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TRADE, TRAGEDY, AND THE COMMONS

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ABSTRACT

We develop a theory of resource management where the degree to which countries escape the tragedy of the commons is endogenously determined and explicitly linked to changes in world prices and other possible effects of market integration. We show how changes in world prices can move some countries from de facto open access situations to ones where management replicates that of an unconstrained social planner. Not all countries can follow this path of institutional reform and we identify key country characteristics (mortality rates, resource growth rates, technology) to divide the world's set of resource rich countries into Hardin, Ostrom and Clark economies. Hardin economies are not able to manage their renewable resources at any world price, have zero rents and suffer from the tragedy of the commons. Ostrom economies exhibit de facto open access and zero rents for low resource prices, but can maintain a limited form of resource management at higher prices. Clark economies can implement fully efficient management and do so when resource prices are sufficiently high. The model shows heterogeneity in the success of resource management is to be expected, and neutral technological progress works to undermine the efficacy of property rights institutions.

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1. Introduction

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 of international trade. This emphasis is not surprising because natural resource products are a significant export for much of the developing world. Property rights over renewable resources are difficult to define and often poorly enforced. And it is well established that when property rights are completely absent, trade liberalization can be devastating to both resource stocks and real incomes in resource-exporting countries.[1]

But property rights are not immutable country characteristics such as weather, mineral deposits or topography; they are instead market institutions developed to facilitate transactions and protect scarce resources. Consequently, changes in world prices 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 which take the strength of property rights as fixed. The purpose of this paper is to examine the relationship between access to international markets and renewable resource use within a framework where the enforcement of property rights, and hence the efficacy of resource management, is endogenously determined.

[1] See for example Chichilnisky (1994) and Brander and Taylor (1997).

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.

Using this theory we show that the degree to which countries escape the tragedy of the commons depends on parameters of their economies (resource growth rates, mortality rates, time preference rates, and technologies) together with the level of world prices and trade policy. We focus on the impact of changes in world prices on the enforcement of property rights, as this is most relevant to understanding how a small developing country adjusts its resource management with greater access to world markets. We find that the world's resource-rich economies can be divided into three categories according to their ability to enforce property rights as world prices vary. These categories are defined by simple and intuitive restrictions on basic parameters.

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. Hardin economies always exhibit de facto open access (in steady state) and no rents are earned on the resource. A trade liberalization that raises the domestic resource price raises consumption possibilities in

the short run, but leads to stock depletion in the long run. Future generations who inherit the now lower resource stock achieve lower expected lifetime utility than they would have in the absence of trade liberalization.

Ostrom economies have more favorable characteristics but still exhibit open access for low resource prices. At high prices a degree of protection is afforded the resource, and with limited management in place, the resource generates rents. But even if resource prices approach infinity, the first best is never obtained. When limited management is in place, a trade liberalization that raises the domestic resource price raises welfare in both the short and long run. De facto property rights strengthen with this trade liberalization.

Clark economics can obtain the first best at relatively high resource prices. At low resource prices, even a Clark economy exhibits open access or limited management. But at higher resource prices, fully efficient management is possible. When management is limited or perfect, trade liberalization is welfare improving.

Our categorization of countries shows that some of the spectacular variation we see around the world in the protection given renewable resources could arise from well-meaning governments doing the best they can in difficult situations brought about by a combination of slow resource growth rates, productive harvesting technologies and large populations with relatively short life spans. It highlights the often ignored and positive role international trade may play in raising the value of natural resources and thereby strengthening a country's incentive for management. And by linking the success or failure to gain from trade liberalization to fundamental determinants, it allows us to disentangle the impact of price changes from other changes brought about by market integration

(technology transfer for example).

To generate these results we develop a model with three key features. First, it is dynamic because the key externality in renewable resources arises from the intertemporal incentives to invest in the resource stock: if property rights are not 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 a companion paper.[2]

Second, we adopt the relatively simple general equilibrium model taken from Brander and Taylor (1997). There are two sectors: resource harvesting and manufacturing. 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.

