of what will happen next in the environmental trajectory is nearly

FIGURE 7

System Phase Portrait: Sample Trajectory with 15-Year Public Lag, Partisan Policy Differences, and Gradual Partisan Policy Changes Using Alternate Parameter Values



Note: Modest parametric variation in the four-equation model can produce very complex oscillations in environmental damage. Here, $r = .5$ and $e = 1.7$. Democratic and Republican ideal policy response goals are 1 and 0, respectively. This corresponds to position B in Figure 6.

impossible to predict. This is due to complexities in the oscillatory components imbedded in the trajectory movements. The oscillations portrayed in Figure 5 seem easy to follow, but for other values of the parameters e and r, the situation changes dramatically and can easily become much more complicated.

To show these conditions, an additional phase portrait is constructed, using the parameter values as identified in Figure 6 by the letter *B*. Figure 7 presents such a complex trajectory using the parameter values $e = 1.7$ and $r = .5$. From this figure, it is clear that policy managers would have a difficult time predicting the future of environmental change given this political and pollution context. The oscillations are evident, but they do not settle down into a clearly discernable pattern within any reasonable length of time. On a technical level, such complexity in trajectory structure may not be certifiably chaotic (classically defined), since the characteristic Lyapunov exponents calculated using these parameter values do not indicate a strong sensitivity to initial conditions (analysis not shown). However, a Fourier analysis of the system's periodicity (not shown) indicates a complexity very typical of chaotic systems. From a macro substantive perspective, there seems little difference between these complex oscillations and pseudorandomness, since the level of longitudinal complexity is sufficiently high to make a practical ability to predict the future virtually impossible.

Substantively, this implies that a great deal can happen quickly with regard to the environment when small changes occur in pollution and policy rates and when the political parties differ in their environmental policies. This is precisely the fear raised by Schelling with respect to global warming (1992, 8). It is this potential characteristic of the environmental system that holds the greatest long-term danger for planetary ecological management.

CONCLUSION

It would be absurd for an astronaut in a space vehicle to start a fire in the cabin to keep warm. No one would question this because we understand that the regulatory mechanisms within the vehicle would be overloaded from the consequences of the fire. The problem with making a similar statement with regard to damaging the environment of our planet is that we do not entirely understand the automatic processes of environmental management. These processes include political structural components as well as ecological and physical components, and these political structural components have been largely ignored in the environmentally related literature.

I have endeavored to describe some of the political components that may strongly interact with the rest of the overall biological system. The normative hope is that the discussion will engender a more balanced approach to the discussions of our environmental problems. The social-scientific angle to the environment is not just economic. Since politics is at the root of all attempts at environmental management, political scientists should play a major participatory role in the evaluation of current problems and in the prescription of current and future remedies.

This analysis presents a model of environmental change in which the political, social, and economic inputs into the system interact nonlinearly to produce highly varied global patterns of ecological damage. The model is developed with respect to presidential-electoral and regulatory practices in the United States. The results of the analysis suggest that relatively minor parametric changes in the system can lead to major alterations in the longitudinal patterns of environmental change.

One of the major implications of these experiments is to suggest that the regulation of our environment may be a much more challenging task than we have presently envisioned. Indeed, our current electoral structures may directly assist the long-term degradation of our environment. The complexities that exist within the simplified system investigated here suggest a greater level of complexity in the actual physical system. The political components of that complexity certainly play an important role in the determination of the general structure.

In terms of recommendations, it is likely that substantial benefit for environmental management from a political point of view would be to reduce the impact of party policy differences on ecological cycling. A complete plan on how to do this is beyond my present scope, since I am here concerned more with demonstrating the dilemma we are in than formulating a way out. However, some suggestions to initiate the discussion of solutions may be helpful.

First, in the Federal Reserve Board we have an example of an institution developed in order to deal with potential cycling problems (in this case, in the economic arena). Thus, we have experience with related problems in other areas and the effectiveness of some of the solutions that have been attempted. It is not likely that a simple political compromise between the political parties would last sufficiently long to be meaningful to the long-term global properties of the system. The temptations to exploit short-term political gain would eventually destroy any temporary effects that would result from the compromise. Something more permanent and substantial is needed, and the creation of some type of independent Environmental Preserve Board may be one answer.

It may also be possible—perhaps more so in countries other than the United States—to create, through constitutional means, an elected position independent of the influence of the office of president or prime minister. This elected official would serve as the head of the environmental regulatory agency of a country. This could have major implications on the management of the environment, since the official would gain reelection solely on the basis of whether voters are happy with how the environment is being regulated. Thus, it would not be possible to avoid the issue of the degradation of the environment by talking about other issues in which the voters might also be interested. The basic problem is to isolate the environmental concerns from other political matters.

Yet another suggestion would be to institutionalize the role of the United Nations in monitoring—and to some extent regulating—the planetary environment. Rules could be constructed that would establish planetary norms with which each country would have to abide. Some fair system of penalties would have to be established in order to obtain cooperation across nations. Such penalties would likely involve trade and economic issues, but technology transfers and political cooperation in other areas could also be factors. Interestingly, the United Nations already seems to be becoming much more involved in new global matters since the end of the Cold War. Thus, the stage may already be set for the emergence of a new environmental role for this organization.

