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Trade, Tragedy, and the Commons

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We develop a theory of resource management where the degree to which countries escape the tragedy of the commons, and hence the de facto property rights regime, is endogenously determined. Three forces determine success or failure in resource management: the regulator's enforcement power, the extent of harvesting capacity, and the ability of the resource to generate competitive returns without being extinguished. The model can explain heterogeneity across countries and resources in the effectiveness of resource management, and it predicts that changes in prices, population, and technology can cause transitions to better or worse management regimes. (*JEL* P14, Q21, Q22, Q23, Q32)

Many of the world's major renewable resource stocks are in a state of decline. This is true for capture fisheries, for forests in developing countries, and for many measures of the biosphere's health. Other renewable resources, including many species of wildlife, marine mammals, and Coral reefs, are also under threat. While poverty and government corruption are surely responsible for some of this record, particular emphasis is often placed on the potentially damaging role played by international trade. This emphasis is not surprising given that natural resource products are a key export for much of the developing world and property rights over renewable resources are both difficult to define and poorly enforced.

But property rights are not an immutable country characteristic such as weather, mineral deposits, or topography; they are instead market institutions developed to facilitate transactions and protect scarce resources. Consequently, changes in prices, technology, and other effects of market integration may alter the de facto property rights regime and lead to impacts quite different from those predicted by existing analyses. The purpose of this paper is to examine renewable resource use within a framework where the enforcement of property rights, and hence the efficacy of resource management, is endogenously determined.

We develop a theory where an existing government regulates the use of a renewable resource by a set of agents who have a right to harvest. The resource could be a fishery, forest stock, aquifer, etc., and we assume it is local and therefore contained within one country. The government sets rules limiting harvests but agents may cheat on these allocations and risk punishment. Property rights are endogenous in this framework because the government must account for agents' incentive to cheat. As a result, the effective protection for the resource—or what we refer to as the de facto property rights regime—may be far from perfect, even though property rights would be perfectly enforced if there was no monitoring problem.

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Using this theory, we divide resource-rich economies into three groups according to their ability to enforce property rights as world prices vary. We refer to these groups as Hardin, Ostrom, and Clark economies. The groups are defined by simple and intuitive restrictions on basic parameters (resource growth rates, mortality rates, time preference rates, and technologies), and we aggregate these parameters into three intuitive measures that jointly determine success in regulation. These measures reflect a country's enforcement power, its overcapacity, and its incentive to extinguish the resource.

Hardin economies are countries with large numbers of agents who have access to the resource, short life spans, resources with a low intrinsic growth rate, and governments with a limited ability to punish recalcitrant agents.[1] Together, these features imply that Hardin economies have limited enforcement power relative to their overcapacity. As a result, they always exhibit de facto open access (in steady state) and no rents are earned on the resource. Ostrom economies have sufficient enforcement power to generate some rents, but not enough to achieve the first best.[2] At low prices they exhibit open access, but at high prices a degree of protection is afforded the resource, and it generates rents. Clark economies can obtain the first best at relatively high resource prices, but at low resource prices, even a Clark economy exhibits open access or limited management.[3]

Our model is highly stylized and fits no resource industry exactly; nevertheless we think it can shed light on several policy questions. To make this case, we provide three applications. First, we examine the effects of trade liberalization in resource-exporting countries. While trade liberalization leads to resource depletion and real income losses in Hardin economies, the trade-induced increase in relative resource prices can lead to a transition to more effective management in Ostrom or Clark economies. We give examples from fisheries and wildlife management consistent with both scenarios.

Next, we examine the role of new technologies in creating the need for regulation. We argue that technological progress played a key role in the introduction of modern fisheries regulation, and give examples of heterogeneity across fisheries in the effectiveness of management, as predicted by our theory. This application demonstrates our theory's ability to examine forces other than prices that create regulatory change.

Finally, we examine one aspect of the debate over deforestation. We show how population growth has two potentially offsetting impacts on forestry regulation: the direct effect of increased population pressure makes regulation more difficult, but the indirect effect of induced price increases can improve regulation. We link this result to recent empirical work on forests in developing countries. While these applications are not a substitute for careful empirical work; they do demonstrate the broad relevance of our theory. And by linking our predictions to three simple country characteristics—enforcement power, overcapacity, and the incentive to extinguish—we hope to provide a springboard for future empirical research in this area.

To generate these results we combine a standard renewable resource model with a simple model of moral hazard. The model has three key features. First, it is dynamic because this is where the key externality in renewable resource industries arises. If property rights are not

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[1] Garrett Hardin was not the first to identify the problem of open access, nor did he analyze it completely in Hardin (1968). This was done by H. Scott Gordon (1954). Hardin did, however, popularize the term "tragedy of the commons" and his work brought national attention to resource issues.

[2] Since Elinor Ostrom has made important contributions to our understanding of when local governance of common property resources will succeed or fail, it seems natural to refer to this class of economies as Ostrom economies. See especially Ostrom (1990).

[3] We name this class of economies after the mathematician Colin W. Clark whose book *Mathematical Bioeconomics* has played a major role in the teaching and study of resource economics. See Clark (1990). See Anthony Scott (1955) for the first recognition of the resource problem as a capital theoretic one.

defined or enforced, then an agent who refrains from harvesting today may not be the one to benefit from the investment tomorrow. Throughout, we focus on the link between country characteristics and management regimes in steady state, leaving a discussion of the transition between regimes to future work.

Second, we assume there is a group of agents who have the right to harvest the resource, but if their harvesting is not regulated, rents will be dissipated and the resource stock depleted. The government manages the resource by limiting harvesting, but cheating may occur. Since the incentives of agents do not lead to efficient outcomes, monitoring is required and we have a problem of moral hazard. For tractability, we adopt assumptions leaving both the government and agents risk neutral, and assume limited liability to bound punishments.

Finally, we adopt the relatively simple resource model taken from James A. Brander and Taylor (1997). There are two sectors, resource harvesting and manufacturing, and for the most part we treat our economy as small on world markets. A general equilibrium framework is necessary for a change in world prices or technologies to affect relative rewards across sectors and influence the incentive of agents to comply with regulations.

Previous theoretical work on this issue has provided results that are conditioned on the property rights regime. If property rights are fully assigned and perfectly enforced, then the usual gains from trade results apply. On the other hand, if property rights are completely absent, then trade liberalization can be devastating.[4] Similarly, technological progress can only raise consumption possibilities with perfect property rights, but can easily lower them otherwise. There is, however, considerable evidence showing that the enforcement of property rights varies across communities, over time, and by resource type. This is a central theme in the book-length treatments of Ostrom (1990) and Jean-Marie Baland and Jean-Philippe Platteau (1996). Most of their evidence comes from case studies on the management of fisheries, aquifers, forests, and common grazing land. Formal empirical evidence on the malleability of property rights is contained in Timothy Besley (1995).

This evidence casts doubt on the conclusions of analyses where the strength of property rights is fixed. Some authors have moved away from the assumption of a given property rights regime to consider the implications of endogenous regulation in a renewable resource context. A series of papers, following Harold Demsetz (1967), argue that property rights will emerge when the benefits exceed the costs. There are many papers on enclosure, some of which discuss incentive schemes to limit overgrazing (see Nancy McCarthy, Elisabeth Sadoulet, and Alain de Janvry 2001; Michael Margolis and Jason F. Shogren 2002; and the important early work of Martin L. Weitzman 1974). There are papers examining entry deterrence in natural resource settings (see Charles F. Mason and Stephen Polasky 1994, for one example), and there are papers examining poaching (see, for example, Louis Hotte, Long, and Huilan Tian 2000). While this literature contains many interesting results, it does not link a country's success or failure to key country characteristics; nor does it provide a method for separating the price effects of market integration from other important impacts such as technology transfer, changes in population size, or improvements in monitoring.

The rest of the paper is organized as follows. In Section I, we set out the model. In Section II we define our categories of countries and link management regimes to world prices. In Section III we present our applications, and in Section IV discuss how our results would change if governments

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[4] For a review of the early literature, see Murray C. Kemp and Ngo Van Long (1984); a contemporary review is Erwin Bulte and Edward Barbier (2005). For theory see the early work of Partha Dasgupta (1982), Graciela Chichilnisky (1994) and Brander and Taylor (1997); Ramon Lopez (1997, 1998) provides empirical evidence linking weak property regimes to real income losses.

invest in monitoring or use a different fine structure. Section V concludes. An appendix contains all proofs.

I. The Model

We consider a resource-rich small open economy populated by a continuum of agents with mass N. Following Olivier J. Blanchard (1985) we assume agents face a constant instantaneous probability of death given by θ. Every instant in time has new births equal to aggregate deaths, θN, leaving the steady-state population N fixed. The economy has a renewable resource held in common by all agents. Agents are endowed with one unit of labor per unit time. Labor may be allocated to harvesting from the renewable resource or production of manufactures.

