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The Rule of Capture and the Economic Dynamics of Natural Resource Use and Survival under Open Access Management Regimes

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THE RULE OF CAPTURE AND THE ECONOMIC DYNAMICS
OF NATURAL RESOURCE USE AND SURVIVAL UNDER
OPEN ACCESS MANAGEMENT REGIMES

BY
JASON SCOTT JOHNSTON*

This article recalls and explores the dynamic economic analysis of natural resource harvest under rule of capture, open access management regimes. It argues that a similar bioeconomic dynamic applies not only to natural resource harvest, but also to environmental pollution and even to private land development. Contrary to popular belief, the open access, rule of capture dynamic does not generally imply resource catastrophes such as species extinction, maximal pollution, or the loss of all open space. Rather, under many plausible conditions, market actors themselves internalize some of the costs of resource overuse, and there are cycles in resource abundance and use intensity. Wise public policies encourage economic mobility out of resource development/harvest even as they force resource users to internalize the costs of overuse. As a matter of political-economic reality, however, legislation often subsidizes resource overuse and overdevelopment. Reconsideration of the formal economic dynamics of the rule of capture, therefore, reminds us that it is not so much the economic incentives created by the rule of capture, but rather state-subsidized resource overuse, that is responsible for the most serious instances of natural resource collapse and overdevelopment.

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I. INTRODUCTION

The “Rule of Capture” may mean many different things. It might be thought of narrowly, as a common law doctrine that determines when and if a person acquires rights to a previously unowned, wild animal by capturing or killing it. Or the rule of capture may be understood a bit more broadly, as stating that a person has a right to however much of a commonly owned, public natural resource she has been able to take and reduce to her exclusive possession. Still more broadly, the rule of capture may be understood as setting up a right to unlimited use of publicly owned natural resources—whether the use is harvesting part of a resource stock, as with fish, or polluting it, as with rivers and airsheds. Finally, and most broadly, the rule of capture may be taken to be equivalent to a general rule of possession for publicly owned natural resources—the first user is the owner, either of what she has used or taken, or of the entire resource stock.

In this article, I explore the economic incentives for resource use created by the rule of capture understood as a general, unregulated right to use publicly owned natural resources to whatever level one pleases, and to keep the flow value of that use. I state the rule of capture in this broad sense because this is the way it has traditionally been understood for natural resource harvest activities ranging from fisheries to oil and groundwater pumping. While it is costly to harvest such publicly owned natural resources—by sinking a well, or buying and operating a fishing vessel—the basic management regime in these core cases is open access. Hence in my terms, the rule of capture is a general management regime under which publicly owned natural resources are free and open for public use, with users not required to pay anything for such use.

My first objective in this paper is to review some of the basic economics of rule of capture management regimes. I do this by comparing what has been called the rule of first possession—essentially the rule of capture as applied to asset stocks¹—to the rule of capture where, to repeat, the first possessor gets whatever she has possessed. In both situations, the rule of capture has certain static inefficiencies: by encouraging too rapid resource use and costly racing in the case of first possession, and by allowing people to neglect the effect of their own use in lowering the value of use by others in the case of the rule of capture.

While I review these basic static inefficiencies, my main concern here is with the kind of dynamic incentives created by the rule of capture. I am interested in particular in what I take to be a widely held folk belief, which is that it is the open access, rule of capture management regime that is responsible for natural resource collapse—the loss of entire species, populations, or ecosystems. By reviewing some of the basic bioeconomics of the fishery, I explain why this belief is generally false. While it is possible for open access harvest to lead to extinction and resource collapse—as populations are hunted down to such low levels that they are no longer viable, and actually continue to crash to zero rather than growing back—the more likely bioeconomic dynamic is one of cycles in the populations of human harvesters and their natural prey. In such cycles, high harvest levels attract more harvesters, but more harvesters eventually lower the stock, meaning reduced profits, which cause harvesters to exit from a particular harvest industry, reducing harvest pressure and allowing the stock to recover, and so on indefinitely.

This analysis has concrete implications for natural resource harvest policies. But the recommended policies—such as those that encourage harvesters to avoid sunk costs in harvesting particular species and systems, and that develop economic alternatives to harvest—have been almost the opposite of those that governments have actually adopted. Indeed, I argue that the major reason for the collapse and imperilment of species and ecosystems is not the bioeconomic dynamic set up by the open access rule of capture, but rather government policies that have systematically subsidized natural resource use and thereby discouraged exit from extractive (harvesting) industries.

The bioeconomics of open access harvest are conventionally linked to, and indeed arose from, the study of resources such as fisheries and forests. Upon closer analysis, however, one can see that the open access, rule of capture management regime sets up a very similar economic dynamic both for natural resource pollution and land development. I present such an analysis here. In the case of pollution, just as the profitability of natural resource harvesters depends upon the size and health of the stock they are harvesting, so too is the productivity of most industries that pollute watersheds and airsheds decreased by high levels of ambient pollution. Moreover, just as resource stocks have natural growth rates, so too do local

¹ A terminological distinction that I borrow from Dean Lueck, *The Rule of First Possession and the Design of the Law*, 38 J. L. & ECON. 393, 395–403 (1995).

environments have natural rates at which they both produce and consume most common pollutants. Thus a parallel to the model of resource harvest exists for resource pollution. I develop this model, and then explain its most important policy implication, which is that just as economically motivated human decisions regarding entry to and exit from harvest industries are key, so too is the regulation of polluters' decisions about when to leave a polluted local environment a central concern of modern environmental laws.

I conclude by stretching the open access model to land development. Land is generally privately owned, and one might think that an open access model therefore cannot shed light on the land development process. While land is privately owned, however, the location of a parcel of land strongly affects its value. In particular, land values in the rapidly developing, allegedly sprawling American urban-rural fringe are strongly affected by the amount of nearby undeveloped, open space land. In a very real sense, land development in such places is an attempt to capture the value of open space. It is thus subject to very similar economic dynamics as are natural resource harvest and pollution. I explain these dynamics and argue that they have the important but generally unrecognized implication that policies which attempt to restrict or cap land development when open space becomes scarce may actually cause a more rapid loss of open space.

II. THE RULE OF CAPTURE AND NATURAL RESOURCE HARVEST

A. Rule of Capture for Natural Resources (Asset Stocks)

As applied to determine ownership of an entire asset stock—such as a mineral deposit—the rule of capture amounts to a system in which the first person to find and develop the natural resource acquires ownership of it. Although it has some efficient properties, such a race to develop is on balance likely to be inefficient.

From an efficiency point of view, the advantage of awarding property rights to the first person to develop a natural resource is it incentivizes development effort, and—at least on average—awards the property right in the resource to the person with the lowest cost or highest productivity in searching for and developing natural resources. Development races also, however, generate clear inefficiencies.

The first is that there is an externality when many persons are competing for a single prize. In competing for a prize, each player's probability of winning—by being the first to develop—depends upon the intensity of effort chosen by the other contestants. The externality arises because no individual takes account of the negative effect of her own effort on the probability that other contestants will be first. Because of this failure to individually internalize the collective cost of capture effort, from a social point of view, too much effort is expended and development occurs too quickly.² Indeed, with free entry into the race to develop, people enter the

² See Dale T. Mortensen, *Property Rights and Efficiency in Mating, Racing, and Related Games*, 72 AM. ECON. REV. 968 (1982). As Mortensen shows, it is possible to overcome this externality by requiring that the capturer compensate the others for their lost net value of play

race provided that they expect a positive return from entry, ignoring the effect of their entry on the chances of others.

This phenomenon—of rent dissipation and excessive entry—is true in a wide variety of contexts in which individuals race for property rights.³ In the natural resource area, whether this problem arises depends very much upon how abundant resources are relative to the number of people racing to acquire rights. With a large number of resources, relative to contestants for property rights, externalities and rent dissipation are unlikely to be a severe problem. When the number of contestants becomes large, relative to resource abundance, however, the rule of capture raises not only the problem of rent dissipation—too much effort invested in capture activities—but also the problem of premature resource development. This result hinges upon a number of key assumptions, as can be seen when we review the argument in one of its clearest and earliest statements.⁴

From an economic point of view, the value of a resource is determined by the discounted present value of the flow of profits from its development. Thus, until farmland is actually put into production, or a mineral deposit mined, it generates no positive return. Suppose now that while there is an annual cost of operating a farm or mine, there is one-time sunk cost of developing the resource for production (building the mine, clearing and draining the farmland). Call this the “set-up cost.” Suppose also that, for unspecified extraneous reasons, it will be some years before the resource will generate positive profits. Consider now the decision of a private owner of the resource, who has acquired ownership simply by acquiring formal title. Such an owner will obviously not incur the sunk set-up costs until she is actually ready to conduct operations (mining, farming). She will, moreover, not commence operations until the annual operating profits are large enough to cover interest charges on the set-up cost plus any appreciation or depreciation in the set-up costs over time.

Now suppose that the only way of acquiring title to the resource stock (land, or a mineral deposit) is by actually incurring the set-up costs and beginning production. Assuming free entry—perfect competition—would-be owners will be pushed by competition to incur set-up costs and begin operations as soon as the present value of future profits is sufficient to cover set-up costs. When the annual profit is increasing over time, and is at first

given discovery. Net values of play depend upon private information, however, particularly regarding individual costs of capture. These values can be elicited with something like a second price auction, implemented by fixing the number of entrants in the race, with the top entrants winning in return for an entry fee equal to the highest losing bid. Through such a mechanism, people will, in equilibrium, bid their true value of participation as an entry fee. This needs to be done sequentially at each stage of the race, and the auction stops only if the bids are at a steady state.

³ For a general demonstration of this result, see Leuck, *supra* note 1, at 398–402.

⁴ Clive Southey, *The Staples Thesis, Common Property and Homesteading*, 11 CAN. J. ECON. 547, 553–557 (1978). Southey’s model is applied to explain and critique homesteading development in Terry L. Anderson & Peter J. Hill, *The Race for Property Rights*, 33 J. L. & ECON. 177 (1990), and to the general problem of first possession rules for asset stock ownership by Leuck, *supra* note 1, at 395–403. The earliest statement of the basic idea of which I am aware is Yoram Barzel, *The Optimal Timing of Innovations*, 50 REV. ECON. & STAT. 348 (1968).

negative, this zero profit condition will generally be met at a point in time which occurs before annual profits have become positive—before it is economically efficient to put the resource into production.⁵

B. Rule of Capture for Asset Flows

As is well known, managing natural resources on an open access, “catch what you can” basis—under the rule of capture—leads to overharvest of the resource. More precisely, in a classic open access problem, an individual harvester’s productivity depends positively on his own effort level, but decreases with the increased effort level of other harvesters. In such a model, both the past and present harvest levels of other users generate an externality in the form of decreased present productivity: past harvest causes a fall in the resource stock that makes future harvest efforts less productive; present harvest causes the congestion effect of increased present day pressure on the resource.⁶

When each user is small relative to the total number of users, they all ignore the marginal effect of their increased harvest on other users and increase harvest levels until average product equals average cost. With declining average product, this means that—just as in the case of racing to capture a stock—harvest levels are too high from a social point of view.⁷ This result is often taken to imply that the rule of capture (open access) will lead to the overexploitation and eventual extinction of non-renewable natural resources.⁸

This perception—that open access harvest leads to resource extinction—is neither theoretically nor empirically sound. As a theoretical matter, although open access harvest is generally above what is economically optimal from a system-wide point of view, it will not generally drive a renewable resource such as wildlife or fish to extinction. The rate of decline of an open access resource is determined by the total effort devoted to harvest (number of harvesters in a world of identical harvesters) relative

⁵ Matters are in one sense less bad, and in another worse, when an individual gets ownership merely by incurring set-up costs. Individuals will wait to begin operations until they are profitable, and will incur set-up costs when the discounted value of profits are sufficient to cover set-up costs. Because negative profits are avoided, set-up costs are incurred earlier. Thus, such a property rights regime induces the earliest expenditure of set-up costs but a delay in actual operations until the optimal point in time.

⁶ For a formal model with both of these effects that solves for the steady state level of harvest and long run level of the resource, see Robin Brooks, Michael Murray, Stephen Salant & Jill C. Weise, *When is the Standard Analysis of Common Property Extraction under Free Access Correct? A Game-Theoretic Justification for Non-Game-Theoretic Analyses*, 107 J. POL. ECON. 843, 845 (1999). One-period models capture only the effect of past harvest on the present stock. For such a model, see Lueck, *supra* note 1, at 398.

⁷ For a demonstration of this basic result, see Lueck, *supra* note 1 at, 404–405. See also David A. Starrett, *Property Rights, Public Goods and the Environment*, in 1 HANDBOOK OF ENVIRONMENTAL ECONOMICS 98, 102 (Karl G. Maler & J. R. Vincent eds., 2003) (using the example of a rancher choosing the number of cows to graze on his land).

⁸ This result traces back to H. Scott Gordon, *The Economic Theory of a Common Property Resource: The Fishery*, 62 J. POL. ECON. 124 (1954) (arguing that fisheries are over exploited because of their common property nature).

to the natural growth rate of the resource. More precisely, the change in any resource stock is equal to the natural growth in that stock, minus the harvest.⁹ Under open access, the equilibrium level of harvest (number of harvesters) is determined by the zero profit, rent dissipation condition. People enter the market to harvest an open access resource until expected profits decrease to zero. It is possible for this open access market dynamic to drive the resource stock to extinction, but only under certain biological and economic conditions. To understand these, it is necessary to describe somewhat more formally the dynamics of open access harvest.

C. Open Access and Extinction

1. The Dynamics of Open Access Harvest

These conditions are important to understand and worthy of careful consideration. First, the impact of the rule of capture on the rate of resource depletion depends upon two separate systems: one biological and one economic. In its simplest form, on the biological side, the basic dynamic says that the per period, or instantaneous, change in the resource stock is equal to its natural growth (or decay) minus the harvest. Symbolically, we have that :

$$(1) \dot{x} = dx/dt = f(x) - y,$$

where x is the level of the resource stock, $f(x)$ is the natural growth and y is the amount harvested, and dx/dt is the (instantaneous) change in the level of the stock. In bioeconomic equilibrium, the size of the resource stock is not changing, so that $f(x)$, the natural growth, equals the harvest, y .