Finally, we assume that regulation of renewable resources is difficult. There is a group of agents who have the right to access and harvest the resource. If harvesting is not regulated, then rents will be dissipated and the resource stock will be depleted. The government manages the resource by limiting the time agents can spend harvesting but monitoring is imperfect and so cheating may occur. If the incentive to cheat is excessive, the management system collapses.

The government allows agents to earn rents by harvesting, but punishes those caught cheating by denying them further access to the resource. Since the resource sector generates rents, the punishment - banishment to manufacturing - amounts to a fine equal

[2] See Brock, Copeland, and Taylor, "Transition, Reform and Collapse: the Creation and Destruction of

to the market value of expected future rents. Agents compare the short-term benefits of excessive harvesting with the long-term risk of losing access. This proves to be a very tractable way to embed the monitoring and punishment problem in a dynamic general equilibrium model.

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 there are no market failures, and so the usual gains from trade results apply.[3] On the other hand, if property rights are completely absent, then trade liberalization can be devastating. 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 Baland and Platteau (1996). The majority of their evidence comes from case studies on the management of renewable resources such as fisheries, aquifers, forests and common grazing land. Further empirical evidence on the malleability of property rights is contained in the empirical work of Besley (1995), Lopez (1997) and Barbier (2002).

This evidence suggests that changes in the strength of property rights are likely to be the rule rather than the exception, casting doubt on the conclusions of analyses where the strength of property rights are fixed. In response to this evidence 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. There are many papers on enclosure, some of which discuss incentive schemes to limit over-grazing in

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Property Rights Institutions" (in process).

[3] This was the focus of much of the literature on trade and renewable resources that emerged in the 1970's, when researchers focused on optimal extraction problems and generalizations of trade theories four core theorems to the renewable resource context. See the review by Kemp and Long (1984).

static contexts (see McCarthy (2001), Margolis (2000), and the important early work of Weitzman (1974)). There are papers examining entry deterrence in natural resource settings (see Mason and Polasky (1994) for one example), and there are papers examining poaching (see for example Hotte et al. (2000)). While this literature contains many interesting results, it does not link a country's success or failure at trade liberalization 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 time preference, or improvements in monitoring.

The rest of the paper is organized as follows. In Section 2, we set out the model. In Section 3 we define our categories of countries and link management regimes to world prices. In Section 4 we consider the effect of trade liberalization and technology transfer. For most of the paper we assume the probability of being caught and punished is given, as it would be in many common property situations because self-monitoring is common. In section 5 of the paper we discuss how our results would change if governments invest in monitoring or use a different fine structure. Section 6 concludes. An appendix contains proofs and lengthy calculations.

2. The Model

We consider a resource-rich small open economy populated by a continuum of agents with mass N. Following 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, and assume that in the absence of

controls all rents would be eliminated.[4] 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.

As is well known, resources that are held in common may be subject to over-harvesting because of externalities. Consequently, we assume that the government manages the resource by attempting to regulate the harvesting activity of agents. The government chooses harvest restrictions to maximize a utilitarian objective function defined over the welfare of both current and future generations. However, we also assume that monitoring of compliance with the regulator's rules is imperfect. The government's regulation problem is therefore constrained by the incentive of agents to cheat on their level of allowed harvesting.

2.1 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:

$$W(v) = \int_{v}^{\infty} U(R(v,t)e^{-(d+q)(t-v)}\,dt \qquad (1.1)$$

where δ is the pure rate of time preference. In writing (1.1) we exploit the fact that when

[4] This means N has to be sufficiently large: in terms of primitives to be defined later, it requires $N > r/\alpha$, which we assume throughout.

the instantaneous probability of death is θ per unit time, an agent's time of death is distributed exponentially with Prob {Death at $\tau \leq t$} = F(t) = 1- exp(-θt).

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.