The government manages the resource by choosing harvest restrictions to maximize a utilitarian objective function defined over the welfare of both current and future generations. The government's actions are however constrained by the incentive of agents to cheat.

A. *Agents*

Agents consume two goods: H, the harvest from the renewable resource; and M, a manufacturing good. Tastes are homothetic; hence indirect utility can be written as a function of real income. Agents are risk neutral and we index generations of agents by their vintage or birth year v. Denote by $U(R(v,t))$ the instantaneous utility flow from consumption when an agent of vintage v at time t has real income of $R(v,t)$. Then the expected present discounted value of lifetime utility for a representative member of vintage v becomes

$$W(v) = \int_{v}^{\infty} U(R(v,t))\, e^{-(\delta+\theta)(t-v)}\, dt, \tag{1}$$

where δ is the pure rate of time preference. In writing (1) we exploit the fact that when the instantaneous probability of death is θ per unit time, an agent's time of death is distributed exponentially with an expected lifetime of $1/\theta$.

Agents must decide how to allocate their time between the manufacturing and resource sectors, taking into account the returns from each activity, and the benefits and costs of complying with government regulations. This decision will depend on technology, endowments, and the monitoring technology, which we now specify.

B. *Technologies and Endowments*

Denote the resource stock level by S. The growth function for the renewable resource is assumed to be logistic and given by

$$G(S) = rS(1 - S/K), \tag{2}$$

where r is the intrinsic rate of resource growth, K is the carrying capacity of the resource stock, and $G(S)$ denotes natural growth.

Harvesting from the resource depends on labor input and the prevailing stock. Adopting the Milner B. Schaefer (1957) model for harvesting, we have

$$H = \alpha L_h S, \tag{3}$$

where α is a productivity parameter, and L_h denotes the labor allocated to harvesting. The manufacturing technology has constant returns to scale and uses only labor; hence by choice of units, we have

$$M = L_m. \tag{4}$$

Finally, full employment requires

$$N = L_m + L_h. \tag{5}$$

C. *The Resource Manager's Problem*

The resource management problem is made difficult by the prospect of cheating and the necessity of weighing utility gains accruing to different generations. We adopt the utilitarian objective function developed by Guillermo A. Calvo and Maurice Obstfeld (1988) that aggregates across the utility of different generations and leads to time-consistent optimal plans. We assume the government has the same pure rate of time preference as agents. In this situation, the Calvo and Obstfeld objective function yields social welfare as

$$SW = N \int_0^{\infty} U(R(t))e^{-\delta t}\,dt. \tag{6}$$

Equation (6) has three important properties. First, social welfare is independent of the individual specific risk of death, θ. This occurs because agents discount by the probability of death—they are mortal—but the government does not because society is infinitely lived. Second, utility flows are discounted by the common (to both agents and the government) pure rate of time preference.[5] Third, social welfare is just N times the utility of a hypothetical infinitely lived representative agent with real income path $R(t)$. These features simplify the planning problem tremendously despite the generational structure, and allow us to consider the very useful simplifying case where the government's discount rate, δ, approaches zero but agents remain impatient (i.e., $\delta + \theta > 0$).

The government devises a set of rules to maximize overall welfare subject to agents' incentive to overharvest. Each agent is allocated a fixed amount of time to exploit the commons. Agents who cheat on this allocation are detected at the rate ρdt. An agent who follows the rules or is not caught cheating can keep all of the harvest produced. An agent caught cheating is subject to a fine of F. Many different instruments are used to manage resource industries: individual transferable quotas, bag limits, quotas, limits on capacity or inputs, and technology standards. While these instruments vary in their ability to make cheating more costly, the key regulatory problem is that agents' actions are not perfectly observable. We model resource policy as a restriction on effort, but the same fundamental problem arises regardless of the choice of policy instrument.[6]

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[5] See the appendix in our discussion paper, Copeland and Taylor (2004), for a derivation of the objective function. Very little hinges on the assumption that agents and the planner share time preference rates. If we give the government a higher rate of time preference, then harvesting is more aggressive and it is easier to support the first best.

[6] Restrictions on inputs can be undone by agents if they can substitute toward unregulated inputs (a bigger boat, a better gun, or a more powerful chain saw); restrictions on output can be undone by quota busting and high grading; and buybacks that lower capacity can be undone by applying better technology and more inputs. In short, whenever rents are available economic actors will prove to be ingenious in their attempts to capture them. This is why monitoring is

D. *The Incentive Constraint*

To render the agents' decision problem interesting, we make two assumptions. First, we assume the resource is capable of generating rents so agents will want to capture them. Denote the relative price of the harvest by p, and the wage available in manufacturing by w; then, using (3), rents earned with one unit of labor are simply

$$\pi^C = p\alpha S - w \quad \textit{with} \quad \pi^C > 0 \quad \textit{for some } S \leq K. \tag{7}$$

Second, we assume there is overcapacity in the resource sector. Setting natural growth in (2) equal to the harvest in (3), we find there is a simple negative relationship between the resource stock and the labor allocated to harvesting in steady state:

$$S = K[1 - \alpha L_h / r]. \tag{8}$$

Therefore, the consistent application of labor in harvesting equal to r/α leads to extinction. The total labor force available for harvesting is N and hence a natural definition for an economy's capacity to harvest would be $\Omega \equiv N/(r/\alpha)$. $\Omega \in [0, \infty]$ and is free of units. When $\Omega \geq 1$, the allocation of all the economy's labor to the resource sector leads to extinction: in this case, there is overcapacity and some form of regulation is necessary to generate rents. When $\Omega < 1$, there are situations where regulation is unnecessary. An examination of the $\Omega < 1$ case shows it is broadly similar to the overcapacity case, although it leads to a few surprises (as discussed in Section IVB).

With these two assumptions in hand, all agents would like to work full time in the resource sector when the stock is sufficiently large, but full-time employment by all is not sustainable. Denote the amount of labor time an agent is authorized to harvest by $l \leq 1$; then an agent who complies with the rules earns $ph = p\alpha lS$ in the resource sector and $(1 - l)w$ in the manufacturing sector. An agent who cheats spends their one unit of time harvesting and earns $ph^C = p\alpha S$.

The decision to cheat rests on a comparison of the expected present discounted value of the nominal income stream earned by each activity. Let $V^C(t)$ represent the expected present discounted value of the income stream for an agent who is currently working in the resource sector and cheating. Let $V^{NC}(t)$ represent the income stream to an agent who is in the resource sector but not cheating. Let $V^R(t)$ be the maximum over these two options at t. An agent who works only in the manufacturing sector has a discounted income stream given by $V^M(t)$.

Consider the returns to cheating over some small time interval dt. The agent earns the cheating level of harvest, $ph^C dt$, but bears the risk he may be caught and fined. If the agent is caught cheating (which occurs at rate ρdt), he pays a fine of $F(t + dt)$. With probability $1 - \rho dt$, the agent is not caught and pays no fine. Future returns are discounted, and the agent dies over the interval with probability θdt. These assumptions imply that the expected present value return to cheating, $V^C(t)$, can be written as

$$V^C(t) = ph^C dt + [1 - \delta dt][1 - \theta dt][\rho dt[V^R(t + dt) - F(t + dt)] + [1 - \rho dt]\, V^R(t + dt)]. \tag{9}$$

An agent who does not cheat obtains the value of the not-cheat option given by

$$V^{NC}(t) = [ph + (1 - l)w]dt + [1 - \delta dt][1 - \theta dt][V^R(t + dt)]. \tag{10}$$

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the key resource management problem: instrument choice can at best make monitoring easier. On this point in general, and problems with individual transferable quotas (ITQs) in particular, see Parzival Copes (1986).

At every point in time agents choose the maximum over these options, $V^R(t) = \max[V^{NC}(t), V^C(t)]$, and hence will not cheat if (10) is greater than (9). Expanding (9) and (10), letting dt go to zero, and simplifying shows an agent will not cheat when expected costs exceed benefits:

$$\rho F \geq [\pi^C - \pi], \tag{11}$$

where the rents to cheating are π^C, and the rents to behaving are $\pi = ph - lw$.