Under open access, the condition for economic equilibrium is that the aggregate effort level devoted to harvest is such that total industry profits are zero. If we think of the aggregate effort level as representing the sum of the individual efforts of identical harvesters, then this condition means economic equilibrium results when the number of harvesters increases until economic rents (above normal profits) have been fully dissipated. In general, the level of harvest, y , is determined both by the aggregate effort level, e , and by the level of the stock, x . That is, $y = h(e, x)$. It is reasonable to think that in its most general form, $\partial h/\partial e > 0$, $\partial h/\partial x > 0$, with $\partial^2 h/\partial e^2 < 0$, meaning that aggregate harvest increases as effort and the stock increase, but (at least in the case of effort) at a declining rate (reflecting diminishing marginal productivity of effort). If we now let the price of the harvested good be given by p and the cost of effort by c , then market equilibrium requires that total revenues equal total costs, or:

$$(2) ph(e, x) = ce$$

A sustained bioeconomic equilibrium for a resource subject to open access harvest is then defined by a level of the resource stock, x^o , and level

⁹ For these basics, see COLIN W. CLARK, MATHEMATICAL BIOECONOMICS 9–12 (2d ed. 1990) (describing basic functions used to evaluate stock changes).

of effort, e^o , such that both equations (1) and (2) are satisfied at (e^o, x^o) . At such a sustained bioeconomic equilibrium, both the economic system determining harvest and the biological system being harvested are at unchanging levels, with a constant level of harvest effort, harvest, and resource stock.

Within such a system, the question of whether or not open access management leads to extinction becomes the question of whether the equilibrium level of the resource stock x^o is greater than zero. In order to answer this question, we need to better understand how the equilibrium levels of economic effort and biological resource stock are determined, that is, the dynamic process by which equilibrium arises. The clearest way to see the underlying forces behind bioeconomic equilibrium is to begin with the competitive (or open access) market equilibrium that determines effort.¹⁰ The condition for open access equilibrium given by equation (2) may be rewritten as $h(e, x) = (c/p)e$, an equality that is captured graphically by Figure 1. The story told by Figure 1 is a very fundamental one: open access equilibrium results when the per unit cost of effort equals its per unit return (price). Hence the higher the price of the harvested resource and the lower the cost of harvest effort, the higher the open access, equilibrium level of harvest effort. Similarly, the larger the resource stock, the more productive the effort and the higher the open access equilibrium level of effort.

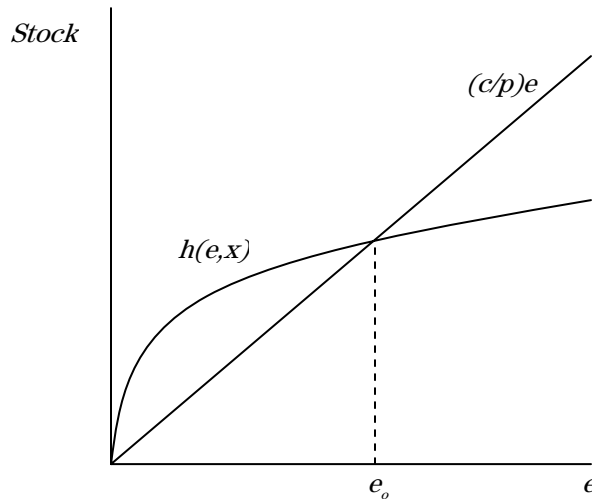


Figure 1
Equilibrium Harvest Effort under Open Access/Rule of Capture

¹⁰ This is not the standard expositional pathway found, for instance, in CLARK *supra* note 9, at 24–35; see also JON M. CONRAD & COLIN W. CLARK, NATURAL RESOURCE ECONOMICS: NOTES AND PROBLEMS 88–90 (1989) (discussing an early model of the common-property fishery). However, as can be seen from equation (2) above, the standard expositional approach tends to create confusion by employing a specific functional form $Y = qex$, for $q > 0$, that obscures the direct role of the market—which is to determine effort—with its indirect effect in determining the equilibrium, sustained population level.

The Figure 1 story is only the first chapter, for the combined biological/economic system is not in equilibrium unless the stock level, x , is such that the harvest $h(e^o, x)$ is such that population is static. For this to be true, it must be that the level of the stock is at a point at which the $h(x, e^o)$ and $f(x)$ curves intersect in Figure 2. This stock level is the sustained, or steady state level x^o —a level such that, given the harvest effort level determined by economic incentives, natural growth (determined by the stock level) just equals harvest.

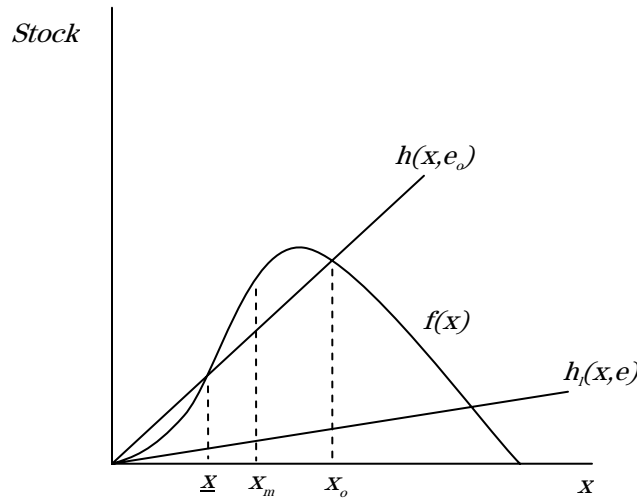


Figure 2
Open Access Dynamics

When the stock level is “wrong,” given economically-determined effort, natural growth and human harvest are not equal, and so the level of the stock will rise or fall. If for example, effort was e^o but the stock level was at some value x' which exceeded the value x^o at which $f(x) = h(x, e^o)$, then as can be seen from the figure, we would have $f(x') < h(x', e^o)$ —natural growth would be less than harvest—and stock level would fall. Likewise, stock level would increase, given harvest effort e^o , if it was initially below x^o .

The perspicacious reader will have noted that given the $f(x)$ curve drawn in Figure 2, there are in fact two values of x for which $f(x) = h(x, e^o)$. This—the existence of multiple equilibrium points of zero net growth in the stock—will in fact be true anytime the slope of the $f(x)$ function increases at first and then declines.¹¹ While there are two equilibrium points, however, only one, x^o , is stable in the sense that a small, random perturbation of the stock will be self-correcting. To see this, consider the lower equilibrium stock value \bar{x} . If the stock were suddenly to jump above this level—due, say to an unusually favorable run of weather that increases the amount of food

¹¹ In the bioeconomics literature, a natural growth function with such a shape is known as depensatory, in that the rate of growth is actually increasing for low levels of the stock. See CLARK, *supra* note 9, at 16–18.

available and hence the population level—then it would be in a range in which natural growth $f(x)$ exceeds harvest $h(x, e^o)$, and so the population would increase to x^o . Conversely, were random events to cause a decrease in the stock from the point \underline{x} , then it would be at a level at which natural growth was less than harvest, causing the stock to fall to zero. Thus, the equilibrium or stationary value \underline{x} is not stable.

In terms of the biological impact of the economic incentives created by open access, what is most interesting about the natural growth function $f(x)$ depicted by Figure 2 is not that there is an unstable low population level, but that open access incentives will drive the population discontinuously to zero long before that low level is ever reached. To see why this is so, suppose we begin at a biological-economic equilibrium (e^o, x^o) , but that market price then begins to increase. From the analysis of market incentives, we know that as the market price goes up, so too does the zero profit level of harvest effort. Hence in Figure 2, as price goes up, the $h(x, e)$ curve also shifts up, causing harvest to exceed growth, so that population falls. But as price continues to increase, and the $h(x, e^o)$ curve continues to rotate upward from the origin, eventually the only stationary point will be x^m , the point where the slope of the $f(x)$ (its steepness) is greatest. For any further increase in price and effort level harvest $h(x, e)$ will exceed natural growth $f(x)$ and the population will fall. This fall in population will not help the system equilibrate—by increasing the growth of the population—but will cause an even bigger decline in population growth. Unless harvest incentives weaken (the $h(x, e)$ function shifts back down), the biological system will go from a stable but declining population to one of continuous decline to zero.

Harvest incentives, given by equation (2), may or may not weaken. From that equation, we see that if the price increases stop soon after the population has been driven down to the level x^m , then the continuous declines in population that begin at that point cause continuous declines in industry harvest. Beginning from an initial industry or open access market equilibrium at x^m , where total revenues equal total costs, total costs will rise above total revenues. On average, harvesters will be losing money. If, as standard economic theory predicts, such losses trigger rapid exit from the industry, and total effort falls by a sufficiently large amount, then the harvest function will shift down dramatically to something like the $h_i(x, e)$ function in Figure 2. With so little harvest effort, natural growth now exceeds the harvest even at the low stock level x^m . The stock will begin to increase, attracting new entrants to the market, thus pushing the harvest function $h(x, e)$ back up. If the stock has not fallen too far, then the bioeconomic system may return to stable, steady state harvest at a level such as x^o .

Such a happy, self-correcting open access system is only a possible, not a necessary result. If a long period of price increases has increased harvest and brought the stock below x^m , but harvesters are very slow to exit the industry, so that harvest remains above natural growth, the population may continue to fall. If industry exit is so slow that the population falls so far that it is below the level \underline{x} , then even if industry exit does finally lower the harvest function $h()$, the population level may be so low that harvest still

exceeds growth, so that the population cannot grow back up to a stable level, but will continue its slide toward zero.

In other words, whether or not open access harvest drives a resource stock to zero depends upon how market dynamics—the dynamic of entry and exit—compare with biological dynamics, the natural growth of the harvested resource stock.¹² Generally speaking, the quicker harvesters exit when the stock becomes low and profits disappear, the lower the likelihood that open access harvest will drive the resource stock to zero. Market entry and exit decisions differ when harvesters base them on rational expectations about future harvest based on the current resource stock and aggregate harvest capacity rather than the most recent profit or loss experience. In particular, under rational expectations, harvesters will begin leaving the market even when the level of the resource stock and aggregate harvest effort is consistent with temporary positive profits and so would not trigger exit by myopic harvesters.¹³ Still, whether myopic or rational expectations drive harvesters' market entry and exit decisions, the interplay between biological growth and economic entry and exit decisions is likely to generate cycles in an open access resource. When the stock is high and the number of harvesters is low, profits attract more harvesters. Such market entry lowers the stock and continues to occur until the stock is so low, relative to the number of harvesters, that harvesters are losing money. Such economic losses induce harvesters to leave the market, which eventually allows natural growth to exceed harvest so that the stock increases. Eventually the stock is so high that profitability returns, and the cycle begins again.¹⁴

And what, finally, of true extinction, which occurs when the resource stock is driven to zero and cannot return ever again to a positive level? Extinction in this sense can result only if there is a minimum viable population, where this means that there is a level of the population x_c such that $f(x) \leq 0$ for all $x < x_c$ so that once x falls below x_c , the population will fall inexorably to zero. Figure 3 depicts such a natural growth function (which is

¹² To prove this formally requires that one specify a dynamic equation for market entry that is analogous to the dynamic equation for biological growth given by equation (1). Since Vernon L. Smith's influential article, the standard way to model market entry and exit dynamics has been to assume that entry is proportional to present profits (or exit is proportional to loss). See Vernon L. Smith, *Economics of Production from Natural Resources*, 58 AMER. ECON. REV. 409 (1968). For demonstrations of how the interplay between such an economic dynamic and the biological dynamic determine extinction possibilities, see Jon M. Conrad, *Bioeconomic Models of the Fishery*, in HANDBOOK OF ENVIRONMENTAL ECONOMICS 405, 408–412 (Daniel W. Bromley ed., 1995), and CLARK, *supra* note 9, at 190–192. The possibility of extinction depends very much on the shape of the natural growth function $f(x)$ and of the harvesting cost function. Peter Berck has shown that in the "standard" bioeconomic model, where $f(x)$ is assumed to be such that $f(x) \geq 0$ and $f'(x) < 0$ for all x (what is known as a "compensatory" growth function) and cost is linear, extinction cannot result. Peter Berck, *Open Access and Extinction*, 47 ECONOMETRICA 877 (1979). That extinction is possible for more general natural growth functions and cost structures can be verified by working some of the problems that appear in CONRAD & CLARK, *supra* note 10, at 97–109.

¹³ This is illustrated by Peter Berck & Jeffrey M. Perloff, *An Open-Access Fishery with Rational Expectations*, 52 ECONOMETRICA 489 (1984).

¹⁴ For a demonstration of such cycling in the stock and harvest effort level, see CLARK, *supra* note 9, at 192.

known as critical depensation in bioeconomic literature). As the figure shows, if open access harvest is so intense and exit so slow that it pushes the population down to x_c , then the natural growth rate in the population will become negative, so that even with a ban on all harvest, the stock will fall to zero. Small increases above zero, moreover, will not succeed in creating a viable population, for at such low levels the natural growth rate is negative.

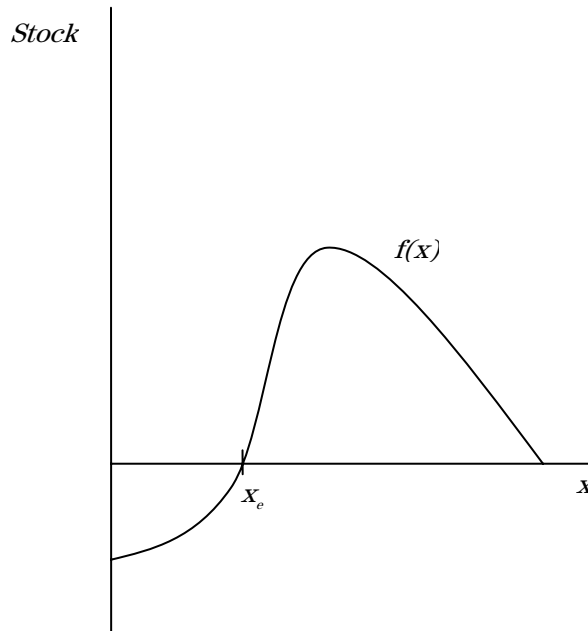


Figure 3
Population Growth and Critical Value
(Minimum Viable Population)

2. Selected Implications of Harvest Dynamics for the Diagnosis and Cure of Problems of Overharvest and Extinction

a. Market Incentives are Not to Blame: Overharvesting by Native Peoples, and Long Term Market Cycles

It is tempting to think that the problems of overharvest and potential resource extinction are due to market incentives—that if harvesters were not driven by the profit motive, then the bioeconomics of open access harvest would be less likely to drive resources to extinction. The underlying idea behind such thinking seems to be that it is relatively limitless market demand that accounts for overharvest and extinction, so that if harvesters were only catching fish or killing animals to feed themselves and their families, then their own limited needs would naturally moderate their harvest levels.