2.2 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:

$$G(S) = rS(1 - S/K) \tag{1.2}$$

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 Schaefer (1957) model for harvesting we have:

$$H = aL_hS \tag{1.3}$$

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:

$$M = L_m \tag{1.4}$$

Finally, full employment requires:

$$N = L_m + L_h \tag{1.5}$$

2.3 The Incentive Constraint

The government devises a set of rules to maximize overall welfare subject to agents' incentives to over-harvest. Each agent is allocated a fixed amount of time to exploit the commons.[5] 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 penalty. The size of penalties must be bounded to make the problem interesting, and limited liability is often invoked to bound penalties in similar situations. We assume the maximum penalty available to the resource manager is to terminate the agent's right of access to the resource.[6] That is, we can think of agents as being born with the right to a harvesting license, but this license can be terminated if the harvesting rules are violated.[7]

The mechanism that deters cheating here is similar to that at work in an efficiency wage model (Shapiro and Stiglitz,1984). Agents with access to the resource stock can earn rents, provided they follow the rules and do not collectively deplete the stock by over-harvesting. They are 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.

Denote the relative price of the harvest by p, and the amount of labor time an agent is authorized to harvest by $l \leq 1$. An agent who complies with the rules earns

$$ph = palS, \tag{1.6}$$

[5] We could think about regulation as choosing the technology for harvesting, the length of season (this is harvesting time), and investing in detection (raising the probability of detection when cheating). We have chosen to focus on harvesting time since this is the most common form of regulation. See however section 5 for a discussion of how investments in monitoring change our results.

[6] Larger punishments can also be incorporated into the model - we consider these in section 5.

[7] As Ostrom (1990) and Baland and Platteau (1996; chapter 12) note, fines or punishments typically escalate with ostracism (or exclusion from the resource) being a final recourse. It is relatively easy to incorporate smaller punishments into our model, but these will not be optimal in our framework. The motivation for small initial fines may be to limit Type II errors; i.e. punishing an individual who is innocent or to allow the resource stock to play an insurance role for agents facing idiosyncratic shocks. Neither motivation is present in our framework.

in the resource sector and (1-*l*)w in the manufacturing sector. An agent who cheats spends one unit of time harvesting and earns:

$$ph^c = p\,aS \tag{1.7}$$

If the agent is caught cheating (which occurs at rate ρdt), they lose access to the resource stock and must work full time in manufacturing earning a return of w.

The decision to cheat is an investment decision. Since the agent is risk neutral, and prices are fixed in a small open economy, this decision will rest on a comparison of the expected present discounted value of the nominal income stream earned by each activity. To render this decision interesting, we assume the resource is capable of generating some rents. That is, we assume:

$$p > w/\alpha K. \tag{1.8}$$

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 (it represents the expected present discounted value of being able to work in the resource sector at time t). An agent who has been caught can only work in manufacturing and has a discounted income stream given by $V^M(t)$.

With these definitions in hand we can now derive the incentive constraint. To start, consider the returns to cheating over some small time interval dt. The agent earns the cheating level of harvest, $ph^c dt$. If the agent is caught cheating (which occurs at rate ρdt), he loses access to the resource and achieves a continuation value of $V^M(t+dt)$. With probability 1−ρdt, the agent is not caught and remains in the industry. In this case the agent can once again choose between the options of cheat or not cheat and achieves a continuation value of $V^R(t+dt)$. Future returns are discounted, and the agent dies over the interval with probability θdt. These assumptions imply $V^C(t)$ can be written as:

$$V^C(t) = ph^c dt + [1-ddt][1-qdt]\left[rdtV^M(t+dt) + [1-rdt]V^R(t+dt)\right], \tag{1.9}$$

where we have exploited the fact that exp{-aΔt} is approximately equal to 1-aΔt for Δt small.

An agent who does not cheat remains in the resource sector with probability one. The value of this not-cheat option is given by:

$$V^{NC}(t) = [ph + (1-l)w]dt + [1 - ddt][1 - qdt]\left[V^{R}(t+dt)\right], \tag{1.10}$$

An agent chooses the maximum over these options $V^{R}(t) = \max[V^{NC}(t), V^{C}(t)]$, and hence will not cheat if (1.10) is greater than (1.9). Simplifying shows an agent will not cheat when:[8]

$$\frac{\Pi}{N} + \dot{V}^{R} / p \geq \left[\frac{d+q}{d+q+r}\right]\left[[h^{c} - w/p] + \dot{V}^{R}/p\right] \tag{1.11}$$

where H=Nh, L=Nl, and Π = H-L[w/p] are the aggregate harvest, aggregate labor in harvesting, and aggregate resource rents (measured in terms of the resource good) when the government's harvesting rule is followed and no cheating occurs.