Several observations follow. First, not surprisingly, cheating is deterred when expected costs exceed benefits: the left-hand side of (11) is the expected cost of cheating while the right-hand side is the benefit. Second, given agents are risk neutral, only the product ρF matters and not its individual components. This simplifies our analysis and allows us to focus on how changes in the size of the fine F affect compliance, leaving a discussion of how the manager may want to vary ρ until Section V. Finally, although the manager would like to impose an extremely large fine, limited liability is often invoked to bound penalties in similar situations. Here we assume the maximum penalty available to the resource manager is to terminate the agent's right of access to the resource. This is equivalent to imposing a limited liability constraint that the agent can be no worse off than being employed permanently in manufacturing.[7] Unless the manager could, in addition, confiscate an agent's entire future income stream from working in the outside goods sector (a possibility we consider later), the maximum punishment available is the seizure of a cheating agent's only asset—the right to harvest.[8] In this case, we can write the fine as $F = [V^R(t) - V^M(t)]$, or in terms of primitives:

$$F = [\pi + \dot{V}^R]/[\delta + \theta]. \tag{12}$$

This fine is both simple and powerful. It is powerful because as rents in the resource sector rise, the deterrent value of losing access rises; it is simple because the fine adjusts automatically to changes in prices, technologies, etc. These two properties ensure that the punishment for cheating reflects the severity of the crime. Our mechanism to generate compliance should also be familiar, as it is similar to that at work in efficiency wage models (Carl Shapiro and Joseph E. Stiglitz 1984). Agents with access to the resource stock can earn rents, provided they follow the rules and do not overharvest. They will be deterred from cheating if the rents are sufficiently high—and hence access to the resource stock is analogous to having a good job that they don't want to lose.

It proves useful in what follows to collect parameters and define a government's enforcement power as $\Phi \equiv [\rho + \delta + \theta]/[\delta + \theta]$. $\Phi \in [1, \infty]$, which is free of units. By construction, enforcement power ranges from one (no power at all) to positive infinity (maximum power). It is increasing in the probability of being caught and punished, ρ, but falls if agents have shorter expected life times, $1/\theta$, or higher pure rates of time preference, δ. A government's enforcement power reflects not only its ability to catch and punish cheaters, but also how agents view the prospect of future punishments.

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[7] There are two natural candidates for a limited liability constraint in our context. The first is that an agent who is caught and fined cannot be worse off than in manufacturing, i.e., $V^R - F \geq V^M$. He can lose at most all his assets when fined. The second possibility is that the agent could, in addition to losing his assets, have some or all future returns from manufacturing confiscated, i.e., $V^R - F \geq 0$. We impose the first constraint here, and consider a more general version of the second in Section V. See Robert D. Innes (1990) for the introduction of limited liability in a moral hazard context.

[8] That is, we can think of the agents as being born with the right to a harvesting license, but this license is terminated if harvesting rules are violated. As Ostrom (1990) and Baland and Platteau (1996, ch. 12) note, fines or punishments typically escalate, with ostracism (or exclusion from the resource) being a final recourse. It is easy to incorporate smaller punishments into our model, but these will not be optimal.

Substituting (12) into (11), and evaluating in steady state, we find an agent will not cheat when $\pi \geq \pi^C/\Phi$.[9] The manager must ensure rents per agent obtained by behaving, π, exceed a fraction of the potential rents earned by cheating with this fraction determined by enforcement power. To go further, note $\pi = l\pi^C$, let $L = Nl$, and rewrite the incentive constraint as $L\pi^C \geq N\pi^C/\Phi$. This constraint can be met in one of two ways. First, if resource rents are positive at the current stock, then $\pi^C > 0$, and we can cancel it from both sides, obtaining

$$L/N \geq 1/\Phi. \tag{13}$$

When rents are positive, the incentive constraint can be met only if the fraction of time each agent is allowed to harvest, L/N, exceeds a threshold determined by enforcement power. By rearranging, we find the aggregate amount of time agents must be allowed to harvest, and denote it by L^T. We denote the implied steady-state stock S^T. Using (8) and (13), we find:

$$L^T = N/\Phi, \quad S^T = K\left(1 - \frac{\alpha L^T}{r}\right). \tag{14}$$

It is possible, however, that $L = L^T$ is inconsistent with positive rents, i.e., $p\alpha S^T - w < 0$. In this case, the incentive constraint is satisfied only when there are zero rents in the resource sector. To find this second solution, set $\pi^C = 0$ and use (8) to solve for the level of labor effort driving rents to zero. Since this is the level of labor that would be employed under open access conditions, we denote it L^O, and its associated steady- state stock, S^O:

$$L^O = (r/\alpha)[1 - w/p\alpha K], \quad S^O = K\left(1 - \frac{\alpha L^O}{r}\right). \tag{15}$$

For future purposes, we note that the labor employed under open access is rising in the resource price. A higher resource price creates incipient rents that must be eliminated by greater effort, which drives the resource stock lower. As the resource price approaches infinity, the labor employed under open access approaches r/α and the stock approaches zero.

Putting the two solutions together, we conclude that when (14) is consistent with positive resource rents, the manager must allow agents to spend at minimum the fraction of time that satisfies (13) with equality. But when this amount of time, added up over all agents, would eliminate all rents, the best the manger can do is throw up his hands and allow agents to harvest all they want. We refer to this situation as de facto open access. Property rights over the resource are present; it is only the severity of the monitoring problem that leads to an outcome indistinguishable from a situation where there are no property rights at all.[10] This discussion implies the incentive constraint is met, in steady state, when

$$L \geq \min[L^O, L^T]. \tag{16}$$

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[9] Outside of steady state, the constraint becomes $\pi + \dot{V}^R \geq [\pi^C + \dot{V}^R]/\Phi$.

[10] This is an important distinction. Overcoming de facto open access requires solving the monitoring problem; correcting a situation of true open access requires both creating property rights and solving the monitoring problem. Demsetz (1967) and much of the resulting law and economics literature are primarily concerned with this latter case, as is the literature that views property rights as the outcome of cooperation in dynamic games. For a recent contribution in this area, see Nori Tarui (2007). It is unclear, however, whether the rent dissipation we observe around the world arises from monitoring problems or a true lack of property rights. We suspect much of it arises from monitoring problems.

E. *The Steady-State Economy*

The resource manager maximizes (6) by choosing a time allocation $l(t)$ that each agent can spend harvesting, subject to technologies given in (3) and (4), full employment in (5), biological growth in (2), and the incentive constraint (16). There are three possible solutions.

The first occurs when the incentive constraint does not bind at the first-best level of labor. To characterize this solution, we ignore (16) and solve a standard optimal control problem using L_h as the control. Denote the solution to the unconstrained first best by L^* and the resulting steady-state stock by S^*.

A second possibility arises when L^* violates (16) because it is too low. In this situation agents who cheat obtain a great windfall since the additional time they gain in harvesting $(1 - l)$ is relatively large and the productivity of their efforts is also great because S^* is relatively high. To offset these incentives, the government raises the allowed time in harvesting. This reduces the time left over for any individual agent to cheat, and lowers the productivity of cheaters by driving down the resource stock. Eventually, the allowed harvest time is high enough to remove the incentive to cheat, and (16) holds with equality. If L^T is the minimum in (16), then this constrained optimum will have positive resource rents. Since the steady-state harvest must equal natural growth, this constrained optimum is given by L^T and S^T.

Alternatively, it is possible the government has no ability whatsoever to limit resource harvesting. This occurs when the government has to raise harvesting to such an extent that rents are dissipated before L^T is reached. In this case, L^O is the minimum in (16) and de facto open access results. The steady-state solutions are given by L^O and S^O. It is relatively easy to show these are the only possible steady states, and that, for any parameter values, only one of these three solutions can obtain. Therefore, we have:

PROPOSITION 1: *The steady state is unique. It exhibits either de facto open access, limited harvesting restrictions, or an outcome equivalent to that of the unconstrained first best.*

PROOF:
See Appendix.

Proposition 1 sets out the possibilities, but it does not link these possibilities to country characteristics, world prices, or a country's trade regime. To understand the challenge that managers face in setting limits on harvesting while trying to achieve the first best, we will need to examine the first-best solution more closely.

Routine calculations show that the unconstrained first-best allocation, L^*, and its associated stock, S^*, satisfy[11]

$$\delta\pi^C = G'(S^*)\pi^C - G(S^*)\hat{c}^h, \qquad S^* = K\left(1 - \frac{\alpha L^*}{r}\right), \tag{17}$$

where $\hat{c}^h < 0$ is the percentage change in unit harvesting costs, $w/\alpha S$, created by a marginal increase in the stock. The intuition for the condition is well known. Leaving a marginal unit of the stock in situ is an investment of foregone rents, π^C, and this investment must earn δ. To earn δ, the stock is adjusted so that the marginal unit left in situ raises steady-state harvests by $G'(S^*)$

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[11] See the proof to Proposition 1 in the Appendix for a derivation.

with value π^C while reducing harvesting costs by the increment $\hat{c}^h$ applied to all units harvested in steady-state $G(S^*)$.