Such thinking is supported neither by theory nor by historical evidence. As a theoretical matter, if harvest is not marketed but instead consumed,

then a population of human harvesters is essentially the same as a population of animal predators, with the harvest level a simple function of the size of the (human) predator population and the population itself increasing in the harvest level.¹⁵ In such a world, it is possible that the bioeconomic system will settle into a stable or stationary state, with the human population generating a level of resource harvest such that both the human population and the resource stock will be forever unchanging.¹⁶ On the other hand, similar to cyclical market-induced dynamics, when the growth rate of the harvested population is relatively low and/or the growth of the human population is very responsive to the level of harvest, then the system tends to cycle around a positive level of the harvested resource. Perhaps most importantly, however, if the growth of the resource is sufficiently slow, the system will exhibit cyclical overshooting. Humans may have little impact on the resource for decades or even centuries, but as human population reaches a sufficiently high level, harvesting vastly exceeds resource growth, leading to resource collapse and also, if the resource is indeed critical to the human population, to a collapse in the human population as well.¹⁷

The historical record of human subsistence societies is replete with evidence of such human-driven extinctions. The failed human civilizations of Easter Island, the Chaco Anasazi in the southwestern United States and ancient Mesopotamia all are cases in which resource harvest led to population growth that eventually exceeded the renewal capacity of the resource.¹⁸ More distantly, while scholars are no longer convinced that it was “man, and man alone” who was responsible for the mass animal extinctions that occurred at the end of Pleistocene period 11,000 years ago,¹⁹ there is no longer any scientific question but that native peoples had huge impacts on their environment and accounted for at least some extinctions.²⁰

Just as it is not true that non-market societies necessarily manage their natural resources so as to avert extinction and resource collapse, so too has the long term pattern of market-driven exploitation exhibited precisely the sort of non-catastrophic cycling that the theoretical model predicts. Long term evidence on commercial fish harvesting strongly confirms the

¹⁵ For a model of such “Malthusian” population dynamics, see James A. Brander & M. Scott Taylor, *The Simple Economics of Easter Island: A Ricardo-Malthus Model of Renewable Resource Use*, 88 AM. ECON. REV. 119, 123–124 (1998).

¹⁶ See *id.* at 125 (displaying the “steady-state analysis”).

¹⁷ *Id.* at 128–131.

¹⁸ Easter Island illustrates the pattern most clearly, perhaps, in that the Jubea Palm—that was so crucial a food and resource for Easter Islanders—was not only uniquely large but also uniquely slow growing. *Id.* at 129–132. For an interesting, albeit less rigorous, account of the decline and extinction of the Easter Island and Anasazi civilizations as well as many others, see JARED DIAMOND, *COLLAPSE: HOW SOCIETIES CHOOSE TO FAIL OR SUCCEED* 79–328 (2005).

¹⁹ As classically stated by Paul W. Martin, *Pleistocene Overkill*, NATURAL HISTORY, Dec. 1967, at 36. Changing views on the role of native societies in this mass extinction are discussed in SHEPARD KRECH III, *THE ECOLOGICAL INDIAN: MYTH AND HISTORY* 29–43 (1999).

²⁰ On newer models and evidence on settling and overhunting by Clovis Age peoples in North America, see PAUL A. DELCOURT & HAZEL R. DELCOURT, *PREHISTORIC NATIVE AMERICANS AND ECOLOGICAL CHANGE: HUMAN ECOSYSTEMS IN EASTERN NORTH AMERICA SINCE THE PLEISTOCENE* 142–160 (2004).

prediction of bioeconomic cycling. Almost a century of records on the annual catch of cod off the Lofoten Islands show not only cycling, but also relatively prolonged periods of relatively low (as well as high) catches and catch rates per fisherman.²¹ Likewise, a half-century of records on the French sardine fishery in Brittany and thirty years of records on the Fraser River sockeye salmon harvest also clearly depict dramatic oscillations, with periods of tremendous catches followed by crashes.²² Such dramatic and continuing oscillations in harvest have been observed for virtually every commercially valuable fish species; indeed, in the English herring fishery, it has been commented upon since the Middle Ages.²³ As early as the late nineteenth century, commercial salmon harvest in the Pacific Northwest clearly depicted the paradox of bioeconomic cycling: increases in aggregate effort (such as gillnets) increased total harvest, but decreased individual productivity and earnings.²⁴

At the same time, there is clear historical evidence that if market exit does not occur quickly enough, then fish stocks can be harvested into extinction. In the United States, perhaps the most well-known instance of such extinction is provided by the California sardine fishery, where catches increased dramatically, with only a few leveling off periods, from the beginning of commercial operations in 1917 until 1946 when catches began a precipitous fall that ended in the complete collapse of the fishery in 1952.²⁵ Just as with the collapse of Easter Island, there are several biological characteristics of the California sardine fishery that, when plugged into the bioeconomic model, fully explain its relatively rapid extinction. First, sardines were valuable primarily because they could be reduced into fishmeal, the sale of which yielded huge profits, hence a market incentive for very high harvest effort levels.²⁶ Second, and equally importantly, sardines are a schooling fish, which makes it possible to net very large quantities once a school is located. But sardines school even when their overall stock declines, so that harvest efficiency does not decline rapidly with a decline in the stock.²⁷ Thus declines in sardine stocks do not cause a rapid decline in productivity. Coupled with high prices for fishmeal, this biological fact meant that exit from the industry would be relatively slow. Making extinction even more likely was that for sardines, as for other schooling fishes, the survival rate of the young is more or less independent of the size of the stock, making for a linear growth function.²⁸ As seen in Figure 1, with

²¹ TIM D. SMITH, SCALING FISHERIES: THE SCIENCE OF MEASURING THE EFFECTS OF FISHING: 1855-1955, at 10-20 (1994).

²² *Id.* at 10-20.

²³ *Id.* at 170.

²⁴ JOSEPH TAYLOR, MAKING SALMON: AN ENVIRONMENTAL HISTORY OF THE NORTHWEST FISHERIES CRISIS 140-147 (1999).

²⁵ SMITH, *supra* note 21, at 239-254.

²⁶ See ARTHUR F. McEVROY, THE FISHERMAN'S PROBLEM, ECOLOGY AND LAW IN THE CALIFORNIA FISHERIES, 1850-1980, at 145 (1986). McEvoy notes that the profits from producing fish meal from sardines were so high that during the 1930s the entire investment cost of a plant could be recovered in a single season.

²⁷ *Id.* at 148.

²⁸ *Id.* at 149.

a linear growth function $f(x)$, once the harvest exceeds growth, the only thing that can prevent eventual extinction is exit from the industry.

b. Avoiding Human-Induced Extinctions: Patterns and Lessons of Institutional Adaptation and Change

i. What Does the Theory Recommend?

While formal and highly stylized, the basic mathematical bioeconomic model of open access, rule of capture harvest teaches lessons for policies that may reduce the chance that open access harvest will lead to resource extinction. In keeping with the dual, biological/economic nature of the model, these are lessons that affect both the harvesting industry and the biological or physical dynamic of the resource.

The first lesson is the most basic: The static efficiency of any particular level of resource exploitation may be a very poor indicator of what is dynamically efficient—efficient, that is, given the change in resource stock over time induced by a particular harvest level. Localized fishing industries, for example, often realize that their own profit maximization requires that they restrict entry into the fishery through exclusive fishing grounds and similar norms.²⁹ Such localized stratagems allow the internalization of one kind of common pool externality—the effect that increasing one fisherman's effort has in lowering the productivity of other fishermen's efforts. Whether such strategies allow groups of fishermen to optimally manage the resource over time—taking account of how high present harvest levels will lower the stock and productivity in the future—is an entirely different matter.

From this dynamic point of view—that of ensuring open access harvest is itself sustainable in that it does not push the resource to extinction—the model carries a second important lesson: The better a harvester group's economic alternatives to harvesting a particular resource stock, and the cheaper it is for them to move to such alternatives, the better the chances that the biological-economic system will cycle around a relatively high level of the stock, with the stock never falling to zero. If, for example, harvesters are mobile hunter-gatherers with a large number of possible prey, then the model predicts that any particular prey stock does not need to fall very much before the hunters decide to move on to a better, more abundant prey. If, however, we have something like the Easter Island case, where the costs of moving on to a better environment are very high and harvesters have very little information about the returns such a move might bring them, then they are likely to stay and continue harvesting until the resource stock, and their own population, collapse.

Hence policies that promote economic alternatives for resource harvesters, and increase their mobility, will systematically lessen the risk of economically driven resource collapse. Somewhat paradoxically, the last

²⁹ A classic example of such exclusive territorial harvest rights is the Maine lobster fishery, described in detail in JAMES M. ACHESON, *THE LOBSTER GANGS OF MAINE* (1988), and modeled more rigorously in James M. Acheson & Roy M. Gardner, *Spatial Strategies and Territoriality in the Maine Lobster Industry*, 17 *RATIONALITY & SOC.* 309 (2005).

thing that one would want to see, from the point of view of encouraging a bioeconomic cycle that never pushes the resource stock too low, is a harvesting industry whose members have made very large, sunk investments in harvesting a particular resource, but which are worthless in other economic endeavors.

This same argument condemns policies that encourage harvesters to remain attached to particular harvest activities despite very low resource stock levels—such as harvest subsidies and various forms of public aid to harvesting communities—as those policies likely deter biologically desirable exit and reduced aggregate harvest effort. However, care must be taken not to conflate fixed communities with sunk, specialized investments in particular harvest activities. Local communities that are almost entirely dependent upon harvest industries but that have lots of different resources available for harvest—such as multiple species of fish, or game in addition to fish—may actually illustrate stable and sustainable cycling among resources. As pressure on one resource increases, decreasing stock and productivity, harvesters may naturally move to other nearby resources. If such harvest alternatives are sufficiently abundant and productive, then in effect the local harvesting industry is highly mobile in the relevant sense, with rapid substitution away from overharvested resources. Conversely, a much more technologically sophisticated harvest industry that is perfectly mobile in the sense that it is not based in any particular community—such as offshore fishing fleets—may be far less mobile in the relevant economic sense, because it has a large, sunk investment in harvesting a particular resource (e.g. species), and cannot switch to harvesting other species without incurring large costs.³⁰

On the biological side, the fundamental lesson from the model is that different resources have different growth and decay dynamics. Some resource stocks are more resilient than others, able to bounce back even from very low stock levels, while for others, natural growth becomes negative when the stock falls too low. In particular, different biological species have varying ranges and migratory capabilities, with some limited to only a few locations from which members are unlikely to migrate to new habitats, while others are both widespread and easily mobile. There is indeed a striking parallel between the economic dynamics of human harvest and the biological dynamics of a harvested resource. The alternatives and the greater the mobility of individuals in finding those alternatives, the lesser the chance that open access human harvest will lead to an irreversible extinction of the resource.³¹

Variation in resource resiliency carries two policy lessons. First, to prevent open access management from leading to disaster, one needs information about resource dynamics before resource stocks fall to such

³⁰ For a more extended and concrete discussion, comparing the flexibility of the New England inshore fishery across species with the sunk costs and species-dependent nature of offshore fleets, see SUSAN R. PLAYFAIR, *VANISHING SPECIES: SAVING THE FISH, SACRIFICING THE FISHERMAN* (2003).

³¹ For an extended and much more illuminating discussion of this parallel than my discussion here, see GEERAT J. VERMEIJ, *NATURE: AN ECONOMIC HISTORY* (2004).

low levels that they may have already passed the critical point at which extinction becomes inevitable and possibly irreversible. One needs to know not only where the critical level lies, but how that level is affected by larger environmental disturbances. The second lesson, little discussed, is the potential desirability of policies that attempt to increase the range of the resource. As recent concern over invasive and exotic species displays, transplanting species is fraught with uncertainty and risk, and adverse unanticipated consequences. However, for a species of especially high economic and social value, increasing the range and migratory capabilities of the species is, at least in principle, a potential way to prevent its collapse due to overharvest in any particular location.

*ii. The Simple Political Economy of Perverse Open Access
"Regulation": The Coastal Fisheries Example*

Deep within the story of the collapse of the California sardine fishery is a small but important fact. Despite the high prices for sardines and sardine-based fish meal that persisted during much of the 1930s and 1940s, declining stocks during that time may well have moderated fishing pressures. Such market forces, however, never had a chance to work, because with the advent of World War II, the federal government bought virtually the entire product of the sardine industry at very high prices; in 1945, the War Food Administration actually ordered the catch increased by one-third from very high levels.³² While we cannot be sure how significant these government policies were in encouraging unsustainable levels of the California sardine catch, they encouraged overharvest at a time when market forces alone would have encouraged industry exit and harvest decreases. Such policies illustrate a very general pattern: Observed governmental policies that regulate open access harvest have not only failed to meet the general theoretical prescriptions set out above, they have been, in many cases, contrary to the objective of preventing resource collapse.

Most seriously, rather than pursuing policies that tend to create valuable alternatives to resource harvest, governments across the world have subsidized harvest, as in the case of the California sardine. This is true for resources ranging from fisheries to forests.³³ Even worse, as resource stocks have declined, lowering the average return to harvesters, governments typically increase the subsidies, thus tending to keep harvest levels much higher, and for a far longer period, than they would be in the absence of subsidies.³⁴

Interestingly, government subsidies for open access harvest have generally increased when individual countries assert national ownership and control rights over the resource than when they do not. This is most dramatically illustrated by the case of coastal fisheries. Since 1945, countries

³² McEVOY, *supra* note 26, at 153.

³³ See NORMAN MYERS & JENNIFER KENT, PERVERSE SUBSIDIES: HOW TAX DOLLARS CAN UNDERCUT THE ENVIRONMENT AND THE ECONOMY 148–186 (2001) (discussing government subsidization of natural resource harvests).

³⁴ *Id.* at 152.

have increasingly asserted ownership rights over coastal ocean resources, a trend that culminated in 1983 with the United Nation's authorization of the 200 mile Exclusive Economic Zones (EEZs).³⁵ Within these zones, coastal states have essentially unlimited jurisdiction over natural resources,³⁶ and by the 1990s, the vast majority of coastal states had declared such zones, encompassing over ninety percent of the world's fisheries.³⁷ Among major powers, the United States led the way with the creation of a "Fishery Conservation Zone" that extended the limit of U.S. fisheries control from 12 to 200 miles offshore.³⁸ To regulate and control harvest of the newly nationalized coastal fisheries resource, the United States established a system of regional fisheries management councils.³⁹

The general failure of these councils to effectively manage America's national fisheries, epitomized by the collapse and closure of the New England cod fishery, has been discussed at length by a number of authors.⁴⁰ However badly constructed, the council regulatory structure was doomed to fail because, as in virtually every other coastal state, the declaration by the United States of the EEZ generated a massive increase in fishing fleet size and capacity—an increase fueled by government subsidies.