The resource manager must ensure the constraint is met or all rents will be dissipated. In steady state there are no ongoing capital gains or losses, and $\dot{V}^{R}$ in (1.11) is zero. The incentive constraint then simplifies to:

$$\frac{\Pi}{N} \geq \left[\frac{d+q}{d+q+r}\right][h^{c} - w/p] \tag{1.12}$$

and it is now apparent that the manager must ensure rents per agent, Π/N, exceed a fraction of the rents earned by cheating. Use (1.6) and (1.7) to write this condition in terms of primitives:

$$L[paS - w] \geq \left[\frac{d+q}{d+q+r}\right]N[paS - w] \tag{1.13}$$

This incentive constraint can be met in one of two ways. First, if resource rents

[8] A complete derivation is provided in the appendix.

are positive, then pαS-w > 0 and we can cancel it from both sides showing that (1.13) requires:

$$L \geq N\left[\frac{d+q}{d+q+r}\right] \equiv L^c \tag{1.14}$$

When rents are positive, the incentive constraint can only be met if the fraction of time (L/N) each agent is allowed to spend exploiting the resource exceeds some threshold. Given constant returns, a cheating agent earns a multiple of the rents earned by an agent who is not cheating, but faces some probability of being caught and punished. To make cheating unattractive the government must choose an access rule that is sufficiently generous. Sufficiently generous is defined by agents' impatience, their expected lifetime (which is 1/θ) and the instantaneous probability of being caught.

The right hand side of (1.14) is independent of prices and the resource stock because an individual agent's impact on the stock is negligible and there are constant returns to harvesting.[9] In aggregate though, a more generous access rule lowers the resource stock. Using (1.6) and (1.2) it is easy to show the resource stock is a declining function of *L*. Therefore the aggregate effort implied by (1.14) may be inconsistent with positive rents in the resource sector. As a result, an alternative solution to (1.13) must occur when resource rents are driven to zero.

To find this alternate solution, set unit labor costs equal to the resource price (p=w/αS), and solve for the open access level of labor, L^O:

$$L^0 = (r/a)\left[1 - w/paK\right]. \tag{1.15}$$

Putting these results together we find that when (1.14) is consistent with positive resource rents, the manager must allow agents to spend at minimum the fraction of time that satisfies (1.14) 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 its hands allow

[9] See Section 5 however where ρ, and hence the harvesting rule, becomes a function of world prices.

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 no agent or government body has property rights at all.[10] This discussion implies that the incentive constraint is met, in steady state, when:

$$L \geq \min\left[L^0, L^C\right]. \tag{1.16}$$

2.4 The Regulator's Problem

The resource management problem is made difficult by the prospect of cheating and the necessity of the weighing utility gains accruing to different generations. We adopt the utilitarian objective function developed by Calvo and Obstfeld (1988) that aggregates across the utility levels of different generations and leads to time-consistent optimal plans.[11] For the most part we assume the government has the same pure rate of time preference as agents.[12] In this situation, the Calvo and Obstfeld objective function yields social welfare as:

$$SW = N \int_0^\infty U(R(t))e^{-dt}dt \tag{1.17}$$

Equation (1.16) has three important properties. First, social welfare is independent of

[10] This is an important distinction. Overcoming *de facto* open access requires solution of the monitoring problem; correcting pure open access requires both the creation of property rights *and* solving the monitoring problem. It is unclear whether the rent dissipation we observe around the world arises from monitoring problems or true lack of property rights. We suspect that much of it arises from monitoring problems.

[11] Calvo and Obstfeld (1988) show this objective function eliminates time inconsistentcy arising from the Strotz problem. Even with this objective function harvest plans could still be time inconsistent in a more general model (where for example agents make irrevocable commitments like sinking capital in a sector).

[12] See the appendix for a derivation of the objective function when the government and agents have different rates of pure time preference. Very little hinges on them sharing rates of time preference. If we make the government impatient by giving them a higher rate of time preference then they are more aggressive in harvesting and this makes it easier to support the first best. It also means future generations are under-represented in their plans.