But it is important to understand that helpful environmental management cannot function only on the level of bureaucratic organization: individuals must understand the need for this management. In particular, the regulation of the environment is influenced by the lag in the public's perceptions of our environmental problems. To some extent, this can be addressed through an enhanced role for environmental education in our society. On the level of formal education, it is most likely that a comprehensive approach to curriculum reform across all age categories will be required in order to achieve any lasting benefit to the overall problem, since generational biases often persist for lifetimes and it may be too late in the game for college courses to make a meaningful impact.

This last recommendation cuts to the heart of the matter. If nonlinearities dominate the political–environmental system, it may be futile to try to fine-tune current environmental policies in a rational-decision-making sort of way in an attempt to fix the ecological problems. If political leadership, regardless of party, tends (at least on average) to reflect in practice the policy preferences of large numbers of a nation's citizens, then it is necessary to upgrade the preferences of the citizens through education before environmental disaster does it for us. It is not that evil political and corporate leaders continually dupe the ignorant political masses. Rather, in a democracy, it is the masses that let their leaders do what they do. The bottom line is that unless large majorities of the citizens of democratically governed countries become strongly environmentally sensitive, there can be no long-term solution to this problem. The electoral and ecological cycling will continue as parties with differing and large constituencies oscillate in office, and the costs of environmental cleanup will remain both high and volatile. Possible governmental–structural fixes may help in the long run, but only if the educational component is also present.

Fundamentally, any successful approach to environmental management will require an understanding of the political processes that influence that management. At the outset, it is important to understand how these processes extend to the basic electoral practices of our democracy. The current discussion has attempted to demonstrate that the political–environmental connection in the context of contemporary democratic governance is complex. This nonlinear complexity is associated with questions relating to human quality of life, and indeed, survivability. We address these matters not as mathematical curiosities but as issues with a direct bearing on the physical characteristics of our planetary habitat.

Notes

1. Indeed, the collapse of the former communist governments of Eastern Europe and the former Soviet Union led to near-immediate revelations of how deep and widespread such damage can be (*New York Times*, Nat. Ed., 13 May 1992, pp. A1, A4.)

2. See Mesterton-Gibbons 1989 for a more complete overview of such guidelines.

3. In all of the numerical results presented herein, the half-life for the system's environmental damage was fixed at six years.

4. Recent anecdotal evidence nicely illustrates how sitting presidents can and do change regulatory environmental policy to achieve electoral benefit with regard to current constituents. The following list of articles and editorials, all drawn from the National Edition of the *New York Times* during the 1992 presidential primary season, describe how President Bush made an effort to reduce, wave, or eliminate environmental regulations that adversely affected potential or current supporters of his campaign. This partial listing is *not* meant to

imply that President Bush is unique in any way in this regard. The argument made here is that this is a natural occurrence of partisan politics in the United States in which environmental concerns fall victim to the same constituency pressures as any other issue or set of issues.

"Icy Words on Global Warming," 30 March, p. A14
"Administration Tries To Limit Rule Used To Halt Logging of National Forests," 28 April, p. A7
"The Environmental Pollution President," 29 April, p. A15
"Freezing Government," 4 May, p. A14
"2 Admit E.P.A. Violated Hazardous Waste Law," 8 May, p. A10
"E.P.A. Head Allows Project on a Lake Michigan Marsh," 9 May, p. A7
"Showdown on Endangered Species," 11 May, p. A15
"White House and Congress Face Showdown on National Forests," 12 May, p. A8
"Bush to Relax 1990 Rule on Air Pollution Notices," 18 May, p. A9
"Environment Laws Are Eased by Bush as Election Nears," 20 May, pp. A1, A10

5. I am indebted to G. Robert Boynton for suggesting this second justification for parameter *p*.

6. This approach to the numerical evaluation of such systems is described more fully in Kocak 1989, as well as Mesterton-Gibbons 1989.

7. Throughout this analysis, all numerical solutions to the differential equations were obtained using a fourth-order Runge-Kutta algorithm. Moreover, all of the results presented here were obtained using software written by the author in Think Pascal and run on a Macintosh Quadra 900. The computer was made available to the author through a grant administered by James Johnson, vice provost of Emory University's Information Technology Division.

8. In Figures 1–5, the parameter *r* is given a value of 1.

9. Of course, actual partisan changes would not be as evenly spaced. Holding the spacing constant here, however, acts to control the structure of this new input, thereby clearly identifying its effect on the overall system.

10. By way of casual observation, this scenario indeed seems a partial contributor to what may have happened to the Great Lakes of North America. The public's response to the increasing levels of pollution was very slow, probably due to the indirect ways that lake pollution affected peoples' lives.

11. For example, the Bush administration passed a flurry of regulations regarding the environment in the final days of its tenure (*New York Times*, Nat. Ed., 16 January 1993, p. A1). Similarly, the Reagan administration engineered a dramatic decline in funding for the Environmental Protection Agency during President Reagan's first term in office (Wood 1988).

12. Figure 6 was constructed using imaging software provided by the National Center for Supercomputing Applications at the University of Illinois, Urbana–Champaign.

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