Government subsidization of fisheries has a long history,⁴¹ but the declaration of EEZs is remarkable in how it led to a vast expansion in such government involvement. Fishermen across the world had viewed the assertion of national jurisdiction over coastal fisheries as a way of protecting them against an onslaught of fishing competition from foreign fishing fleets. In the United States, fishermen lobbied for declaration of the EEZ because they believed it would simply exclude foreign fleets from American coastal

³⁵ See United Nations Convention on the Law of the Sea, arts. 56–57, *opened for signature* Dec. 10, 1982, 1833 U.N.T.S. 397 (entered into force Nov. 16, 2004) (establishing the rights, jurisdiction, and duties of the coastal countries in EEZs). See Rognvaldur Hannesson, *From Common Fish to Rights Based Fishing: Fisheries Management and the Evolution of Exclusive Rights to Fish*, 35 EUR. ECON. REV. 397 (1991) (noting that significant economic changes in the global fishing industry have necessitated changes in the ownership rights of the sea).

³⁶ Hannesson, *supra* note 35, at 398.

³⁷ Gunnar Kullenberg, *The Exclusive Economic Zone: Some Perspectives*, 42 OCEAN & COASTAL MANAGEMENT 849, 850 (1999).

³⁸ Magnuson-Stevens Fishery Conservation and Management Act, Pub. L. No. 94–265, 90 Stat. 331 (codified at 16 U.S.C. §§1801–1882 (2000)). Such Exclusive Economic Zones were officially authorized and formally defined in the 1982 United Nations Convention on the Law of the Sea, *supra* note 35 arts. 56–57.

³⁹ These are succinctly described in JOHN H. HEINZ CENTER FOR SCIENCE, ECONOMICS AND ENVIRONMENT, *FISHING GROUNDS: DEFINING A NEW ERA FOR AMERICAN FISHERIES MANAGEMENT* 26–27 (2000). For a discussion of the many problems and difficulties with these regional management councils, see MICHAEL L. WEBER, *FROM ABUNDANCE TO SCARCITY* 85–93 (2002), and PLAYFAIR, *supra* note 30, at 43–108.

⁴⁰ See, e.g., PLAYFAIR, *supra* note 30, at 93–108 (discussing the failures of the New England Fishery Management Council).

⁴¹ As early as the 1830s, Newfoundland fishermen were complaining that the bounty system set up by the French government had stimulated the buildup of a French fleet of huge ships whose use of seine and set lines was severely depleting Grand and Sable Bank cod stocks. HAROLD A. INNIS, *THE COD FISHERIES: HISTORY OF AN INTERNATIONAL ECONOMY* 375–377, 380–381 (1954). According to Canadian observers, the French cod fleet was “more of a governmental affair than of private mercantile enterprise,” with the Marine Royale setting down detailed rules regarding the operation of each and every vessel. *Id.* at 380–381.

fishing grounds.⁴² In New England, for example, nationalization of fisheries was provoked by the arrival of foreign fleets of heavily subsidized modern factory trawlers, especially from the Soviet Union, who by 1965 were taking sixty-five percent of the Georges Bank haddock landings, leading to such a badly depleted Georges Bank haddock stock that foreign fleets then switched in 1966 to cod, which then led to a sustained fall in cod landings.⁴³ By the early 1970s there was a clear cut position among New England politicians that the decline of the New England fishing industry was the direct result of “foreign overfishing and the massive invasion of the foreign fleets during the early 1960s.”⁴⁴

To Congress and the fishing industry, the declaration of exclusive American fishing rights within the 200 mile zone was an opportunity to bolster and modernize the American fishing fleet. In addition to general subsidies, such as the investment tax credit, the United States designed financial subsidies for the fishing industry, including government-guaranteed boat-building loans at lower interest rates and for longer terms than traditional five-year boat loans.⁴⁵ Coming on the heels of several very good harvest years, and with “visions of vast waters supposedly now lightly fished,”⁴⁶ U.S. fisheries responded with a massive increase in fleet size and technological sophistication. In the Alaska pollock fishery alone, Congress guaranteed close to \$65 million in low-interest loans to finance construction of ten factory trawlers, and by 1988, the federal government had used such loans to finance roughly eighty percent of the \$520 million cost of the forty-three U.S. owned factory trawlers in the fishery.⁴⁷ In New England the number of boats in the groundfishing fleet doubled from 600 to 1200 boats between 1976 and 1982, and with new technologies the harvest capacity of the fleet grew even faster, with cod, haddock and yellowtail flounder landings doubling in only four years.⁴⁸ These subsidies, combined with similar state subsidy programs, financed the largest buildup of U.S. fishing vessels in the history of the United States, with 13,340 documented fishing vessels built in the first ten years after the law’s passage, fully forty-four percent of all vessels built between 1950 and 1997.⁴⁹ Notably, while the number of small boats declined forty percent between 1976 and 1996, the number of large vessels increased seventy percent, to almost 29,000.⁵⁰ With so many large, highly efficient boats on the water, total landings—which in

⁴² See, e.g., MARGARET E. DEWAR, *INDUSTRY IN TROUBLE: THE FEDERAL GOVERNMENT AND THE NEW ENGLAND FISHERIES*, 132–147 (1983) (discussing efforts by fishing interests to protect fisheries from foreign fishing pressures).

⁴³ *Id.* at 105–106.

⁴⁴ *Id.* at 113.

⁴⁵ DAVID DOBBS, *THE GREAT GULF: FISHERMEN, SCIENTISTS, AND THE STRUGGLE TO REVIVE THE WORLD’S GREATEST FISHERY* 103 (2000).

⁴⁶ *Id.* at 104.

⁴⁷ PLAYFAIR, *supra* note 30, at 202.

⁴⁸ DOBBS, *supra* note 45, at 104.

⁴⁹ WEBER, *supra* note 39, at 86.

⁵⁰ *Id.*

1976 were near their average after World War II—grew sixty-six percent, while fishing income in 1996 was 2.5 times what it had been in 1976.⁵¹

Essentially the same dynamic took place in virtually every coastal state: The nations' fishermen lobbied for passage of the EEZ, and responding to their newly created exclusive sovereign rights, national governments then stepped up subsidies for fishermen leading to a vast increase in fishing capacity so that, ultimately, the worldwide fishing resource was subject to much greater harvest pressure than before the declaration of EEZs.⁵² Indeed, since the factory trawler fleets that descended upon coastal waters en masse beginning in the 1950s were themselves the product of massive government subsidies (or actually state owned, as in the case of the huge fleets sent from the communist Soviet Union and Eastern European countries), it is clear that government subsidies played a very significant role in the increase in worldwide fishing effort that occurred in the late twentieth century. This led to the collapse of ancient and valuable resource stocks, such as the cod fishery of the northwestern Atlantic. Far from encouraging flexible and responsive market responses to changing fish stocks, governments acted to directly increase the size and capacity of the fishing industry and then took steps to keep that industry from shrinking in response to declining stocks.

While precisely the opposite of sustainable open access harvest, such policies have a natural political/economic explanation. In countries that are functioning representative democracies, democratically elected legislatures

⁵¹ *Id.* at 86–87.

⁵² For a short history of worldwide subsidies, see WILLIAM E. SCHRANK, INTRODUCING FISHERIES SUBSIDIES, FAO FISHERIES TECHNICAL PAPER NO. 437 (2003). In Canada, landings of cod had varied cyclically over hundreds of years of open access fishing between 150,000 and 300,000 metric tons annually, until the arrival of the Eastern European and Soviet factory freezer trawlers after World War II, with distant water fleet harvest from Canadian offshore waters—Grand Banks and Flemish cap—increasing from 117,000 metric tons (39% of total) in 1956 to 783,000 metric tons, and 85% of the total, in 1968. Christopher Finlayson & Bonnie J. McCay, *Crossing the Threshold of Ecosystem Resilience: The Commercial Extinction of Northern Cod*, in LINKING SOCIAL AND ECOLOGICAL SYSTEMS: MANAGEMENT PRACTICES AND SOCIAL MECHANISMS FOR BUILDING RESILIENCE 311, 316 (Fikret Berkes, Carl Folke & Johan Colding eds., 1998). Just as in the United States, the Canadian fishing industry lobbied for the declaration of an exclusive national property right in the coastal fishery, and Canada responded by declaring a 200 mile EEZ in 1977. MIRIAM WRIGHT, A FISHERY FOR MODERN TIMES: THE STATE AND THE INDUSTRIALIZATION OF THE NEWFOUNDLAND FISHERY, 1934–1968, at 104–112, 152 (2001). Unlike U.S. coastal states, the provincial government of Newfoundland had spent over \$53 million since the late 1940s on low interest loans and loan guarantees to subsidize the construction of frozen fish processing plants and deep sea trawlers, and due in part to these cost-lowering subsidies, Newfoundland has displaced New England as the primary supplier of groundfish to the U.S. frozen fish industry. *Id.* at 13–14, 81–88. The Canadian federal government got involved in fisheries subsidies in direct response to the arrival of foreign factory fleets, with the 1966 Fisheries Development Act providing low rate loans for trawlers and fish processing plants. *Id.* at 141–145. This initiated a general Canadian federal policy favoring the construction of a large, technologically sophisticated trawler fleet, a policy that greatly accelerated after the declaration of the 200 mile EEZ, with increases in Canadian federal government subsidies for constructing new vessels and upgrading old ones, and for constructing new fish processing facilities. *Id.* at 152. The subsidies had the predictable effect of increasing the number of fishermen licensed in Newfoundland threefold between 1974 and 1980. Finlayson & McCay, *supra*, at 320. The subsidies also helped to increase the number of fish processing plants from 89 in 1974 to 138 in 1980, despite continuous declines in landings since 1985. WRIGHT, *supra*, at 152, 154.

oversee and control public regulatory agencies that manage public resources. It is my view that the model that best explains the behavior of such agencies is one that assumes that agencies manage natural resources so as to maximize their net political support, where political support is determined by legislators who represent the short-run interests of their constituents.⁵³ More than almost any other industry, natural resource harvest industries are necessarily geographically concentrated near the location of the resource. Fishermen live in coastal towns near the waters they fish; loggers live in lumbering towns near the forests they log. Legislators from these harvesting districts are likely to be intensely concerned with protecting and even increasing the size of their local harvest industry. The last thing that legislators would want to encourage is exit from the industry, since exit also means an often severe short-run decline in local resource-dependent economies and a decline in local population—events that are generally inconsistent with re-election. Of course, legislators from resource harvesting districts are unlikely to be a majority in the legislature, but there is generally no reason for other legislators to take interest, one way or the other, in the highly theoretical and abstract matter of selecting policies that are, or are not, consistent with the long term sustainability of a particular resource. The median voter in Michigan, for instance, is likely to see no relation between the health of New England cod populations and her own welfare.

Because resource harvest industries are so singularly, indeed almost uniquely, concentrated geographically, representative majoritarian legislatures are very likely to pass laws that have the objective of maintaining and subsidizing harvest industries, even when such policies threaten to drive resource stocks to zero. Legislation that requires resource management agencies to sustainably manage resource stocks, the harvest of which the legislature has in fact subsidized, is inherently self-contradictory. Such vague, contradictory legislation is good for legislators, in that it gives legislators the opportunity to proclaim that they have served everyone's interests while preserving the option of ad hoc, politically motivated intervention in agency decision making. Even today, the politico-economic logic of legislative survival explains public resource management statutes, not the bioeconomics of sustainable resource management.⁵⁴

A similar politco-economic logic explains another quite remarkable thing about the crisis of global fisheries; that the crisis occurred after, and in large part, as a direct result of the declaration of EEZs by coastal states. In order to exclude, or at least regulate, competition from foreign factory

⁵³ For a formalization of such a model, applied to explain why statutes that require regulatory cost-benefit analysis may not have their intended effects, see Jason Johnston, *A Game-Theoretic Analysis of Alternative Institutions for Regulatory Cost-Benefit Analysis*, 150 U. PA. L. REV. 1343 (2002).

⁵⁴ My discussion here has focused on fisheries, but for a striking example of a statute that vaguely encourages such goals as "sustainability" while preserving ample room for Congress to intervene to pressure the relevant agency to adopt policies that preserve jobs and resource communities, see the National Forest Management Act of 1976, 16 U.S.C. §§ 472a, 521b, 1600, 1611–1614 (2000) (amending Forest and Rangeland Renewable Resources Planning Act of 1974, Pub. L. No. 93-378, 88 Stat. 476).

fleets, coastal states declared EEZs. With less foreign harvest pressure, coastal states and their national fishing industries saw an opportunity to increase government subsidies for the buildup of their own fleets. They succeeded in bolstering their own fleets and increasing employment in fisheries. But this buildup led to an even larger and more vociferous fisheries constituency—more vociferous because it is one thing to ask for government help, but quite another for the government to refuse to help after it has itself funded the very industry expansion that has caused the resource crisis. With more political pressure, subsidies increased rather than declined when resource stocks began to succumb to increased harvest pressure. The declaration of exclusive national rights by coastal fishing nations was a response to an international rule of capture dynamic among competing fishing nations, a dynamic in which coastal states had fallen behind in building up technologically advanced factory fleets. While we cannot run the experiment in reverse, coastal states were so far behind that it is hard to imagine them subsidizing the expansion of their own national fishing fleets without the competitive protection afforded by EEZs. Hence, while the declaration of EEZs did, at least in some cases, cut the level of harvest by the Soviet, Japanese and Eastern European factory fleets, it also stimulated a large, and in some cases more than offsetting, buildup of publicly subsidized coastal nation fleets.

This is not a prediction that one can reach within the context of the model of a competitive open access fishery, because at the level of nation states, the game is not one of perfect competition but of strategic interdependence. In such a strategic world, not only do governments adopt policies to maximize political support rather than to maximize profits, but each government's optimal policy depends upon its expectations regarding the actions of other governments. When a few countries were already far ahead in financing, building and operating distant water fishing fleets, the optimal level of coastal nation fleet investment was lower than when such distant fleets were excluded. I believe that an important lesson from the late twentieth century fishing stock collapses is that in a strategic world, where "property" rights are national rather than private, the declaration of such exclusive sovereign rights may actually exacerbate overharvest incentives.