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. 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. δ+θ > 0).

3. The Steady State Economy

The government maximizes (1.38) by choosing a time allocation $l(t)$ that each agent can spend harvesting, subject to technologies given in (1.3), (1.4), full employment in (1.5), biological growth in (1.2), and the incentive constraint (1.11). There are three possible solutions to the government's problem. The first occurs when the incentive constraint does not bind at the first best level of harvesting. To solve for this solution we can ignore (1.11) and solve a standard optimal control problem using L as the control. Denote the first best optimal harvesting labor by L* and the resulting steady state stock by S*. Routine calculations show L* and S* satisfy:[13]

$$d[p-1/aS]= G'(S^*)[p-1/aS]+ L^*/S^*, \qquad S^* = K(1-\frac{aL^*}{r}), \tag{1.18}$$

We refer to this solution as the first best optimum as property rights are perfect in this case despite the monitoring problem.

A second possibility arises when L* given in (1.18) violates (1.16) because it is too low. In this situation agents who cheat obtain a great windfall since the additional

[13] See the appendix for a derivation.

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 in aggregate lowers the resource stock thereby lessening the productivity of cheaters. Eventually the allowed harvest time is high enough to remove the incentive to cheat and (1.16) holds with equality. If L^C is the minimum in (1.16), then this constrained optimum will have positive resource rents. Since the steady state harvest must also equal the natural growth we can use (1.2) and (1.3) to find that in this constrained steady state the outcome is given by L^C and S^C:

$$L^C = \left(\frac{q+d}{q+r+d}\right)N, \quad S^C = K\left(1-\frac{aL^C}{r}\right). \tag{1.19}$$

We refer to these solutions as the constrained optimum for obvious reasons.

Finally, 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^C is reached. In this case, L^O is the minimum in (1.16) and de facto open access is the result. The steady state solutions and then given by L^O and S^O:

$$L^O = \frac{r}{a}\left(1-\frac{1}{paK}\right), \quad S^O = K\left(1-\frac{aL^O}{r}\right) \tag{1.20}$$

It is relatively easy to show that 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. Any steady state 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. The next step is to show how these possibilities are related to factors such as country characteristics, world prices, and the trade regime. To help build intuition, we will frequently discuss the limiting case where the rate of time preference δ approaches zero. In this case, the planner does not discount the future and so maximizes sustainable surplus. However, agents will continue to discount the future because they face a probability of death $\theta dt > 0$ in each period dt. This will allow us to use some simple diagrams to illustrate our analysis. The more general case where $\delta > 0$ will be dealt with in our propositions.

3.1 The Infinitely Patient Regulator

When δ approaches zero, the solution to our optimal control problem mimics that of the static problem of maximizing sustainable surplus subject to (1.12).[14] Surplus, in units of the harvest, is given by:

$$\Pi = H(L) - [w/p]L \tag{1.21}$$

where we have written the aggregate harvest, H, as a function of L. To find the sustainable harvest note that sustainability requires the harvest equal natural growth, or:

$$aLS = rS(1 - S/K) \tag{1.22}$$

Solving (1.22) for S as a function of L and using (1.6) yields H(L) as follows:

$$H(L) = aLK[1 - aL/r] \tag{1.23}$$

Therefore when δ is small, our possible steady state solutions can be found by maximizing (1.21) subject to (1.12) and (1.23). The benefit of this approach is that we can investigate the problem with familiar graphical methods that will help build intuition; our results however will be proven under the more general requirement where δ need not

[14] See Clark (1990) p. 42 for a proof.

be close to zero.

In the upper quadrant of Figure 1, we have plotted the sustainable harvest, H(L) as a function of aggregate labor input L. This function is concave given the properties of (1.23). The opportunity cost of labor is measured by the straight line wL/p. There are two points of note in the top quadrant. The open access outcome is at $L = L^o$. This is the point at which rents in the resource just fall to zero. L* represents the allocation of labor that maximizes surplus (ignoring the incentive constraint). Since $L^* < L^O$, it is clear that open access leads to excessive harvesting.