Straightforward differentiation of (17) shows optimal harvesting effort rises and the optimal resource stock falls as the price of the resource good rises. The intuition is simply that as the resource price rises, the opportunity cost of leaving rents in situ rises relative to the cost reduction a greater stock provides. This result is important because it means that meeting the incentive constraint will be easier with higher resource prices. While this is true, the extent to which the manager responds to prices depends importantly on what we will call the *incentive to extinguish* a resource, Γ, with $\Gamma \equiv (\delta + r)/r$. $\Gamma \in [1, \infty]$, is free of units, and will vary across resources and countries. The incentive to extinguish plays an important role in our analysis because it determines the maximum harvesting effort expended in the first best. At very high prices, only the foregone rent component of the return in (17) matters and the first best simplifies to $\delta = G'(S^*)$ with $L^* = (r + \delta)/2\alpha$.[12] To put this level of effort in perspective, divide by r/α (the labor force that produces extinction) to find $L^*/(r/\alpha) = (r + \delta)/2r = \Gamma/2$. Therefore, when the maximal instantaneous return on the resource, r, exceeds the time preference rate, δ, then $\Gamma < 2$ and adjusting the resource stock to earn a competitive return is possible (even at very high prices) without extinguishing the resource. We refer to the $\Gamma < 2$ case as a low incentive to extinguish the resource. Conversely, the incentive to extinguish is high when $\Gamma > 2$. Therefore, while higher prices lead to greater harvesting, the aggressiveness of this harvesting depends critically on the incentive to extinguish.

II. Country Characteristics and the Management Regime

Our goal is to provide a simple and intuitive set of conditions linking country characteristics to the likelihood of success or failure in resource management. We find three key forces determine the success or failure of resource management: the enforcement power of the government, the extent of overcapacity in the resource sector, and the incentive to extinguish the resource.

The basic intuition is simple. Enforcement power determines the extent to which harvesting effort can be reduced to protect the resource. If enforcement power is sufficiently weak relative to overcapacity, then a regulator will never be able to improve on open access. This is a Hardin economy. If enforcement power is sufficiently strong, then harvesting effort can be restricted enough to generate some resource rents. Whether or not the first best can be obtained depends on whether enforcement power is strong enough to reduce harvesting below the level that is needed to implement the first best; and the first-best harvesting effort depends on the regulator's incentive to extinguish the resource. A high discount rate, for example, gives the regulator a strong incentive to run down the resource stock; and this makes the first best easier to implement because less enforcement power is needed. Transitions from open access to rent-generating outcomes can occur via changes in technology or monitoring ability (these affect capacity and enforcement power) or via price changes. Higher prices increase market pressure on the resource, but also increase the penalty for cheating; and if the penalty for cheating is the loss of harvesting license, these two effects offset each other. Hence price increases do not affect enforcement power. However, price increases also increase the first-best level of harvesting effort, and this makes the regulator's job easier, because a smaller share of capacity needs to be excluded from harvesting at higher prices.

First, consider economies where enforcement power is small relative to overcapacity, and where open access always occurs, no matter how high prices are. To characterize such economies, recall

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[12] Substitute for the percentage cost reduction to find the first best is $\delta\pi^C = G'(S^*)\pi^C + G(S^*)/S^*$. Divide both sides by π^C, assume S^* is bounded above zero, and take the limit as p goes to infinity.

that when the incentive constraint binds, de facto open access results whenever $L^T \geq L^O(p)$ or equivalently when $\Omega/\Phi \geq [1 - w/p\alpha K]$. This inequality is harder to satisfy as p rises; however, if $\Omega/\Phi \geq 1$, then it will be satisfied for any level of p. Hence, de facto open access always results when capacity, Ω, is greater than enforcement power, Φ. In these economies we have a classic "Tragedy of the Commons" and it seems natural to define them as *Hardin economies*.

PROPOSITION 2: *Hardin economies will always exhibit de facto open access in steady state. For any finite relative price* p *of the harvest good, we have* $L = L^O(p)$ *and no rents are earned in the resource sector.*

PROOF:

See Appendix.

The intuition is straightforward. We have assumed there is excess capacity in the resource sector: $\Omega > 1$. By definition, if all of the economy's capacity were applied to resource harvesting, then the resource would be driven to extinction. Enforcement power determines that portion of this capacity a government can credibly deter from harvesting. It is *as if* the manager's enforcement power shrinks excess capacity by $1/\Phi$, to Ω/Φ. But if this reduced capacity is still greater than that needed to drive the resource to extinction, then $\Omega/\Phi > 1$. In this case, the capacity the manager *cannot* deter from harvesting is still large enough to dissipate any rents the resource may provide, and we obtain a Hardin economy.

Proposition 2 tells us there exists a set of countries that may never solve their open access problems, regardless of how valuable the resource good may be. Countries are more likely to fall into this category if their resources are slow to replenish (low r), if agents are impatient (high $\delta + \theta$), if cheating is hard to detect (low ρ), if harvesting technology is more productive (high α), and if a large number of agents have access to the resource (high N).

While open access is a necessary outcome in a Hardin economy, other countries will be able to sustain a rent-generating management regime at some prices. These countries may have greater enforcement power because their legal system or monitoring capabilities are better, or they may have been able to lower harvesting capacity through other means. Our second result is that even when countries have relatively strong enforcement power or only limited capacity, so in principle they could sustain rents ($\Omega/\Phi < 1$), they will still exhibit open access as an equilibrium outcome when the resource price is very low. In fact, at low resource prices, open access is the equilibrium outcome in *all* countries.

PROPOSITION 3: *Whenever (7) holds and there is overcapacity in the resource sector, all economies will exhibit open access and zero rents at low resource prices.*

PROOF:

See Appendix.

This is a somewhat surprising result, but the logic is straightforward. Enforcement power can lower the portion of capacity the manager must allow to harvest, but it cannot drive it to zero. When the price of the resource is very low, resource rents are positive only when the resource stock is very high—perhaps very close to its carrying capacity (recall 7). To maintain such a large stock, agents must spend very little time harvesting, and herein lies the rub: this small amount of effort will be less than what the manager can credibly bar from harvesting. Therefore, for low enough resource prices, all rents will be dissipated and an open access equilibrium results.

Proposition 3 is important because it tells us that all economies will look like Hardin economies if they face low resource prices, even though some of them may be able to sustain rents at higher prices. In a world with purely exogenous property rights, we could be assured that a country exhibiting open access at some prices exhibits them at all prices; in a world with endogenous property rights, this is a dangerous supposition.

To see why rents can be sustained at higher prices, consider increasing p from the level where it led to open access. Since $L^O(p)$ rises with p, and we are not in a Hardin economy, at some higher $p \equiv p^+$, the labor employed under open access will equal the threshold level needed to deter cheating and we will have $L^T = L^O(p^+)$. At this point regulation becomes effective. At a price slightly higher than p^+, more labor will want to move into the resource sector to capture the incipient rents it creates (recall $L^O(p)$ is rising in p). But additional harvesting can now be deterred by the manager who asks for slightly less effort in return for a share of the now positive rents. Agents weigh their options, and the possibility of earning positive rents now deters cheating and the manager limits aggregate effort to L^T.

As prices rise further, there are two possibilities—either the manager will always hold effort at L^T, or the incentive constraint may eventually no longer bind and the manager can allow greater effort than L^T. Which outcome occurs depends on how the manager responds to price increases. We refer to economies where the incentive constraints always binds, but where some rents are possible, as *Ostrom economies.* These are economies that are not Hardin economies, but where $L^T > L^*$ for all p. Equivalently, Ostrom economies are defined by the following restriction on enforcement, capacity, and the incentive to extinguish:

$$1 > \Omega/\Phi > \frac{\Gamma}{2}. \tag{18}$$

The first inequality rules out Hardin economies; the second says the first best will always call for less effort than the capacity the manager must allow to harvest given its enforcement power. Recall that at very high prices the first-best labor allocation (measured relative to extinction labor) equals $\Gamma/2$. Therefore, when the incentive to extinguish is low *relative* to the capacity the manager cannot deter from harvesting, the first best will never be achieved. Recalling Proposition 2 it should be clear that Ostrom economies exhibit de facto open access in steady state when $p \le p^+$ (where p^+ depends on country characteristics); but for $p > p^+$, harvesting restrictions are successfully implemented and the resource generates rents. It is straightforward to show the transition price, p^+, is higher in economies with higher populations (N), lower life expectancy ($1/\theta$), better harvesting technologies (α), and higher rates of time preference (δ); it is lower in economies with a faster growing resource (high r), a larger resource base (K), or a greater probability of detecting cheating (ρ).

We refer to our last set of countries as *Clark economies.* These are economies that are not Hardin and for which the incentive constraint does not bind when prices are sufficiently high. They satisfy

$$1 > \Omega/\Phi \textit{ and } \frac{\Gamma}{2} > \Omega/\Phi.$$

The first inequality rules out Hardin economies; the second says the first best will eventually call for more effort than what the manager cannot deter from harvesting. In Clark economies, there exist two critical prices, p^+ and p^{++}, such that for low prices ($p \le p^+$), there is de facto open access; with somewhat higher prices ($p^{++} > p > p^+$), harvesting restrictions are successful and rents are positive, but the incentive constraint binds; and for very high prices $(p > p^{++})$, the first best is supported.