Although I have spoken exclusively of the incentives of democratically elected legislatures, I do not mean to suggest that representative democracies are by any means the worst at managing their publicly owned natural resources. In many developing countries with weak or corrupt political institutions, there is abundant evidence that corrupt and impatient political elites have managed national natural resources so as to maximize their own short term gains from resource harvest, with no regard either for resource preservation or even for present value maximization.⁵⁵ What I do mean to suggest is that natural resource collapse is due primarily to political, institutional structures that encourage resource harvest well beyond the

⁵⁵ See generally WILLIAM ASCHER, WHY GOVERNMENTS WASTE NATURAL RESOURCES: POLICY FAILURES IN DEVELOPING COUNTRIES (1999) (discussing the political and programmatic reasons for the adoption of wasteful natural resource policies in third world countries).

point at which competitive, open access economic incentives would have dictated market exit and declining harvests.

iii. Some Realism About the Role of Science

I thus disagree with a very large and seemingly growing literature that encourages the belief that natural resource collapse is due to inadequate science and/or the failure of policymakers to properly understand and respond to scientific understanding of resource dynamics. This literature implies that if only we could spend more money on science, and then let scientists, rather than politicians, determine how publicly-held, open access resources are managed, then overharvest and resource collapses could be avoided. In a recent discussion of the collapse of the Canadian cod fishery, for instance, Finlayson and McCay do acknowledge the role played by massive government subsidies,⁵⁶ but what they really emphasize are the errors in the assessment of the size of the cod stock. They find particular fault with a 1982 report by the Department of Fisheries and Oceans (DFO), an agency that was a creature of the 200 mile EEZ declaration, claiming that the stock rebuilding process was well underway and predicting that the 1987 quota would be 400,000 metric tons, with a long term sustainable yield of 500,000 metric tons.⁵⁷ The DFO did not realize until 1989 that it had seriously overestimated stock size, by as much as 100%, while mortality had been underestimated by 50%. As a result, the quotas had been too high and had to be quickly and drastically reduced. There were a number of reasons for these drastic errors in estimating stock size and growth,⁵⁸ errors that are virtually inevitable in estimating something as complex as the stock-growth relationship (more generally known as the stock-recruitment relationship). However, the policy response to scientific uncertainty—to lower fishing quotas and manage conservatively⁵⁹—can hardly be undertaken politically when, as in the Canadian (and the United States') case, the federal government has been pumping hundreds of millions of dollars into subsidies, creating a vastly larger and vastly more efficient national cod fishing fleet.

More generally, greater attention needs to be paid to the political economy of biological and ecological knowledge. Knowledge about the

⁵⁶ Finlayson & McCay, *supra* note 52, at 320 (“[G]overnment policy played a strong role in shaping this tragedy of the commons.”).

⁵⁷ *Id.* at 321–322.

⁵⁸ According to Finlayson and McCay, some of the error was due to bad science, as in treating cod as a unit stock when in fact there were several distinct populations with different migratory patterns and an underestimation of natural mortality and its variability. Others reflected a certain fundamental lack of understanding about using catch data to estimate stock, as in the DFO’s persistent refusal to listen to reports of declining yield and size by inshore fishermen, while not adjusting the good yields from the offshore fleet to take account of the fact that new technologies were resulting in many more fish per unit of labor effort, by among other things, targeting cod when they concentrated to spawn on the offshore slopes of the banks. *Id.* at 321–328.

⁵⁹ For a formal demonstration that this is indeed an optimal policy response given uncertainty, see Anastasios Xepapadeas & Catarina Roseta-Palma, *Instabilities and Robust Control in Fisheries* (Univ. of Crete, Working Paper No. 110.2003, 2003), available at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=486066.

biological dynamics of a publicly owned and regulated natural resource is itself a public good, in that it is generally made available to, and can be used by, any interested and informed person. Like any other public good, the level of its provision is determined politically. To continuously study and monitor the dynamic behavior of all natural resource stocks would entail a vast expenditure of public funds. Moreover, with the vast majority of such stocks far from critical levels, incurring the cost of such continuous monitoring would not make economic sense and would certainly be low on the list of governmental funding priorities. As a matter of stylized historical fact, legislators generously fund science only when there is a crisis that affects a locally important harvest industry and the survival of a very well known and popular or economically important species.⁶⁰ By the time there is a demand for knowledge, it may be too late to save the resource.

iv. The Limited Possibilities of Privatization

If governments actually have an incentive to increase the likelihood that open access harvest will lead to resource collapse, then one might suppose that the opposite regime—exclusive private ownership—might do better. After all, for a single owner, the aggregate industry level of effort is equal to her own individual effort level. Thus, she internalizes the effort externality—both current effort and past effort (through its effect on present stock level). An economically rational owner will maximize the discounted present value of profits from harvest, given the natural rate of resource growth. Whether, however, the single owner's intertemporal harvest and management scheme is socially desirable depends upon how the single owner discounts the future. If the single owner discounts the future at a rate that is very high relative to the natural growth rate of the stock, and the price is sufficiently high, then it will be optimal for her to harvest until extinction.⁶¹ If a fish stock is growing at only three percent annually, but the market interest rate (a profit maximizing owner's discount rate) is six percent, then the owner would maximize her intertemporal profits by harvesting the stock as quickly as possible and investing the proceeds of sale. At the extreme, a single owner that has an infinitely high discount rate would choose precisely the same level of rent-dissipating harvest as results under open access (in that

⁶⁰ In the case of marine ecosystem research, the best example is the Steller sea lion program. In the year 2000, a federal court blocked the Pollock trawling season because it found that the National Marine Fisheries Service had violated the federal Endangered Species Act by failing to adequately assess the impact of Pollock trawling on the Aleutian Islands Steller sea lion population. In response, Alaska Senator Ted Stevens pushed through a rider to a federal appropriations bill, which allowed Pollock fishing to continue while the National Research Council funded research on the causes of the decline in the Steller population. As of 2005, the federal government had spent \$120 million on the Steller research initiative, a far greater amount than is spent on many endangered marine animals that are much closer to extinction, indeed an amount so large that one biologist working on the Steller initiative described it as "obscene." See Rex Dalton, *Conservation Biology: Is This Any Way to Save a Species?*, 436 NATURE 14, 15 (2005).

⁶¹ For formal treatment of the single owner case, including the extinction possibility, see CLARK, *supra* note 9, at 39–62.

with such discounting, she, like open access harvesters, has no interest in the level of the future stock). Conversely, a single owner who does not discount the future at all would choose a harvest level that maximizes long term, infinitely sustainable economic rents.

Because rational private resource owners manage harvest levels over time, so as to maximize the present value of the resource, policies designed to prevent a private owner from collapsing the resource necessarily differ from those that are appropriate under open access competition. A private owner is likely to avoid harvesting to extinction when the resource is growing at a higher rate than the current market of interest (because the owner will make more in terms of increased stock value than she would get by harvesting and investing). In other words, the private owner harvests slowly when investing in the resource stock generates a higher return over time than alternative investments, and by the same token will harvest quickly to extinction when the resource is slow-growing and the market return on investments is high. Such a self-interested calculus ignores social values that inhere in resource preservation but which do not generate revenue for the owner. Such social value may arise for any number of reasons, notably the value of a particular harvest species in maintaining the health and resiliency of a larger ecosystem.⁶² Whatever the resource, a private owner will manage it so as to promote its market value, not its natural or biological value. When such natural or biological values have significant social value, private incentives may well dictate that the resource be entirely used up (made extinct) even when extinction is not socially desirable.⁶³

Such a divergence is a classic instance of externalities from resource use that arise under both private ownership and open access. The general

⁶² The external impact of resource harvest on species biodiversity and ecosystem health is a central concern in many contemporary natural resource management controversies. For recent literature dealing with these effects on ocean fisheries and western United States rangeland grazing, see respectively DEBRA L. DONAHUE, *THE WESTERN RANGE REVISITED: REMOVING LIVESTOCK FROM PUBLIC LANDS TO CONSERVE NATIVE BIODIVERSITY* 114–160 (2002) (detailing the impacts of cattle and sheep grazing on native ecosystems and ecosystem diversity), and Boris Worm et al., *Global Patterns of Predator Diversity in the Open Oceans*, 309 *SCIENCE* 1365 (2005) (finding that tuna and billfish diversity declined between 10 and 50% over the last 50 years, indicating that ecosystem-wide changes are occurring due to climate and fishing pressure).

⁶³ Only recently have economists extended the bioeconomic harvest model, set out earlier, to deal with the biological dynamics that arise when species interact in an ecosystem. See William A. Brock & Anastasios Xepapadeas, *Management of Interacting Species: Regulation Under Nonlinearities and Hysteresis*, 26 *RES. & ENERGY ECON.* 137 (2004) (analyzing the optimal regulation of an open access fishery under two management regimes: social optimal, and rational expectations competitive equilibria with full property rights). For a formal demonstration that an owner who values both profits and biodiversity will harvest less and maintain a higher equilibrium stock, see Chuan-Zhong Li, Karl-Gustaf Lofgren, and Martin L. Weitzman, *Harvesting versus Biodiversity: An Occam's Razor Version*, 18 *ENVTL. & RES. ECON.* 355 (2001). Note that when only profits matter, socially and privately, extinction may be socially and privately optimal. Furthermore, private and social incentives as to the timing of extinction will coincide if the private and social rates of discount are identical. See Maureen L. Cropper, Dwight R. Lee & Sukhraj Singh Pannu, *The Optimal Extinction of a Renewable Natural Resource*, 6 *J. ENVTL. ECON. & MGMT.* 341 (1979); Maureen L. Cropper, *A Note on the Extinction of Renewable Resources*, 15 *J. ENVTL. ECON. & MGMT.* 64 (1988).

policy approaches for harmonizing social and private incentives when there are large social but not private benefits from resource preservation are well known.⁶⁴ Rather than rehash them, I turn now to explore the surprising generality of the dynamic story about resource use told by the rule of capture, open access harvest model. In particular, I ask whether the market forces that lead to environmental pollution and overdevelopment of land might not also be self-correcting, in the same way that open access fisheries sometimes are.

III. THE RULE OF CAPTURE AND THE POLLUTION PROBLEM

The rule of capture—open access—applies to more than just the case in which a natural resource generates a marketable flow of goods or services. It is also the baseline management rule that applies when natural resources are used to dispose of wastes from productive activities. In the unregulated state, the rule of capture applies both when a pulp and paper mill located next to a river draws clean river water as an input into its production process and when it disposes of wastewater from its process back into that same river. Insofar as industrial waste disposal into air and watersheds is governed by an open access, first-in-time management regime, it is reasonable to think that the same models that illuminate problems of overharvest under the rule of capture might also illuminate the problems of air and water pollution.

The problem is that whether applied to asset flows or asset stocks, the standard economic models of the rule of capture (open access), that I have explicated above, ask whether the rule of capture generates optimal levels or timing of resource use, given that the only externalities are among users of the same type. That is, those models are designed to get at questions such as whether the rule of capture leads to an economically desirable level of fish that are harvested, or oil that is pumped, over time. With air and water pollution the problems seem different. Unlike fishermen or oil producers, the pollution problem is not that individual polluters fail to internalize the harm their pollution does to other users of the same type (other polluters), but that they fail to internalize the harm that their activity does to other competing users. From a dynamic point of view, the pollution problem is not

⁶⁴ For a discussion of solutions to the problem of divergent private and social incentives in the context of forest management (one where the resource stock is often privately owned), see TOM TIETENBERG, ENVIRONMENTAL AND NATURAL RESOURCE ECONOMICS 263–275 (5th ed. 2000). My discussion here does not deal with the very important and popular policy of awarding tradeable private permits to use a publicly owned resource. While it is clearly more efficient than a similar limit without tradeable permits (because trading gets the permits into the hands of those who are the most efficient users of the resource), regulated use with tradeable use rights does not solve the fundamental externality problem, which is to set a cap on total use that takes account of external effects. This is illustrated by the case of fisheries, where tradeable permits do not by themselves solve the problem of socially inefficient bycatch. See, e.g., John R. Boyce, *An Economic Analysis of the Fisheries Bycatch Problem*, 31 J. ENVTL. ECON. & MGMT. 314, 331–333 (1996) (showing that when the bycatch species has existence value, a system of individually transferable quotas does not induce socially optimal internalization of the social cost of bycatch).

that the stock may be driven to zero and exhausted too soon, but that other uses may be foreclosed.

The first problem—of static externalization of the harm of pollution—is in fact the same for resource pollution as for resource harvest. Just as harvesters fail to take account of the impact of the negative effect of their harvest effort in lowering the productivity of other harvesters, so too do polluters fail to take account of the negative effect of their use of the resource—as a waste depository—on other users of the resource. Just as the rule of capture leads to overharvest (rent dissipation), so too does the rule incentivize too much pollution.

A. A Dynamic Harvest Model of the Pollution Problem

As we have seen, the dynamics of open access harvest are controlled by two equations. One equation shows how harvest interacts with natural growth to determine equilibrium or steady state stock growth, and the other shows how entry and exit into the harvest game are determined by the present or expected future profitability of the game. In this two equation system, as harvest goes up, equilibrium stock size falls, lowering the return to harvest and tending to drive harvesters out of the market, leading the system to cycle around an interior stable point—that is, a positive value for the resource stock or population.

Analogously, there are two equations that similarly determine the dynamic behavior of open access pollution. Industries that pollute the air and water very often need clean air and water as inputs to their production process, and their average (and marginal) productivity typically falls when the level of air and water pollution gets too high. Indeed, even for a completely modern business, the cleanliness of a local airshed and waterway will affect its attractiveness to employees and its cost of offering those employees basic services, such as water and air, that help define the quality of the workplace environment. Hence, just as harvesters enter a resource market until the level of the stock is so low that entry is no longer profitable, so too will various industrial and other users enter a particular local resource market until the level of pollution is so high that it is no longer profitable to locate there. To illustrate, let us simplify by assuming that there is a single industrial user—pulp and paper mills on a river—just as we assumed a single type of harvester. Then given that pollution of the river managed on an open access, capture basis, we have that pulp mills enter and use and pollute the river until:

$$(3) \quad pq(e, y) - ce = 0,$$

where p is the price for the paper mill output, c is the cost per unit of non-natural-resource inputs and e is the level of such inputs, and y gives the ambient level of pollution—the quality after pollution—of the local natural resource stock. In general, $\partial q/\partial y \leq 0$, so that output is non-increasing in the level of ambient pollution.