To investigate when the incentive constraint binds, we have plotted the sustainable surplus in the bottom quadrant. This is found by subtracting the opportunity cost line from the harvest curve H(L), and must reach a maximum at L* and be zero at both L = 0 and $L = L^O$. This surplus is the left hand side of (1.11) (evaluated in steady state) multiplied by N. To find the right hand side, note that $h^c = \alpha S = H/L$. That is, an agent who cheats allocates his one unit of labor to harvesting and obtains the aggregate average harvest per unit labor or H/L. Solving for S as a function of L we find N times the right hand side of (1.12) becomes:

$$N\left[\frac{q}{q+r}\right][aS(L)-w/p]=N\left[\frac{q}{q+r}\right][aK-w/p-a^2KL/r] \qquad (1.24)$$

which is a linear function of L as shown by the line labeled IC originating at the open access labor allocation L^O and intersecting at point X.

Note the vertical height of incentive constraint IC falls with more labor in harvesting since this reduces the stock and reduces the incentive to cheat. The incentive constraint is just barely met at point X, and is trivially met at the open access point. Routine calculations show at X, labor in the resource sector is equal to L^C. Therefore, Figure 1 depicts a situation where the incentive constraint does not bind because L*(p) satisfies (1.16).

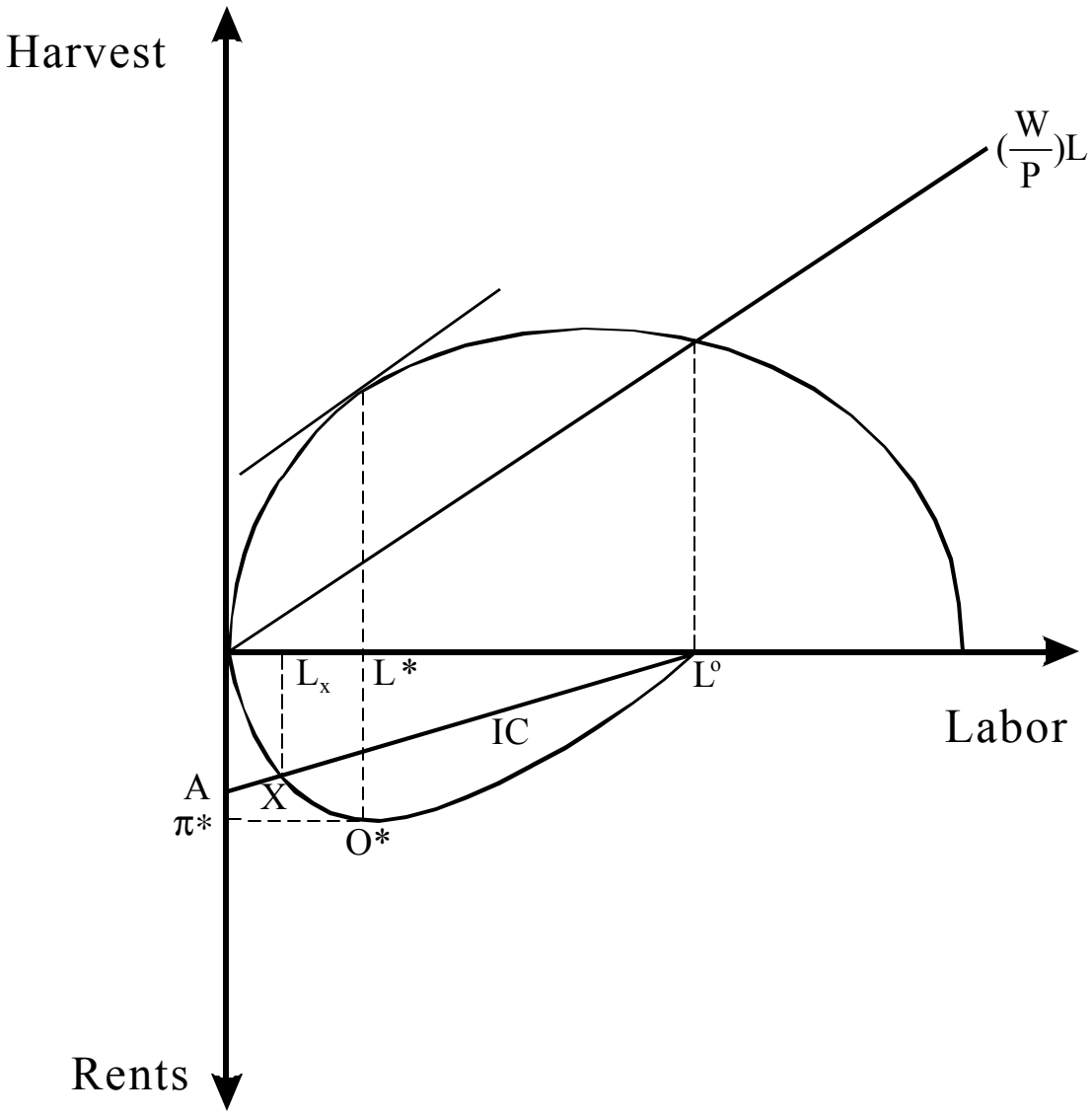

Figure 1. The Regulation Problem

3.2 Country Characteristics and the Management Regime

Figure 1 illustrates a situation where the regulator can choose the rent-maximizing labor allocation L*. This happy state of affairs is possible because resource prices are relatively high and population size relatively low. High resource prices imply that the resource will produce positive rents even when its physical stock is low. Recall that resource rents are equal to pαS-w, and therefore a large p can yield positive rents when S is small. This is an important consideration because the planner must allow each agent a minimum amount of time in harvesting to deter cheating. If the population is small then summing this minimum allocation across N agents gives us a relatively small aggregate labor allocation, a relatively small aggregate harvest and a relatively robust resource stock capable of generating rents.