Clark economies are those where (all else equal) there is strong enforcement power, not much overcapacity, and a strong incentive to extinguish. In terms of primitives, resource growth affects both our measures of capacity and the incentive to extinguish. A higher rate of resource growth raises the instantaneous rate of return earned on any stock, and this makes the planner less aggressive in lowering the stock to generate a competitive return, but a higher resource growth rate also reduces our measure of capacity since it means the resource sector can absorb more effort without driving the resource to zero. Simple algebra shows a higher resource growth rate always works toward successful regulation; hence slow growing marginal resources are the most difficult to manage successfully. A similar issue arises with the rate of time preference. A higher rate of time preference lowers enforcement power, but raises the aggressiveness of the planner by raising the incentive to extinguish. One result is clear. If we start from either an Ostrom or Clark economy and raise time preference sufficiently, we must obtain a Hardin economy.

We now combine our results to prove:

PROPOSITION 4: *Assume a group of Hardin, Ostrom, and Clark economies exist, and let them share the same minimum price* $p^{min} = w/\alpha K$ *at which rents in the resource sector are zero. Then there exists a* $p^{low} > p^{min}$ *such that for any* $p < p^{low}$*, all countries exhibit de facto open access. There also exists a finite* $p^{high} > p^{low}$ *such that for* $p > p^{high}$*, there is heterogeneity in the world's resource management with some countries at open access, others with limited management, and some with perfect property rights protection and full rent maximization.*

PROOF:

See Appendix.

Proposition 4 forces us to ask what part of the observed variation in property rights protection worldwide is consistent with governments doing the best they can under difficult situations. Success should vary across countries that differ in their enforcement power, whether this variation comes about from differences in life expectancy, in time preference, or in political economy factors that determine their ability to capture and punish cheaters. Other differences would arise when population size, technologies, or resource growth rates leave some countries with more or less overcapacity in their resource sectors. And, finally, countries could differ in the extent to which their resources have a low or high incentive to extinguish. Variation in management success may also show up across resources within a given country, since monitoring ability, resource growth rates, and harvesting technology are all likely to be resource specific.

III. Applications

Property rights issues are at the center of debates over protecting biodiversity, limiting deforestation, and improving the sustainability of fisheries. Much of the theoretical work examining these issues takes the strength of regulatory regimes as fixed or exogenous. While this may be a reasonable assumption in the short run, in the long run we expect adjustment in the protection given resources if world markets value them more highly, if population increases, or if technology changes. Once we accept that the success of resource management should vary with resource- and country-specific circumstances, it becomes much easier to understand episodes where property rights improved or worsened as the result of shocks, such as new technologies, or why some countries succeeded with the imposition of entirely new management regimes while others failed.

The purpose of this section is to demonstrate that while our model is highly stylized, it has broad significance and provides several insights relevant to policy debates in different renewable resource industries. These applications are not a substitute for empirical work; and we make no claim that our model explains all aspects of the issues discussed below. Rather, they serve to illustrate that the model can serve as a useful guide for future empirical analysis of a variety of questions related to resource management.

A. *Trade Liberalization*

Much of the concern over the effects of globalization on the environment stems from the weak protection afforded resources in many developing countries. Brander and Taylor (1997) and Chichilnisky (1994) have shown that a country exporting an open access renewable resource will experience increased resource depletion and may experience a real income decline as trade is liberalized. This is because a trade-induced increase in the resource price attracts entry into the resource sector and exacerbates the open access externality.

Once we allow for endogenous responses of the management regime, we obtain a richer set of predictions. A straightforward application of the results of the previous section implies that trade liberalization can, in some cases, lead to the emergence of an effective management regime. This is because a trade-induced increase in the resource price in an exporting industry makes it easier for Ostrom and Clark economies to satisfy the incentive constraint and enforce harvest restrictions. Consequently, in some cases where the Brander-Taylor model predicts a fall in steady-state real income as a result of trade, our model predicts an increase in real income. Our model also predicts heterogeneity across resource-exporting countries in the impact of trade liberalization. Hardin economies will always experience resource depletion and a steady-state real income reduction.

To avoid taxonomy (and to facilitate comparison with Brander and Taylor 1997), we assume the planner's discount rate approaches zero, and for simplicity, we assume the barriers are trade frictions that drive a wedge between domestic and foreign goods prices. Let $\gamma \leq 1$ be the fraction of a good that arrives at its destination; then, if the world price is p, and home exports H, a domestic agent must ship $1/\gamma$ units to the foreign market to receive a price p. Equilibrium requires the domestic price p^d satisfy $p^d = \gamma p < p$. We associate a trade liberalization with a fall in these trade frictions (an increase in γ), and this will lead to an increase in the domestic price of H. It is now easy to prove:

PROPOSITION 5: *Suppose the planner's discount rate approaches zero and the country exports the resource good. Then a marginal fall in trade frictions will*

(*i*) *Reduce steady-state real income in a Hardin economy.*

(*ii*) *Increase steady-state real income for a Clark or Ostrom economy, if* $\gamma p \geq p^{+}$.

(*iii*) *Decrease steady-state real income for a Clark or Ostrom economy if* $\gamma p < p^{+}$; *but there exists a* $\underline{p}$ *such that if* $p > \underline{p}$, *then an elimination of trade frictions leads to the emergence of a management regime and increases in steady-state real income.*

(*iv*) *For a Clark economy, if* $\gamma p < p^{+}$, *and* $p \geq p^{++}$, *then the elimination of trade frictions results in a transition from de facto open access to fully efficient management. Steady-state real income rises.*

PROOF: See Appendix.

Part (i) of the proposition shows Hardin economies will exhibit open access both before and after the liberalization, and as a result real income falls with the trade liberalization. These changes in steady-state real income carry with them welfare significance for future generations who are born sufficiently far in the future. In this case, a trade liberalization fails to improve management and fails to provide any rents.

Part (ii) demonstrates that for economies with at least some form of management—i.e., Ostrom or Clark economies with domestic prices above a certain threshold—trade liberalization and higher resource prices can only raise real income. In this case, a country with some demonstrated success in resource management will have its success reinforced by access to world markets with higher prices.

Parts (iii) and (iv) give conditions under which trade-induced transitions in the management regime can occur. In both of these cases, Ostrom and Clark economies exhibit no control over harvesting prior to liberalization, and on those grounds appear to be very poor candidates for trade liberalization. Nevertheless, in both these cases a discrete change in barriers leads to improved management and increases in real income. In the case of a Clark economy, the transition can be dramatic, with a country moving from de facto open access to fully efficient management. These results suggest that for some economies, there need not be any demonstrated success in resource management prior to liberalization.

Without careful empirical work, it is difficult to come up with definitive evidence that trade has help induced transitions in management in some cases and failed to do so in others. However, there are some suggestive examples. Demsetz (1967), in his classic study of endogenous property rights, argues that the introduction of the export market for fur led to the emergence of property rights for hunting grounds in early Quebec. This is a case where potential enforcement power was relatively high (because beaver are nonmigratory and access to hunting grounds could be monitored) and the incentive to extinguish the resource was relatively low (the intrinsic growth rate of the beaver population is relatively high). For a more recent example, the geoduck fishery in British Columbia began in the 1970s, primarily in response to export demand from Asia. It was initially open access, but made a successful transition to a well-managed fishery with individual harvest quotas (Laura Jones and Miriam Bixby 2003). Although geoducks mature relatively slowly (suggesting a relatively high incentive to extinguish), enforcement power is quite high (reflecting both good institutions and a highly developed monitoring technology). In contrast, M. Scott Taylor (2007) presents evidence that the near extinction of the buffalo in the US plains was exacerbated by the development of an export market for buffalo hide. This is a case with significant overcapacity (many potential harvesters with a very efficient harvesting technology), and little ability to enforce regulations over an incredibly large area (the Great Plains). The transition of the Soviet system to a market economy provides another example—Markus Vetemaa, Redik Eschbaum, and Toomas Saat (2006) document how the opening of the Estonian coastal fishery to exporting in the 1990s contributed to the rapid depletion of fish stocks, an outcome that seems to be attributable primarily to weak enforcement power and significant overcapacity.

B. *Fisheries*

Up to this point, we have emphasized the role of relative price changes in inducing a transition in the effectiveness of management. Transitions can also occur in response to other types of shocks, and the most important of these is technological change. In this section, we focus on fisheries. Our model predicts that improvements in harvesting technology will lead to the introduction of restrictions on fish harvesting, that management will be more successful for some fisheries than for others, and that eventually even neutral technological progress (in both harvesting and monitoring) can destroy management regimes.