Just as with resource harvest, we need another equation to be able to solve for the equilibrium level of productive use and pollution of a local

natural resource. Unlike resource harvest, which directly affects resource quantity, it is most natural to think of resource pollution as directly affecting the quality of a natural resource such as a stream. However, just as the impact of any given harvest on the size of a resource stock depends upon the level of the stock, so too does the effect of any given flow of waste on the quality of an air or watershed depend upon the size of the flow of the pollutant relative to the existing ambient level of the pollutant in the resource. If the ambient level of the pollutant is low, then even a relatively high flow rate of the pollutant may have very little impact on the quality of the resource stock. For higher ambient levels, however, even small increases in flow may begin to lower the stationary or steady-state quality of the resource. This is just to say that for any given pollutant, a natural resource such as an airshed or watershed has a natural carrying capacity, that is, a natural ability to absorb pollution. Just as the growth of a natural resource stock depends upon the level of the stock, so too does the carrying capacity of a resource of a given size depend upon its existing level of pollution.

The following equation formalizes this relationship between the flow of pollution, the resource's existing carrying capacity, and the change in its state:

$$(4) \dot{y} = dy/dt = E(q(e, y)) - g(y),$$

where $E(q(e, y))$, the flow of pollution, increases with output (so that $\partial E/\partial q > 0$), and $g(y)$ is the rate at which the pollutant is degraded or absorbed by ambient biological and/or chemical processes. Just as the growth rate of a harvested resource stock is a function of the level of the stock, so too is the rate at which a resource degrades or decomposes a pollutant a function of the ambient concentration of the given polluting substance.⁶⁵

Equation (4) expresses a fundamental biogeochemical fact that extends far beyond interaction between humans and their environment. Pollution, in the sense of waste from resource consumption, is a basic fact of nature. Indeed, the general theory of consumer-resource interactions, based on the law of conservation of matter, says that " X consumer biomass + Y resources $\rightarrow X$ consumer biomass + aY new consumer biomass + $(1 - a)Y$ waste products."⁶⁶ Many human "pollutants" are both used and produced by living organisms. For such pollutants, there is a natural, positive threshold level of pollutant concentration (quality y) so that if concentration were to fall below this, natural processes would bring it back up (that is, $g(y)$ is negative for y below the threshold—the pollutant is being produced, rather than absorbed, on net). There are many examples of such natural production processes. In the oceans, organic compounds are both produced and released by marine organisms; indeed, a leading textbook author summarizes that "most marine organic matter is produced *in situ* as a result of biological activity," with living organisms responsible for all of the production of particulate organic

⁶⁵ This is a standard formulation, one version of which (assuming a constant rate of degradation) is presented in JON M. CONRAD, RESOURCE ECONOMICS 101 (1999).

⁶⁶ ROBERT W. STERNER & JAMES J. ELSEY, ECOLOGICAL STOICHIOMETRY: THE BIOLOGY OF ELEMENTS FROM MOLECULES TO THE BIOSPHERE 180 (2002).

matter.⁶⁷ Various atmospheric gases are produced by marine and terrestrial systems, such as hydrogen sulfide and dimethyl sulfide (both via direct emission from sediments, soils and plants, and from microbial decomposition of sulfur-containing organics); carbon monoxide is both produced and consumed by a wide variety of microbes, fungi and plants, and very efficiently consumed by soil; natural halomethanes, which are greenhouse gases, are produced by microbial decomposition and contribute to natural or background levels of ozone depletion; most well known, perhaps, methane is produced by all kinds of natural systems, ranging from wetlands to the digestive systems of many invertebrate and vertebrate herbivores.⁶⁸ Used in agricultural fertilization, nutrients such as nitrogen and phosphorous run off into rivers and lakes, but these water bodies themselves have baseline levels of such nutrients, in that not only are nutrients recycled by a whole range of biological consumers, from bacteria on up,⁶⁹ but such consumers also produce nutrients.⁷⁰ In rivers, nutrient concentrations are the result of meteorological precipitation chemistry, weathering, human nutrient transports and uses, uptake and retention within the watershed, and *in situ* sedimentation and conversions such as denitrification.⁷¹ The primary productivity of all kinds of ecosystems, ranging from lakes and temperate streams, to grasslands and forests, is increased when the system is fertilized, and such fertilization may change, in potentially desirable ways, the community structure of such ecosystems.⁷² Perhaps most crucially of all, one must remember that what makes earth unique is the presence of free oxygen (O_2), but O_2 is here only because it is produced by living organisms. Indeed, earth began with very low levels of O_2 , and these levels increased only when photosynthetic organisms evolved.⁷³

Of course, a very basic list of human pollutants would have to include not only nutrients, organic matter, and various naturally generated gases, but also microorganisms, petroleum, radionuclides, trace metals, and a number of artificial substances that include high molecular weight aromatics such as PCBs, polynuclear aromatic hydrocarbons, pesticides (made by adding an unsaturated carbon ring to an organic compound to make it toxic), low molecular weight, volatile organic compounds such as freons, and organometallic compounds. Many of these are not produced naturally, and for such pollutants, the only "natural" process is degradation or dilution (in terms of the above mathematical formalism, the function $g(y)$ is always

⁶⁷ SUSAN M. LIBES, AN INTRODUCTION TO MARINE BIOGEOCHEMISTRY 394 (1992).

⁶⁸ T. FENCHEL, ET AL., BACTERIAL BIOGEOCHEMISTRY: THE ECOPHYSIOLOGY OF MINERAL CYCLING 219–226 (2d ed. 1998).

⁶⁹ STERNER & ELSER, *supra* note 66, at 244.

⁷⁰ *Id.* at 230–261. Crustacean zooplankton have been estimated to contribute 20–25% of particulate phosphorous in lakes. *Id.* at 319.

⁷¹ *Id.* at 329.

⁷² *Id.* at 339–340. It is important to note that because of the energy cost of breaking the triple bond in the N_2 molecule, there are very few marine organisms that can "fix" nitrogen, the most notable being blue-green algae and spartina saltmarsh grass, so most fixed nitrogen in oceans comes from river runoff. FENCHEL ET AL., *supra* note 68, at 178–180.

⁷³ FENCHEL ET AL., *supra* note 68, at 210–213.

above zero). For example, human activity (primarily using leaded gasoline for auto fuel) is responsible for putting most of the lead into marine environments; lead has no stimulatory effect at any level and is toxic to marine organisms even at relatively low thresholds.⁷⁴ Mercury, by contrast, is naturally produced in marine environments.⁷⁵ Even pollutants that are not naturally produced will generally degrade when placed into the environment. Pesticides are, generally speaking, degraded both by biological organisms and by chemical processes.⁷⁶

Thus from the point of view of the formal biogeochemical dynamics captured by equation (4), there would seem to be two empirically important cases: one involving a human pollutant that is also produced naturally (so that there is a threshold level of ambient concentration below which the level will actually increase back up to the threshold even without human involvement), and one involving a human pollutant that is not found naturally (and for which the natural system has only the capacity to degrade or assimilate).

A bit more precisely, for a "natural" pollutant, if the ambient concentration (or "quality") ever drops below a critical level y_c (that is, $g(y) < 0$ for all y such that $0 \leq y < y_c$), is in natural equilibrium at this critical level (so that $g(y_c) = 0$) and then begins to eliminate the pollutant, initially at increasing effectiveness (so that $g'(y)$ is positive up to some value Y of the pollutant), but eventually at decreasing effectiveness, so that $g'(y) < 0$, for $y \geq Y$. Such an assimilation function $g(y)$ depicts a resource that naturally has a positive level of some "pollutant," and which is initially increasingly effective in assimilating the pollutant, but which eventually becomes so clogged with the pollutant that its ability to assimilate the pollutant becomes very weak. For non-natural pollutants, the difference is that the $g(y)$ function is never negative.

⁷⁴ For a general discussion of these pollutants, see LIBES, *supra* note 67, at 603–645, and for lead in particular, see *id.* at 626–627.

⁷⁵ Indeed, when accurate methods of measuring environmental mercury concentrations were developed in the 1970s, it was discovered that most marine and aquatic fish have levels high enough to represent a health threat. However, the initial supposition that anthropogenic pollution had caused such concentrations was shown to be incorrect, as analysis of museum specimens showed that species such as tuna and swordfish simply have naturally high mercury concentrations. Indeed, some swordfish have high enough natural concentrations so that consumption of even "reasonable amounts" of the species would cause a person to exceed her daily recommended mercury intake. LIBES, *supra* note 67, at 627.

⁷⁶ The compounds into which pesticides degrade may be more or less harmful to aquatic and marine organisms than are the parent compounds. For examples of recent research on the process of pesticide degradation that attempt to assess the toxicity of the degradation (or transformation) compounds, see, Chris J. Sinclair & Alistair B.A. Boxall, *Assessing the Ecotoxicity of Pesticide Transformation Products*, 37 ENVTL. SCI. TECH. 4617 (2003); and A.C. Belfroid et al., *Relative Risks of Transformation Products of Pesticides for Aquatic Ecosystems*, 222 SCI. TOTAL ENV'T. 167 (1998).

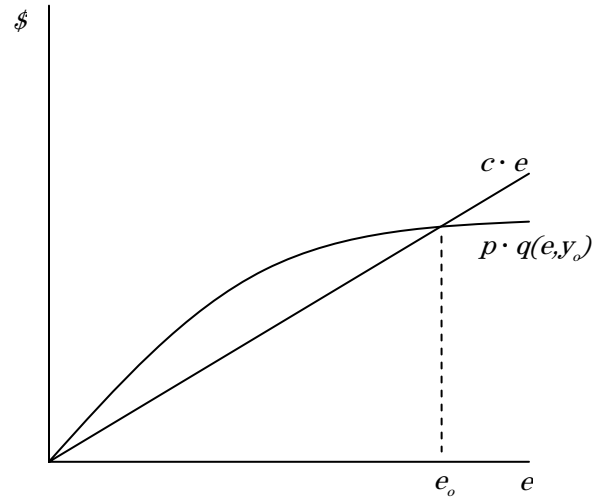


Figure 4
Open Access Pollution

Just as equations (1) and (2) determined the steady state level of the population, so too do equations (3) and (4) determine the equilibrium amount of pollution—steady state resource quality. The market equilibrium of Equation (3) is depicted in Figure 4. As in Figure 1, market incentives determine equilibrium effort, output, and hence the amount of pollution. Equation (4), depicted in Figure 5, then shows what is happening to the level of pollutant in the river, given the flow of human pollution and the existing level of pollution. Importantly, unlike resource harvest—which is increasingly productive, the higher the resource stock—resource pollution, given by the pollution function $E(q(e, y))$ in Figure 5, is decreasing in pollution. This is true when, as assumed, productivity declines with pollution.

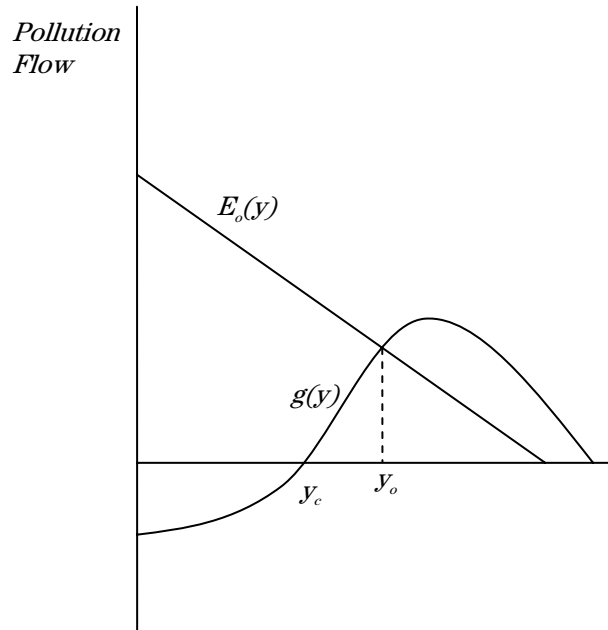


Figure 5
The Dynamics of Pollution

Using Figures 4 and 5, we can see how the combined market-biological system moves, beginning from an initial level of ambient pollution given by y_0 . Given this level of stock pollution, equation (3) determines an equilibrium, open access level of effort e_0 . With this effort level, we have the pollution function $E_0(y)$ in Figure 5. The intersection of $E_0(y)$ and the $g(y)$ function in Figure 5 gives the stationary value of stock ambient pollution, y_0 , that is consistent with market-determined pollution. Were the ambient pollution level greater than this, the natural uptake of the pollutant would be greater than the flow of pollution, so that the level of pollution would fall. This would increase productivity, increasing effort and output, and shifting the pollution function E_0 out. The system would eventually equilibrate at a new, higher effort and output level, but lower level of pollution.

The implication of Figures 4 and 5 is remarkable for being so little realized. Even in a highly polluted resource, when the pollution flow is high, but less than the amount that the resource is itself using up, the natural system will self-correct, lowering pollution and increasing output until the level of pollution is at just that level which the resource itself can assimilate.

I do not mean to suggest that this happy result is by any means the norm. A crucial assumption underlying it is that industry productivity $q(e,y)$ is negatively impacted by ambient pollution. If we instead take an industry in which ambient pollution has no effect on productivity, then increasing ambient pollution does not harm the polluters at all, and there is no fall in output with increasing pollution. In the worst case, with continuously declining $g(y)$ —so that above y_c the system has permanently lost its ability to assimilate or take up the pollutant, but actually produces more of it—any industrial pollution will cause maximal pollution of the resource.

This worst case scenario is possible only when ambient pollution has no deleterious effect on industrial productivity. Perhaps most interestingly, one can have a situation where only the lower level of pollution is stable. In such a case, if we begin with the higher stationary level, but then can somehow lower the ambient level even by a small amount, the system will self-correct to a new, lower level. Conversely, if the ambient level is ever perturbed even slightly above the higher stationary level, then the system will move to such a high level of pollution that it has lost all assimilative capacity.

B. Policy Implications of the Dynamic Harvest Model of Pollution

As the previous discussion indicates, unlike resource harvest—where it is clear that all harvesters suffer when overharvest reduces the stock—there are two cases with polluters: One in which polluters are harmed by the pollution that they cause, and another in which they are unaffected. Although the first situation has typically been ignored in traditional economic modeling of pollution, both are empirically important. Importantly, the policy responses to curbing pollution are quite different in these two different situations.