It is immediate then that increases in the population size work against limiting harvests, while increases in resource prices work towards it. For example, as N rises, the incentive constraint rotates downwards while H(L) and the opportunity cost line wL/p are unaffected. Eventually, N is large enough so that the incentive constraint just binds at the maximum sustainable surplus. This occurs when the incentive constraint intersects the sustained surplus curve at point O*. For further increases in N, the incentive constraint binds, and the manager has to allow access to the resource stock to rise above L* and this leads to a decline in the resource stock. For sufficiently high N, the incentive constraint will be so steep that it does not intersect the sustained surplus curve at all, and so cannot be satisfied for any labor allocation less than the open access level L^o. That is, for sufficiently high N, the manager is unable to sustain any rent in the resource and *de facto* open access obtains. It is not that everyone cheats and the government is frustrated; rather, the government foresees the incentives and provides a rule whereby no one is in violation. *De facto* open access occurs if $L^C \geq L^O$, or in terms of primitives, when:

$$N\left[\frac{q}{q+r}\right] \geq \frac{r}{a}\left[1-\frac{w}{paK}\right]. \qquad (1.25)$$

The right hand side of (1.25) is positive for any resource capable of generating

rents.[15] Our model thus predicts that when the population is small, rent-generating resource management is possible; but for high levels of population, the resource will be subject to open access and not protected. This is consistent with empirical evidence linking population size to the collapse of informal property rights arrangements and deforestation.[16]

Increases in resource prices can undo the negative impact of greater populations, but within limits. This can be shown graphically by noting wL/p falls with increases in p. This can in some cases reestablish a equilibrium with positive rents. But some economies will not be able to sustain any rent no matter how high the resource price. To see this, note that as p goes to infinity, we can rewrite (1.25) as:

$$\left[\frac{q}{q+r}\right] \geq \frac{r}{aN} \tag{1.26}$$

In countries that satisfy (1.26), the resource manager is not able to restrict access to the resource stock and so open access is always the result. These are economies for which the minimum level of labour L^C required to satisfy the incentive constraint is always to the right of the extinction level of labor r/α. Rents are dissipated and we have a classic "Tragedy of the Commons". It seems natural then to refer to this set of economies as *Hardin economies*.[17] Generalizing to the case of positive discount rates, Hardin economies are those satisfying the parameter restriction:

$$\left[\frac{q+d}{q+d+r}\right] \geq \frac{r}{aN} \tag{1.27}$$

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 $L^*(p) = L^O(p)$ and no rents are earned in the resource sector.