Technical change and its induced increase in effective harvesting capacity has been a key factor threatening the viability of fish stocks. Daniel Pauly et al. (2002) note that many of the fisheries that were sustainable in the past survived only because fish were out of the range of traditional fishers.[13] As technological change put increased pressure on fish stocks, the need for effective management increased. Rögnvaldur Hannesson (2004) argues that improvements in harvesting technology and the ensuing pressure on fish stocks were major factors contributing to the emergence of modern rights-based fisheries management.[14]

To see how technical change can induce a transition to active management, consider a fishery where harvesting capacity is low, and hence managers have no need to introduce quotas. That is, suppose initially that our measure of capacity $\Omega = N\alpha_0/r < 1$ because the initial level of the harvesting technology parameter α_0 is low. This means that there is not enough harvesting capacity to fully extinguish the stock, and Hardin economies do not exist. The manager's problem now has an additional constraint: $L_h \leq N$. Employment in harvesting cannot exceed the total amount of labor available. This constraint was not made explicit previously because it can never bind when $\Omega > 1$.

Let L^* denote the first-best allocation of labor to the fishery when we ignore this additional constraint. There are two possibilities: either $L_h \leq N$ binds or it doesn't. We start with the case where it binds; that is where $L^* > N$. This will always hold when capacity is sufficiently small. If $L^* > N$, then there is no need for the manager to restrict harvesting. The first best outcome is to simply let everybody fish as much as desired.

Now suppose there is a large improvement in harvesting technology so that $\Omega > 1$, with the new level of the harvesting technology, $\alpha_1 > \alpha_0$. There is now overcapacity in an unregulated fishery, and so the analysis of Section II applies. The manager will need to impose restrictions on harvesting to protect the stock and generate rents. If multiple fisheries experience the technological improvement, we would expect to see heterogeneity across fisheries in the effectiveness of management: those fisheries where there is strong enforcement power or a fast growing resource will achieve the first best, while others with binding incentive constraints will have to tolerate some rent dissipation.

In our model, the manager's restriction on harvesting effort is equivalent to an individual harvest quota, which is a policy that has been adopted in a number of fisheries since the mid 1980s, most notably in New Zealand and Iceland. In reality the types of instruments used to regulate fisheries have varied widely—including restrictions on mesh size of nets, length of season, number of boats, restrictions on effort, harvest quotas, and many others. It is beyond the scope of our paper to try to explain instrument choice;[15] the main point is that no instrument

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[13] There are numerous examples of how technological progress has increased pressure on fisheries—Michael Heazle and John G. Butcher (2007), for example, note that in 1960, fewer than 1,500 (1 percent) of the fishing boats in Indonesia had any kind of motor, while by 2002 there were over 5,000 fishing vessels of "industrial scale." Fish-finding technology, on-board freezers, and electronic communication equipment are just a few of the other innovations that have increased pressure on fish stocks.

[14] Another key factor necessary for effective management of many fisheries was the Law of the Sea Convention that led to the establishment of the 200-mile offshore exclusive economic zone. This ensured that fisheries within such zones were under the jurisdiction of a single country. Our model does not seek to explain the evolution of international law. Rather, we focus on fisheries that are under the jurisdiction of a single country (or local government), and we ask which of these fisheries will be well managed, which will not, and what factors can trigger a change in the effectiveness of the management regime.

[15] Hannesson (2004) notes that the instruments used in fishery regulation have often undergone a progression—initially season closures or age/size restrictions might be used, followed by overall caps on the total allowable catch, entry restrictions. and, in some cases, individual quotas. Gary D. Libecap (2007) argues that heterogeneity among fishers, uncertainty about who will gain and lose from regulation, and political economy considerations can explain the

alone solves the manager's problem—each requires monitoring and enforcement, and hence an incentive constraint limits the ability of some managers to obtain the first best.[16] Although individual harvest quotas have a number of advantages over alternative instruments, monitoring is required to ensure that quotas are complied with, and highgrading (discarding lower value fish) may be exacerbated under a quota system (Copes 1986; Trevor A. Branch, Kim Rutherford, and Ray Hilborn 2006).

Much heterogeneity in management success exists across fisheries. Some countries, such as New Zealand, have been quite successful in implementing individual transferable quota systems that both protect fish stocks and generate rents. Others have been much less successful. Elena Anferova, Vetemaa, and Hannesson (2005) describe a three-year experiment using auction quotas as a regulatory tool in the Russian Far East between 2001 and 2003. They cite evidence of a significant increase in illegal fishing during this period and argue that a major reason for this failure was a weak enforcement and monitoring system; in our model, this would correspond to a low Φ. Similarly, Maria Hauck and Marcel Kroese (2006) find that significant compliance problems have contributed to stock declines in South Africa. Consistent with the predictions of our model, there is also heterogeneity of success within countries. A comparison of the abalone and geoduck fisheries off the west coast of Canada is instructive. Both fisheries were under pressure in the late 1970s from high demand from export markets and technological improvement in harvesting, and this pressure led to attempts to introduced effective management regimes. Individual quota systems were introduced to manage both fisheries; they were successful in the case of geoduck but not for abalone. Evidence indicates that difficulties of monitoring led to significant levels of illegal fishing in the abalone fishery (Jones 2003). Monitoring was difficult because of relatively easy access to abalone in relatively shallow waters in remote areas—in our model, this would correspond to low enforcement power. The fishery collapsed and was closed in 1990. On the other hand, the individual quota system for geoduck has been highly successful. Access to geoducks is more difficult than for abalone. Abalone on the Canadian west coast tend to be found from the low tide line out to a depth of 30 to 40 feet, whereas geoducks are found in intertidal waters up to a depth of 300 feet. The geoduck fishery is also more capital intensive than the abalone fishery, requiring high pressure water hoses and divers supplied with air hoses from the surface. Together these physical differences across the fisheries suggest enforcement power is greater in the geoduck fishery, and Ben Muse (1998) reports that monitoring activity (much of it industry financed) in this fishery has indeed been highly effective.

Although improvements in harvesting technology are a major catalyst for the development of fisheries management systems, continuous technological improvement undermines the manager's ability to manage the fishery by increasing overcapacity. All else equal, continuous increases in harvesting technology (a fall in α) would turn all economies into Hardin economies. However, technical progress can also lead to improvements in monitoring technology. In the long run, the viability of an effective management regime requires that technical progress in monitoring keep pace with, or possibly exceed, that in harvesting.[17]

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choice and timing of the use of regulatory instruments. Our model abstracts from this by assuming identical fishers, and focuses on the monitoring problem. Even with no political economy problems, monitoring problems will imply that some fisheries will be managed well, while other will be managed poorly, if at all.

[16] The importance of monitoring in fisheries has been explicitly considered in the literature on enforcement of fisheries regulations. Jon G. Sutinen and Peder Anderson (1985) provide an early contribution, Linda Nøstbakken (forthcoming) provides a review, and Aaron Hatcher and Daniel Gordon (2005) provide empirical evidence.

[17] In our working paper, Copeland and Taylor (2004), we consider the effect of neutral technical progress in both harvesting and monitoring and show that in some cases, all economies become Hardin economies. This is because there is a fixed factor in the model—nature's ability to regenerate.

C. *Forests*

There is still considerable debate over the causes of deforestation worldwide, despite almost three decades of intensive study. While popular accounts often link international trade to deforestation, academic work has focused its attention on property rights issues and the related effects of population growth on land conversion and fuel wood collection. Many empirical studies find evidence of a direct and positive relationship between population size and deforestation, which may arise because of incomplete property rights.[18] However, in a recent and influential empirical paper, Andrew D. Foster and Mark R. Rosenzweig (2003) argue that population and income growth may have played an important role in the recovery of Indian communal forests over the 1971–1999 period. In their analysis, population and income growth raise the relative price of forest products—such as fuel wood—which raises the return to this activity. They suggest that the large increase in demand for forest products over the 1971–1999 period was in part responsible for the implementation of a new management program in India which allows local villagers to share in the proceeds of timber sales from communal forests (the Joint Forest Management Program). Importantly, the authors speculate that "without the shift in demand for forest products, effective policy reforms expanding forests may not have been feasible." These comments echo our earlier results: a higher price for resource products may be a necessary precondition for a successful policy reform, and distributing these rents to agents plays a key role in determining the success of resource management.

In this section we illustrate how our theoretical framework may be useful in interpreting the conflicting evidence on population growth and deforestation, and perhaps provide some guidance to future empirical work. In our small open economy framework, the relationship between the size of the population and measures of the resource's health such as rents or stock size is decidedly negative. This is true because a greater population raises capacity, and this always works against effective management. In a Hardin economy, population growth can only drive the stock lower and may eliminate it entirely; in an Ostrom economy, population growth will at first dissipate rents, then lead to open access and eventually result in a Hardin economy. In a Clark economy a similar result holds.