In the first case, where firms are harmed by high levels of ambient pollution, pollution lowers profits and will eventually cause firms in a particular industry to either support local environmental cleanup or to leave a polluted location for a cleaner and more profitable local environment. To the extent that firms are searching for relatively pristine resources that they will both use and pollute, there is a natural equilibrium, where once a resource becomes sufficiently polluted, not only will the resource no longer attract new users, but existing users will, when their capital investments in plant and equipment have been sufficiently amortized, begin exiting from use. Users will move from locations with heavily developed, polluted resources to locations with relatively undeveloped, pristine resources. Importantly, if the net benefit from moving is sufficiently low—because, for example, it is costly for firms to move to less developed, cleaner locations—and firms remain in heavily polluted local environments, then they are better off when all firms in the industry spend to reduce their pollution than when none do. Moreover, given that other firms in the same industry are spending, a firm does not put itself at a competitive disadvantage when it also complies with regulations that require money to be spent on pollution reduction.

This analysis uncovers the economic logic behind two signal features of contemporary American federal environmental regulation. First, by imposing minimum regulatory requirements even on relatively pristine and undeveloped parts of the country, statutes such as the Clean Air Act,⁷⁷ through its Prevention of Significant Deterioration Program,⁷⁸ lessened the cost savings that firms would realize by moving from their old, heavily

⁷⁷ 42 U.S.C. §§ 7401–7671q (2000).

⁷⁸ *Id.* §§ 7470–7479.

developed rust belt locations to the south and southwest. On the margin, such laws encouraged firms to remain in older, more developed parts of the country. Firms that stayed had an interest, on this model, in cleaning up local environments. While it is true that for any given firm the optimal outcome was one in which it did not spend on pollution-reduction but every other firm in the locality did, no firm could credibly argue that it should be exempt from pollution-reduction requirements that applied equally to its competitors.⁷⁹ To solve this problem, federal environmental laws require that pollution reduction standards be uniform within a given industry category.⁸⁰

Thus for firms whose own profitability was affected by local ambient environmental quality, the federal environmental laws ameliorated a natural economic response to costly levels of ambient pollution—industrial flight—and created incentives so that collective regulation was actually in firms' self-interest. The laws operated differently on the incentives of firms that are completely indifferent to ambient environmental conditions. Empirically, such complete indifference must be extremely rare. Indeed, the only empirically significant example that I can imagine would be firms whose sole business is waste disposal. For such firms, there is no level of local ambient pollution that is too much. Such firms will not move to escape polluted environments. Neither will they perceive any benefit from local or national pollution reduction, however it might be accomplished. Such firms are precisely the kind that will so degrade ambient environments that they are unsuitable for any other use other than as a waste receptacle, a degree of degradation that is analogous to the complete collapse of a fishery or other renewable resource.

IV. THE RULE OF CAPTURE AND LAND USE

One might suppose that land use is the last place one would expect to find the rule of capture. After all, in market economies, the baseline ownership/management regime is not unregulated open access acquisition of flows by capture, but rather private ownership. A fee simple owner should, on the basic economic model, manage his or her land so as to maximize its discounted present value. Even if the value of a particular piece of land is changing over time (due to exogenous reasons, rather than the owner's land use decisions), a fee simple owner managing the land to maximize its present value will fully take account of such anticipated future changes.

This argument is too simplistic. The value of any particular piece of real property depends not only upon how it is used, but on how nearby

⁷⁹ Indeed, for an entirely domestic industry of identical firms, if all firms have the same compliance costs, then although there might be some impact on profitability and total employment in the industry, regulatory compliance should have no impact on relative employment across firms.

⁸⁰ For example, see the Federal Water Pollution Control Act, 33 U.S.C. §§ 1251–1387 (2000), and its effluent limitation guidelines, which are uniform, and in which industry categories are even geographic. 40 C.F.R. §§ 405.10–471.106 (2004). See also regulations governing Alaska's offshore seafood processing. 40 C.F.R. § 408.100 (2004).

properties are used, and on the location of the parcel in two-dimensional space. Empirical studies have consistently found that people are willing to pay more per square foot for newer houses located closer to open spaces (parks, wetlands, lakes), in areas of less dense development, and with better views.⁸¹ Conversely, traffic congestion and commercial and industrial land uses have significant negative effects on house prices and land development value.⁸² Moreover, the externalities from land use decisions are locally concentrated. One study found, for example, that proximity to the closest small forested area and a forest view had significant positive effects on housing prices, but that the total neighborhood forested area and distance to the closest large forested area did not significantly affect house prices.⁸³ Somewhat similarly, other work has found that land prices increase with the proportion of agricultural and forested lands within a tenth of a kilometer, but decrease as the proportion of such land within a kilometer increases.⁸⁴ This finding may be explained, I believe, by another finding—which is that scarcity matters, in that only when the total amount of open space in a locality is sufficiently small do increases in open space increase residential property values.⁸⁵ On the urban-rural (so-called exurban) fringe, surrounding development has a large negative effect on the development value of undeveloped land, with the presence of adjacent undeveloped land becoming increasingly valuable the farther one moves from the city center.⁸⁶ People, moreover, seem quite rational about the long term nature of land values, in that permanently preserved open space has been estimated to

⁸¹ See the results and survey of the literature in Jun Jie Wu, Richard M. Adams & Andrew J. Plantinga, *Amenities in an Urban Equilibrium Model: Residential Development in Portland, Oregon*, 80 LAND ECON. 19 (2004). For a discussion of some of the older empirical work, see Charles J. Fausold & Robert J. Lillieholm, *The Economic Value of Open Spaces*, 8 LAND LINES 1, 1–4 (1996) (discussing empirical studies of what they term the “enhancement value” of open space), available at <http://www.lincolninst.edu/publs/pub-detail.asp?id=506>.

⁸² See Wu et al., *supra* note 81, at 29 (discussing the negative effect of traffic congestion on housing and land values); Elena G. Irwin & Nancy E. Bockstael, *Land Use Externalities, Open Space Preservation, and Urban Sprawl*, 34 REGIONAL SCI. & URB. ECON. 705, 720 (2004) (noting that parcels with less commercial and industrial land relative to low-density residential land will develop at a higher rate).

⁸³ Liisa Tyrvaïnen & Antti Miettinen, *Property Prices and Urban Forest Amenities*, 39 J. ENVTL. ECON. & MGMT. 205, 216–218 (2000). Consistently, Richard Ready and Charles Abdalla find that both publicly and privately owned forests and pasture within 400 meters of a house have a large positive amenity value, but open space between 400 and 1600 meters from a house has a large impact on house value only if it is either publicly owned land, or privately owned land subject to a conservation easement. Richard C. Ready & Charles W. Abdalla, *The Amenity and Disamenity Impacts of Agriculture: Estimates from a Hedonic Pricing Model*, 87 AM. J. AGRIC. ECON. 314, 320–321 (2005).

⁸⁴ Jacqueline Geoghegan, Lisa A. Wainger & Nancy E. Bockstael, *Spatial Landscape Indices in a Hedonic Framework: An Ecological Economics Analysis Using GIS*, 23 ECOLOGICAL ECON. 251, 258–259 (1997).

⁸⁵ Paul C. Cheshire & Stephen C. Sheppard, *On the Price of Land and the Value of Amenities*, 62 ECONOMICA 247, 258 (1995). For a recent summary of this work, see Elena G. Irwin, *The Effects of Open Space on Residential Property Values*, 78 LAND ECON. 465, 466 (2002).

⁸⁶ Elena G. Irwin & Nancy E. Bockstael, *Interacting Agents, Spatial Externalities and the Evolution of Residential Land Use Patterns*, 2 J. ECON. GEOGRAPHY 31, 47 (2002).

have three times the effect on land prices as developable open space.⁸⁷ As summarized by economic geographer Elena Irwin, recent empirical work on open space preservation has shown that “[t]he benefits of preserving any particular piece of open space are a function of the number of residents within the neighboring area, their preferences, and the relative scarcity of open space in the region.”⁸⁸

A. Unregulated Development and Open Space Harvest: The Dynamics of Overdevelopment

This large volume of empirical literature shows that, even though land is privately owned, so that land development is not itself governed by an open-access dynamic, to develop land is to harvest open space (undeveloped land), and the quality and quantity of open space has a significant and sometimes large external effect on the development value of other nearby properties. Private landowners realize benefits and costs from the development decisions of their neighbors. In the aggregate, such decisions determine the value of a particular place or location. No individual landowner, however, has a property right in the value of neighborhood. Rather, this value is collectively held by whatever political jurisdiction it is that exercises control over local land development decisions.

Inasmuch as private land development is an attempt to capture the value of a particular place at a particular time, unregulated private land development is essentially the rule of capture as applied to neighborhood or community value. More formally, the per period market value of developing a particular property is a function not only of the specific characteristics of that piece of property and of general secular trends such as the population growth rate, but of the amount of undeveloped land in the nearby area. That is, the market value of developing a property with characteristics z at time t , $v(t)$, is given by a function such as $v(t) = g(t, z) + f(u_t)$, where u_t is the amount of nearby undeveloped land (open space) remaining at time t .⁸⁹ The literature on land development generally assumes that with a fixed amount

⁸⁷ Jacqueline Geohegan, *The Value of Open Spaces in Residential Land Use*, 19 LAND USE POL'Y 91, 96 (2002). Defining neighborhood effects by drawing a 400 meter radial buffer around residential property center points, Irwin's instrumental variables estimation confirms the finding (from ordinary least squares regression) that privately owned conserved open space and publicly owned (non-military) lands have a positive and significant impact on property value, while surrounding forest lands have a negative effect, with negative spillovers from surrounding commercial and industrial land use and higher density residential land use being significant and relatively large. Irwin, *supra* note 85, at 474.

⁸⁸ Irwin, *supra* note 85, at 479. For her exurban D.C. study area, which has relatively rapid population growth and open space loss due to land conversion, Irwin puts a lower bound estimate on the value of open space preservation of between \$1000 and \$3300 per acre per neighboring household. *Id.* at 469, 474-475.

⁸⁹ That is, if L is the amount of land in the area, and the amount developed in time period t is given by d_t , then we have that $u_t = L - \sum_{i=0}^t d_i$.

of undeveloped land available, rising population and income over time means that development value increases over time, that is, that $\partial g/\partial t > 0$.⁹⁰

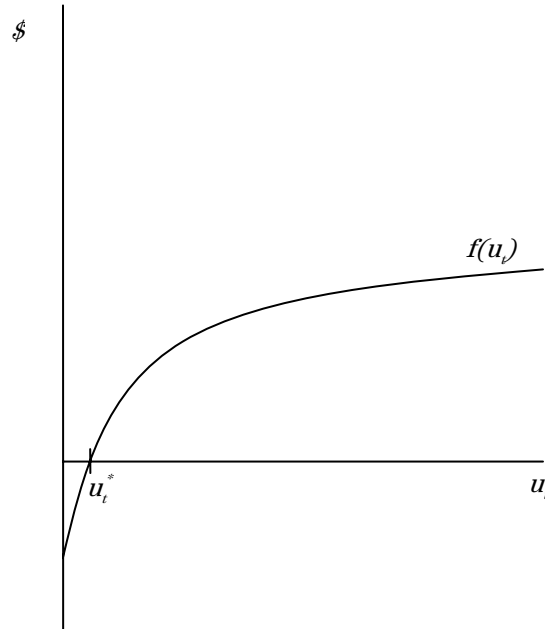


Figure 6
Development Value as a Function of Remaining Open Space

As for the impact of the amount of nearby remaining undeveloped land, the empirical literature briefly surveyed above suggests the following pattern, depicted graphically in Figure 6:

i) When there is a great deal of undeveloped land remaining, development generates positive externalities by making possible the provision of various local public goods, including the public good of simply having neighbors, so that down to some level u_t^* , $f(u_t) > 0$.

ii) Below u_t^* , development begins to generate negative externalities in the form of congestion and loss of amenities provided by local open space, so that $f(u_t) < 0$ for $u_t < u_t^*$.

The socially optimal time and intensity of development are those that maximize the present value of converting the land from open space to

⁹⁰ See Anderson & Hill, *supra* note 4, at 179–180 (relating this model to early U.S. homesteading); Lueck, *supra* note 1, at 396–398 (using this model to describe first possession rules' impact on rent dissipation). See also Dennis R. Capozza & Yuming Li, *Optimal Land Development Decisions*, 51 J. URB. ECON. 123, 126 (2002) (analyzing the optimal timing of private land development when developed value is growing geometrically but uncertainly); Irwin & Bockstael, *supra* note 86, at 39 (noting this expectation as it relates to residential land use pattern).

developed use, taking into account the impact of development of any particular parcel in raising or lowering the present and future value of development through the term $f(u_t)$. From a private developer's point of view, however, development timing and intensity is determined by comparing the value of (optimally intense) present development with the value of postponing development and receiving the per period rental value of the land in its undeveloped state.⁹¹ As the value of development rises with income and population, it will eventually exceed the undeveloped value by a sufficiently large amount to justify the private cost of development. This will be true even if the overall level of development is so high that the landowner's decision to develop generates a negative externality (that is, u_t is less than u_t^*). Crucially, while the stock of existing open space at time t obviously effects the private decision to develop—because it in part determines development value $v(t)$ —a small, competitive private developer will have no concern with the effect of her present decision to develop on future development values of other neighboring parcels. When the time path of open-space preservation takes the form depicted in Figure 6, there is first a positive externality from development when cumulative development is at a low level, and then a negative externality from development when cumulative development is at a high level. Hence at early stages in local development, private incentives to develop are generally too weak, so development proceeds too slowly, while at later stages, private incentives are too strong, so that development goes too far.

Due to this negative externality, once the private value of development exceeds the threshold level that triggers development, private incentives to develop will eventually exceed social development incentives, and the stock of undeveloped, open space lands left by perfect competition in land development will be too low from a social point of view. Just as fishermen overharvest under open access, so too is there overdevelopment under open access “taking” of the value inherent in existing local open space.

The overdevelopment incentive remains even if the development market is not perfectly competitive, so that developers take account of the impact of their present day development decision on the supply of local open space and, through this, on the future development decisions of other private landowners. Indeed, such interactive, strategic decision making is likely to exacerbate the gap between private and social incentives in open space harvest. At low levels of cumulative development, development confers a positive externality on remaining undeveloped lands, making them more valuable, and there is, therefore, an incentive for landowners to wait for others to develop first so as to free ride. This causes development to be delayed even longer than it would be under perfect competition, where there is no such strategic gaming.