While these small open economy results accord reasonably well with the empirical literature finding a negative link between population and forests, they are harder to reconcile with the recent work of Foster and Rosenzweig (2003). By closing our model to allow for endogenous prices changes, we find population growth has two effects on resource management in a closed economy. Population growth raises the domestic relative price of resource products and this works in favor of successful regulation, but it also raises capacity, and this works against it. Only the impact of greater capacity is present in our small open economy, but in a closed economy, prices will adjust and this beneficial impact can outweigh the capacity-raising effect under some circumstances, which we now specify.

To simplify, assume constant elasticity preferences over the two consumption goods, and consider a marginal increase in population size starting from an existing open access steady state in an Ostrom economy.[19] Since we limit ourselves to marginal changes in population, we start this economy in an open access steady state at the transition price p^+. These simplifications allow us to make the basic point very simply. Then we can prove:

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[18] For example, Robert T. Deacon (1994) finds a strong positive correlation between population growth (five years earlier) and deforestation today in a panel of 112 countries. See, also, the other Henning Bohn and Robert T. Deacon (2000) paper. For a partial review of the literature and some new results, see Edward B. Barbier (2005, ch. 5).

[19] The Clark case is similar.

PROPOSITION 6: *Starting from an open access steady state with zero rents at* p^+, *a marginal increase in the population, N, will lead to a new steady state with higher prices, positive rents, partially effective controls on harvesting, and higher incomes, if the demand for the resource good is inelastic.*

Population growth raises the relative price of the resource product, making regulation successful despite the increase in population size. It does so only when demand for the resource product is inelastic. This is not surprising: we require a strong price response to population growth to offset its negative effects in raising capacity. When a strong price response is not forthcoming—as in our small open economy case—open access remains. Foster and Rosenzweig argue that the strength of the price response is, in fact, key to their results, and provides estimates implying a price elasticity of demand for firewood below one. Moreover, in addition to their detailed empirical work on India, Foster and Rosenzweig also provide more broad-based evidence from a panel of over 50 developing countries finding that growth lowers deforestation in relatively closed economies, but raises it in open economies. This is very close to what Proposition 6 and our previous results imply.

IV. Extensions

We have adopted a relatively simple model to explore the interaction of world prices, technologies and resource management. In this section we discuss two of our assumptions and argue that our basic results are not sensitive to reasonable departures from them.

A. *Monitoring*

Assume that, instead of an exogenous probability of being caught, this probability can be raised by government action. Suppose the government can hire monitors at the current manufacturing wage. Let the probability of being caught over the interval dt be related to labor allocated to enforcement over this interval, $L_e dt$, by $\rho dt = \rho_0 L_e dt$, where ρ_0 is a positive constant reflecting the productivity of monitoring. By construction, the instantaneous probability of being caught is linear in L_e, but monitoring is never perfect. It is straightforward, then, to write the total flow cost of achieving a rate ρ of catching cheaters as $C(\rho) = w\rho/\rho_0$, which is linear in ρ. As a consequence, enforcement power is now endogenous and should be written to reflect this as $\Phi(\rho)$.

Given space limitations, we focus on steady states and assume δ is close to zero. The government's problem is to maximize steady-state surplus less monitoring costs. We solve this in two stages. Let $\pi(\rho)$ denote maximized rents for given ρ. This is in fact the problem considered in earlier sections.[20] We now write it to emphasize the role of ρ:

$$\pi(\rho) = \max_{L_h} \{pH(L_h) - L_h : L_h \geq \min(L^O, L^T)\}.$$

The optimal choice of ρ is given by: $\rho^* = \arg\max \{\pi(\rho) - C(\rho)\}$. This problem has several important properties which follow from our previous results. The first is simply that heterogeneity of outcomes still occurs. For example, $\rho^* = 0$, and open access is a possible outcome for some

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[20] Set the discount rate equal to zero in (17) and rewrite the first-order condition as $d/dS[p - w/\alpha S]G(S)$. Formally, when the discount rate approaches zero, the first best approaches the solution of maximizing steady-state rents (see Clark 1990 for further details). To reformulate this condition in terms of labor, substitute for the steady-state stock with $S = K[1 - \alpha L_h/r]$.

countries. To see why, recall that Proposition 2 tells us that when enforcement power is less than overcapacity ($\Phi(\rho) < \Omega$), rents must be zero. Since enforcement power is a continuous function of ρ, and there is overcapacity in the resource sector ($\Omega > 1$), there exists a $\underline{\rho} > 0$ such that for $\rho < \underline{\rho}$ we have $\pi(\rho) = 0$. Over this range of ρ, a marginal investment in monitoring provides no return, $\pi'(\rho) = 0$, but the marginal cost of monitoring is strictly positive. Therefore, when there is overcapacity in the resource sector, the return to the first few investments in monitoring is zero while their cost is positive. Zero monitoring and open access can be optimal.

This outcome is more likely if the monitoring technology is inefficient or the extent of overcapacity large. In situations with better monitoring technologies or less overcapacity, it will pay to invest in monitoring. The optimal solution will be interior and the manager will successfully restrict harvesting. We again find that differences in country characteristics (such as the resource growth rate, population, and technology) matter since they shift the profit function. Consequently, our earlier result that there is heterogeneity across countries in the effectiveness of their management regime applies here; and the same factors that increased the likelihood of successful management also apply. Our earlier result that trade can induce transitions in the management regime continues to hold. Increases in the resource price shift the profit function upward, which increases the likelihood of effective management.

Endogenous monitoring does introduce some changes. Strictly speaking, all countries are now Ostrom economies. This is because, as the resource price p goes to infinity, the profit function shifts up arbitrarily high, which means that all countries can make a management transition if resource prices are sufficiently high. Moreover, the first best is never attained, so Clark economies are not possible in this framework.[21] The reason is simply that increases in monitoring have a vanishingly small marginal benefit as the economy gets close to the first best. In contrast, the marginal cost of monitoring remains finite. However, if we consider a bounded set of resource prices (which is reasonable if resources have either domestic or foreign substitutes), then we once again obtain Hardin economies: within the relevant range of prices, some countries will always be in open access. And countries with resources that are easy to manage will be arbitrarily close to the first best.

B. *Fines*

We have assumed the fine agents receive when caught cheating can leave them no worse off than they would be if they were employed permanently in manufacturing. A more draconian fine could, in addition, confiscate some fraction of the agent's future earnings in manufacturing. This confiscation would lower the agent's lifetime income by reducing their continuation value when caught to $(1 - \beta)V^M(t)$ for some positive fraction β. Taking this more draconian possibility into account shows that when rents are positive, individual effort must exceed a threshold determined by both enforcement power and the prospect of lost returns in manufacturing. In steady state it becomes $L/N \geq [1/\Phi] - \beta w[\Phi - 1]/\pi^C$; our previous constraint obtains by setting $\beta = 0$.

Several observations follow. When $\beta > 0$, the planner has more latitude in reducing L toward the first best. This is simply because the punishment is greater at any level of rents. But achieving the first best is still not guaranteed because when rents rise the threat of losing future returns to work in manufacturing becomes insignificant relative to the benefits of cheating (w/π^C falls). In

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[21] The definition of a Clark economy tells us that at any resource price that can generate rents ((7) holds), there must exist a $\bar{\rho}$, such that enforcement power at this $\bar{\rho}$ is so strong the first best can be obtained. For $\rho > \bar{\rho}$, we again have $\pi'(\rho) = 0$. We have $\pi'(\bar{\rho}) = 0$ as we take the derivative from the left, but $dc/d\rho > 0$ for all ρ. Hence the first-order condition for a maximum will always be satisfied to the left of $\bar{\rho}$, and although we may get close to a Clark economy, we will never reach it. We can obtain a Clark economy if we alter the monitoring technology to allow for some fixed baseline probability of being caught with zero monitoring (as in the specification in earlier sections of the paper).

fact, the additional component of the fine works best in low-rent situations. It was a feature of our previous analysis that the costs and benefits of cheating approached zero at the same rate. This was responsible for our simple condition describing Hardin economies, and it meant that in low-rent environments punishments were also low. This strikes us as reasonable. But if we assume β is not zero, our previous result of open access Hardin economies will be replaced by low-rent equilibria with some limits on harvests. Hence, the major change that a larger punishment brings to our analysis is that the pure open access case is replaced by outcomes with almost, but not quite, all rent dissipated. Strictly speaking, Hardin economies will not exist, but countries where the resource is hard to manage (in the sense discussed earlier in the paper) will be arbitrarily close to open access. Moreover, if monitoring itself consumes resources, as discussed above, then open access outcomes will again result because the benefits of monitoring are also small in low-rent situations.