At higher levels of cumulative development, where additional development generates a negative externality, strategic developers have the opposite incentive, to race to develop before their competitors do, so as to

⁹¹ For formal presentations of this choice calculus, see Capozza & Li, *supra* note 90, at 126; Irwin & Bockstael, *supra* note 86, at 37.

take advantage of the price premium generated by the remaining stock of undeveloped land. Indeed, given a time period in which development would be privately optimal even without considering the effect of cumulative development on development values (that is, development would be privately optimal, assuming away the externality from open-space loss), the dominant strategy for developers will be to develop, since because development generates a negative external effect, they are better off developing sooner rather than later regardless of whether other landowners develop. That is, development of other parcels can only increase the cost from waiting to develop by lowering value, and so if development would be privately optimal even considering such costs imposed by others, then it must be privately optimal when those costs are considered. By this same argument, the prospect that development value will be lower in the future because of the development and loss of existing open space may actually move forward the optimal date of private development.⁹² Anticipating development by others, developers rush to develop, generating negative externalities that make all developers worse off.⁹³

B. Why Overdevelopment Does Not Mean the “Extinction” of Open Space: the Self-Correcting Properties of Land Market Equilibria

Just as the externality in an open access fishery does not mean that open access harvest will necessarily lead to the extinction of the fish stock, so too the open space externality that besets land development does not imply that decentralized, competitive development markets will eliminate all open space in a locality. If the development externality function $f(u_i)$ takes the form depicted by Figure 6, then the externality will eventually be large enough so that the value of development is less than its opportunity cost (the cost of development plus the lost rents from keeping the property in agricultural use). Just as increasing effort devoted to a fishery eventually decreases the stock, decreasing productivity and eventually profitability, leading to exit from the industry, so too will the various external costs of development eventually mean lower local amenities, lower property values, and less effort devoted to development.

⁹² I ignore competitive effects that arise because by developing first a developer may face less competition and have temporary market power, and these tend to further encourage early development. For a consideration of how such competitive effects may interact with the length of the building delay to generate development cascades—simultaneous development—during periods of depressed demand, see Steven R. Grenadier, *The Strategic Exercise of Options: Development Cascades and Overbuilding in Real Estate Markets*, 51 J. FIN. 1653 (1996).

⁹³ It is true that if potential buyers were fully aware of all present day development decisions on their effect on the future value of their homes, then they would discount the present price by an amount equal to the decline caused by present day loss of open space. While it seems plausible that developers might be aware of present day development incentives, it seems a stretch to assume that buyers are so familiar with the structure of the development game, and actual decisions of developers, that they take account of the future cost of the loss of open space caused by present day development. More importantly, even with hyper-sophisticated buyers, given a positive interest rate, a developer is better off obtaining the discounted price paid by such buyers today rather than refraining from development and getting the same price later.

This model predicts precisely what one observes in the current debate over open space preservation. People who are concerned with the loss of open space are not, it seems, so concerned that there will be no open space left; instead they are concerned that market development incentives are generating a highly fragmented pattern of development that is irrational in that it generates an unnecessary negative externality. "Fragmentation" means the tendency for market incentives to lead to low density, diffuse residential development—often called "sprawl"—as opposed to clustered, town-like development.⁹⁴ Sprawl opponents argue that clustered development leaves larger blocks of open space, and that such larger blocks are socially desirable because they cut down on congestion and other negative externalities that accompany fragmented development, while providing higher levels of local public goods such as runoff control, and plant and animal habitat.

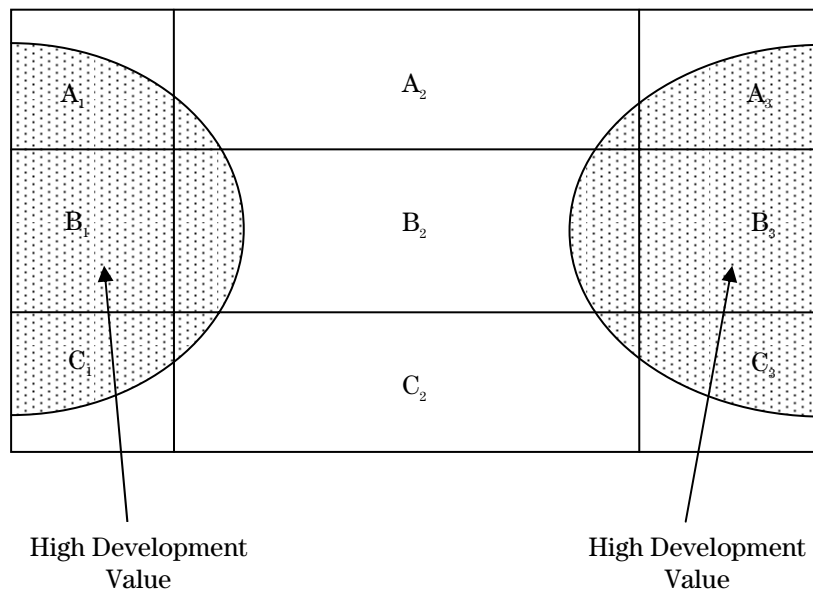


Figure 7
Impact of Open Space Preservation on Development

Such a complaint is predicted by my analysis, which says that precisely because open space is a valuable but highly localized amenity, developers will try to capitalize on that value. However, in the process they will generate both a fragmented overall pattern, and losses for other landowners. Figure 7 depicts this spatial outcome. In that figure, there are two protected open space areas, B₁ and B₃. To capture open space value, landowners develop the shaded strip of land closest to these protected areas. This pattern of development generates negative externalities for landowners

⁹⁴ For a general discussion of fragmentation and some maps depicting fragmented development in central Maryland, see Irwin and Bockstael, *supra* note 86 at, 34–36.

whose lands lie outside the developed area in that the development has generated increased congestion, while depriving other landowners of direct access to the open space. The pattern in Figure 7 is obviously more fragmented than a number of alternatives, such as concentrating higher density development in block B2. Of course, such concentrated development clearly involves a loss to owners of the lands adjacent to the protected open space areas. For such mandatory clustering to be socially beneficial, the collective local benefits from keeping more total undeveloped land must more than offset the loss to landowners who are not allowed to capitalize on open space values.

C. The Regulatory Paradox Redux

As the previous example perhaps indicates, given the complex temporal and spatial dynamics of land development, regulating land development to preserve undeveloped land is a very complex and difficult task. Regulations designed to preserve open space will shift not only development patterns but also land and house prices. If anticipated, such regulations may actually worsen the very race to develop that they are designed to control. Just as with pollution, as the value of open space increases, the less of it remains. Thus the value of open space may not be realized until it has already been lost. Yet by the very same token, a completely undeveloped locality cannot know precisely what level and pattern of open space preservation will maximize long term locational values.

More precisely, as with the regulation of natural resource harvest and pollution, a very basic problem with land development regulation is that while the social goal is to regulate so as to create private incentives to choose the optimal development path over time, regulations are likely, at best, to aim for static efficiency. To see this, consider the following example, which captures in numerical form many of the same points displayed by the earlier graphical analysis. Suppose that we have reached a time period such that, abstracting from the open-space externality, each parcel is worth 100 if developed and 70 if kept undeveloped, say in agricultural use. Suppose further, however, that as captured by Figure 6, we are in a region where development generates a negative externality because of the loss of community open space, and that this negative externality increases, with an increased overall level of development. Further, suppose that the marginal negative externality from one additional parcel of development, shared equally among the four parcels, is 10, then 16, 32 and finally 60, as we go from the first to the last parcel being developed.

Without regulation, each landowner's optimal strategy is to develop immediately. This follows directly from the fact that even if all other landowners are developing, so that the negative externality is maximized, it is still best to develop (if all four develop, the total per parcel externality is 29.5, and so net development value still exceeds undeveloped, agricultural value). From the point of maximizing the net societal benefit from development, however, there should only be two parcels developed, as development beyond two parcels generates external harm—either 32 or 60—

that exceeds the net gain of 30 on each parcel. Hence from the point of view of the basic economic criterion of maximizing total net benefits, uncontrolled development leads to too much development.

Now consider a development ban that is ex post efficient in that it will be imposed, if and only if, a proposed development is inefficient, in the sense that its social costs exceed its social benefits. As clarified by the present numerical example, while it sounds good, such a ban will actually never be imposed. As just shown, the unique (Nash) equilibrium⁹⁵ in the development game is for all four landowners to develop immediately. Moreover, simultaneous development by all four is efficient, at least in the sense that its benefits exceed its costs. Therefore, simultaneous development is allowed under the rule that imposes a ban only on inefficient development.

The problem is that like the other ex post efficient policies considered for resource harvest and pollution, this hypothetical development ban is based upon the static efficiency of actual observed choices, in this case land development, rather than dynamic efficiency—efficiency relative to other feasible intertemporal development paths. In order to get the socially best development path—which is immediate development of two parcels, and a ban on any further development—a choice must be made as to which two parcels can be developed. In the aggregate, such a development limitation generates a net gain of 32, which is far better than the aggregate net of only 2 that results under the ineffective, static efficiency-based ban. However, unless large transfer payments are made to the two developers who are forbidden from developing, the development limitation will make those two developers worse off than under unregulated private development. Hence even though it leads to a far superior result from a social point of view, the dynamically efficient policy—the two parcel development limitation—will face political opposition, whereas the static efficiency-based development ban will be unopposed because it is ineffective.

In practice, such development bans are likely to have even worse incentive effects by actually encouraging early development. Land use regulations that are an ex post reaction to disappearing open space, such as zoning limitations and development moratoria, amount to a first come–last regulated system. They reward early developers by offering them less regulation, thereby penalizing those who wait to develop. If, as argued earlier, there are positive externalities from development at early stages of development, then the first come–last regulated system may actually make sense as intended to offset the incentive for developers to wait too long, in an attempt to free ride off the early developers. At such early stages of development, however, the regulatory system is likely one of relatively uncontrolled development. Rather, as a matter of stylized historical fact, it seems clear that first come–last regulated systems arise only after people become concerned about overdevelopment. At such a stage in the

⁹⁵ A Nash equilibrium is a set of strategies having the property that each player's (in our instance, landowner's) strategy maximizes her payoff, given the strategies pursued by the other players. For this definition and further explication of the Nash Equilibrium concept, see, e.g., DAVID M. KREPS, *GAME THEORY AND ECONOMIC MODELLING* 28–36 (1990).

development process, development likely does generate negative externalities, so the last thing one would want is a regulatory system that offers additional incentives to develop before the development door closes. Yet this is precisely what first come–last regulated systems do.

There are, of course, alternatives to first come–last regulated open space preservation systems. Over the past decade in the United States, a very popular alternative has been for states and localities to buy and preserve open space. Of the 454 open space initiatives placed on state and local ballots between 1998 and 2000, voters approved eighty-four percent, authorizing the expenditure of 17.1 billion dollars on open space acquisition.⁹⁶ Yet the impact of such public open space acquisition programs on the actual amount of open space in an area is ambiguous. The reason is that open space preservation has strong indirect effects that actually stimulate development. One of these effects is to stimulate demand for parcels located near open space. If this is so, then as the authors of one recent study state, open space preservation in the sprawling rural-urban fringe could actually attract new residents to such areas, with the end result that “preservation programs that enhance the value of rural amenities *could* act as a magnet for future growth in areas where preservation occurs.”⁹⁷ Similarly, open space preservation changes the spatial distribution of various local environmental amenities and therefore affects private land development decisions.⁹⁸ When a small area of open space is acquired, the development value of nearby properties increases, thus increasing the rate of development.⁹⁹ Thus, unless large amounts of contiguous open space are acquired (as in the urban growth ring or growth boundary strategies now pursued by some municipalities), increasing the amount of publicly owned and preserved land can actually decrease the total amount of open space in a metropolitan area.¹⁰⁰ When open space values spill over across local metropolitan areas, matters get even more complex, as open space preservation in one municipality may confer such large benefits on an adjacent municipality that the latter acquires less open space than if preservation had not been pursued next door.¹⁰¹

V. CONCLUSION: THE NOT SO PUZZLING PERSISTENCE OF THE RULE OF CAPTURE

I hope to have persuaded the reader that an admittedly stylized, mathematical model that has become the standard tool for analyzing the dynamics of natural resource harvest under open access and other

⁹⁶ Wu et al., *supra* note 81, at 19.

⁹⁷ Brian Roe, Elena G. Irwin & Hazel A. Morrow-Jones, *The Effects of Farmland, Farmland Preservation, and Other Neighborhood Amenities on Housing Values and Residential Growth*, 80 LAND ECON. 55, 56 (2004).

⁹⁸ Wu et al., *supra* note 81, at 20.

⁹⁹ Irwin & Bockstael, *supra* note 82, at 720–722.

¹⁰⁰ This is an important result of the general equilibrium analysis presented by Randall P. Walsh, *Endogenous Open Space Amenities in a Locational Equilibrium*, <http://www.colorado.edu/Economics/CEA/WPs-04/wp04-03/wp04-03.pdf>. (last visited, Nov. 9, 2005).

¹⁰¹ Elizabeth Marshall, *Open-Space Amenities, Interacting Agents, and Equilibrium Landscape Structure*, 80 LAND ECON. 272 (2004).

management regimes also generates substantial insight into the dynamics of pollution and land development problems. The consensus view is that while the open access, rule of capture management regime may have been socially desirable when there was very little pressure on natural resources,¹⁰² its time has long since passed, as it has led to overharvest, overpollution, and overdevelopment that threatens the world with the irreversible loss of natural resources. On this view, what we need now is a regulatory system that both caps overall use levels and allocates uses to particular areas and to particular users in the form of tradable use rights.

The analysis presented here cautions against too much optimism regarding such a regulatory solution. On my view, many problems that are conventionally attributed to open access are, in fact, due to government policies that have systematically subsidized overuse and market entry far beyond levels that would have occurred under a pure open access system. The rule of capture persisted in part, I believe, because of its own self-limiting dynamics. Even if democratic, political processes have no such self-limiting economic dynamic. It remains to be seen whether governments that have systematically intervened to weaken the inherent self-limiting properties of open access resource use will succeed in coming up with better regulatory alternatives.

¹⁰² See Carol Rose, *The Comedy of the Commons: Custom, Commerce, and Inherently Public Property*, 53 U. CHI. L. REV. 711, 717 (1986) (discussing the “plenteous goods” idea, in which goods are so plentiful that a resource management system seems unnecessary); Harold Demsetz, *Toward a Theory of Property Rights*, 57 AMER. ECON. REV. 347 (1967) (discussing an economic theory of property rights). What “little pressure” seems to mean, more precisely, is conditions under which rents are not fully dissipated—there is not entry until average product equals average cost—because there are entry restrictions of some sort, or because there are many resources relative to the number of potential users. As Lueck states, when there are few users, “open access may persist optimally because few people are exploiting the resource or because marginal use costs are high” Lueck, *supra* note 1, at 405.