V. Conclusions

The purpose of this paper was to develop a simple theory of endogenous resource management to help us understand the spectacular variation we see in the protection given renewable resources worldwide. The theoretical literature has, to a large extent, focused on either the extreme of no property rights protection or the extreme of perfect property rights protection. While these polar cases are useful theoretical constructs, they cannot explain *why* some resources are well managed and some poorly or *why* some countries succeed and others fail. Citing property rights failures as the reason for poor management begs the question and does not answer it. Existing analyses, which take the degree of property rights protection as fixed, also provide us with little guidance in a world where property rights are flexible market-sensitive institutions that adjust to changed conditions brought about by international trade, technological progress, or population growth.

As a first step toward resolving these issues, we constructed a relatively simple theory where the efficacy of resource management, and hence the de facto property rights regime, is endogenously determined. The model was dynamic to capture the key externality in renewable resource industries, and it featured a simple monitoring problem, since limiting harvests is the key management problem. The resource manager attempts to choose harvest policies to internalize externalities, but because of imperfect monitoring must contend with an incentive constraint.

We found that three basic forces determine success or failure in resource management: the extent of overcapacity in the resource sector, a government's enforcement power, and the ability of the resource to generate competitive returns without being extinguished. We used these constructs to divide resource-rich economies into three categories according to their potential for improved resource management as the value of resources rises. By doing so we generated the limiting cases of open access and perfect management as endogenous outcomes, and linked these outcomes to primitive country and resource characteristics.

To demonstrate the potential usefulness of our theory as a guide to policy, we presented three applications that illustrate how the impacts of trade liberalization, technological progress, and economic growth can differ quite radically across countries and resources. On balance we found that trade liberalization appears more favorable for resource exporting countries than previously thought, but if market integration also brings new technologies, these tend to destabilize management systems. We also demonstrated that the impact of population growth on resource use may be very different in open versus closed economies. The model predicts that some countries may never escape the tragedy of the commons, while others will; and our framework links the possibility of escape to a relatively small number of country characteristics. The obvious empirical challenge is now to ask how well these country characteristics explain the spectacular cross-country variation we observe in the success of resource management worldwide.

Our model is highly stylized and focuses on three simple determinants of success and failure in resource management; as such, it surely cannot explain all of the variation we observe in resource management worldwide. While we have assumed a welfare maximizing regulator to show how a variety of outcomes are possible even with a benevolent regulator, extending the model to allow corruption or political pressure to influence regulatory outcomes would be a valuable extension. In addition, our model does not generate poaching or cheating in equilibrium, and hence generalizing the model to allow for heterogeneous harvesters could yield a richer set of outcomes. We have also used a very simple, single-species renewable resource model with the Schaefer harvesting technology. There is therefore much scope for further research along these lines.

Appendix

PROOF OF PROPOSITION 1:

In a steady state, all time derivatives are zero; therefore, the optimal choice for L_H must satisfy (16). When the constraint binds, L_H equals either L^T or L^O. When the constraint does not bind, the first-best L^* can be found by maximizing the following current value Hamiltonian:

$$H = U\left(\frac{[p\alpha S - 1]L_H + N}{\beta(p)}\right) + \varphi[G(S) - \alpha L_H S].$$

Note $\beta(p)$ is a price index, and the Hamiltonian is linear in the control. To rule out corner solutions, note $L_H = N$ will drive the resource to extinction because $\Omega > 1$. This can never be optimal with finite p. As a result, manufacturing is always produced and hence $w = 1$ in any steady state. $L_H = 0$ is inconsistent with meeting the incentive constraint in steady state (since (7) holds). The remaining first-order necessary conditions yield

$$\delta = G'(S) + \frac{\alpha L_H}{p\alpha S - 1}, \tag{A1}$$

$$L_H = \frac{r}{\alpha}(1 - S/K) \tag{A2}$$

(A1) and (A2) solve for L_H and S. Equation (A2) is a negative and linear relationship between L_H and S. At $S = 0$, $L_H = r/\alpha < N$; at $S = K$, $L_H = 0$. Equation (A1) gives L_H as a monotonically increasing function of S. At $S = 0$, $L_H = (r - \delta)/\alpha < r/\alpha$. At $S = K$, we have $L_H = ((\delta + r)/\alpha)(p\alpha K - 1) > 0$ by (7). Therefore, a solution exists with L_H nonnegative. It is unique. Straightforward differentiation of (A1) and (A2) show $dL_H/dp > 0$ and $dS/dp < 0$. To obtain (17), multiply (A1) by π^C, substitute for L_H using (A2), and differentiate the unit cost function to obtain the result.

PROOF OF PROPOSITION 2:

Since the unconstrained first best always generates at least some rents when (7) holds, we must have $L^*(p) \leq L^O(p)$. This implies that whenever $L^T \geq L^O(p)$, the incentive constraint must be met with equality. The rest of the proof follows from the argument in the text.

PROOF OF PROPOSITION 3:

Note $L^O(p)$ reaches a minimum of zero when p falls so far as to violate (7). But since $L^T > 0$, we conclude $L^T \geq L^O(p)$ for some p. Since $L^*(p) \leq L^O(p)$, the incentive constraint binds.

PROOF OF PROPOSITION 4:

It is necessary to distinguish between the transition prices in Ostrom economies (subscripted with *II*) and Clark economies (subscripted with *III*). For any p, Hardin economies exhibit an open access steady state; from Propositions 3 and arguments in the text, Ostrom and Clark exhibit open access steady states for prices below p^+_{II} and p^+_{III}, respectively. Choose, $p^{low} = \min[p^+_{II}, p^+_{III}]$; then all economies exhibit an open access steady state at prices below p^{low}. Choose $p^{high} = \max[p^+_{II}, p^{++}_{III}]$. At prices above p^{high}, the Ostrom economy has limited management, and the Clark economy achieves the first best.

PROOF OF PROPOSITION 5:

Because of homothetic preferences, steady-state real income is

$$R = \frac{Nw + \gamma p H(L_H) - wL_H}{\beta(\gamma p)} = \frac{N + \pi(\gamma p, L_H)}{\beta(\gamma p)}, \tag{A3}$$

where π is steady-state resource rents measured in terms of the numeraire, $w = 1$ because the economy is always diversified in production, and β is a price index increasing in p. (*i*) In a Hardin economy, $\pi = 0$, and so an increase in γ reduces R. (*ii*) If $\gamma p \geq p^+$ in a Clark or Ostrom economy then either the incentive constraint binds or the first best is obtained. Since R has the properties of an indirect utility function, we can use Roy's identity to obtain

$$dR = \frac{pXd\gamma - \pi_{L_H} dL_H}{\beta(\gamma p)} \tag{A4}$$

where X is exports of H. If the constraint binds, $dL_H = 0$ and so $dR/d\gamma > 0$. If the constraint does not bind, then $\pi_{L_H} = 0$, since rent is maximized, and so again $dR/d\gamma > 0$. (*iii*) If $\gamma p < p^+$ then $\pi = 0$, and so from (A3), $dR/d\gamma < 0$. If $\gamma p < p^+$ but $p > p^+$, then the elimination of trade frictions $(\gamma = 1)$ allows the incentive constraint to be satisfied and either the first best or limited management obtains. If the first best obtains, then real income must rise because $R(\gamma p) \leq R^*(\gamma p) < R^*(p)$, where R^* is first-best real income, and the second inequality follows since R^* is increasing in γ as shown in (*ii*) above. If constrained management obtains, then the result follows since real income increases in p without bound for given L_H; (*iv*) follows from the same argument in the first part of (*iii*) above.

PROOF OF PROPOSITION 6:

Steady-state relative prices satisfy $RD(p) = \psi p^{-\sigma} = RS(p) \equiv \alpha L_H S/[N - L_H]$, where $RD(p)$ is relative demand, ψ is a positive taste parameter, σ is the constant elasticity of demand, and $RS(p)$ is relative supply of the resource good to manufactures. At p^+ we have $L_H = N/\Phi = L^O(p^+)$, and $S = S^T$. Equate supply and demand and differentiate to find $[\hat{p}/\hat{N}] = [K/S^T - 1]/\sigma > 0$, where "^" denotes percentage change. We need to ensure the change in N does not raise the transition price p^+ so much as to create open access. Equate $N/\Phi = L^O(p^+)$, and solve for the change in the transition price created by population growth to find $[\hat{p}^+/\hat{N}] = [p^+\alpha K/w - 1] > 0$. Limited controls and rents are earned when the population size grows as long as $[\hat{p}/\hat{N}] > [\hat{p}^+/\hat{N}]$. Simplifying, we need: $[K/S^T - 1]/\sigma > [p^+\alpha K/w - 1]$. At $\sigma = 1$, the two sides are equal since p^+ is a transition price and $p^+\alpha S^T = w$. For $\sigma < 1$ the inequality holds; it fails otherwise.

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