[15] Recall our assumption in (1.8).
[16] This is noted by several authors: for example, Ostrom (2000), Seabright (2000) and Place (2001). Empirical evidence directly on this point is provided in Deacon (1994);
[17] See Hardin (1968). Hardin popularized the term "Tragedy of the Commons" and brought national attention to resource issues.

Proof: see Appendix.

Proposition 2 tells us there exists a set of countries that may never solve their open access problems, regardless of how valuable the resource may be either domestically or internationally.[18] 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).

It is easy to show that r/α is the level of labor that, if consistently applied to harvesting, would extinguish the resource. The right hand side of (1.27) then gives the fraction of current capacity, N, that if consistently applied to harvesting, would lead to extinction. A country with tremendous overcapacity in its resource sector is therefore likely a Hardin economy. For example if employment of 20% of capacity in a resource industry leads to extinction, agents have an expected lifetime of 40 years and a discount rate of 10% per year, then this is a Hardin economy if it takes on average more than 2 years to catch agents cheating on their harvest allowance.

While open access is a necessary outcome for a Hardin economy, other types of countries are able to sustain a rent-generating management regime when resource prices are sufficiently high. To examine these types of countries, suppose (1.27) does *not* hold and consider the effects of varying resource prices on the management regime.

First note that for very low resource prices we must obtain the open access equilibrium in any country. For sufficiently low p, the resource sector is very unattractive and this lowers $L^O(p)$ making it the minimum in (1.16). Intuitively, when the price of the resource is very low, rent can be extracted only if the resource stock is very high. To keep S high, agents are required to spend very little time in the resource. But

[18] If we generalize the model to allow the rate of time preference to differ between the planner and harvesters, then one can show that the patience or impatience of the planner is irrelevant to the definition of a Hardin economy and also to the result. This is because a Hardin economy is one for which the minimum labor allocation needed to meet the incentive constraint, L^C, exceeds the first best choice of labor at any price. The planner's preferences are irrelevant when the incentive constraint determines outcomes.

this then leaves them with a large reserve of labor time available to cheat if there are any rents available. Consequently, when the resource price is very low, restrictions on entry to generate rent will not be feasible and open access will be the equilibrium outcome.

Now consider increasing p from this low level. Since labor in the resource sector rises monotonically with p, and since we assume (1.27) fails, eventually for some $p \equiv p^+$, we will have:

$$L^O(p+) = L^C. \tag{1.28}$$

This is the point the incentive where the constraint just binds at the open access outome ($L^O = L^c$).

Now consider increases in p above p^+. There are two possibilities, depending on how hard it is to satisfy the incentive constraint. For some countries full rent maximization is never possible, but some entry restriction will be feasible for sufficiently high resource prices. 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*[19]. Ostrom economies have country characteristics that satisfy:

$$\frac{d+r}{2a} < \left[\frac{q+d}{q+d+r}\right] N < \frac{r}{a} \tag{1.29}$$

Note Ostrom economies can only exist if $\delta < r$. [20] For Ostrom economies we find:

Proposition 3. For every Ostrom economy there exists a finite price p^+ (which depends on country characteristics) such that in the steady state:

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[19] See especially Ostrom (1990).

[20] Intrinsic growth rates vary widely across resources. For example the intrinsic growth rate for Pacific Halibut has been estimated to be .71, while that of the Antartic fin whale is only .08 (see Clark (1990) and references therein).

(i) for $p \leq p^+$ there is *de facto* open access, with $L^*(p) = L^0(p)$ and no rents;
(ii) for $p > p^+$ harvesting restrictions are successfully implemented, the resource generates rents, and $L^*(p) = L^C$;
Proof: see Appendix.

Ostrom economies will make the transition to at least partial control over their resources at higher world prices. In comparison with countries that are not able to restrict harvesting, these countries have faster growing resources, good detection technologies and low populations.[21]

It is straightforward to show that the transition price, p^+, is higher in economies with higher populations (N), lower life expectancy ($1/\theta$), with 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).

To understand why the first best cannot be obtained, consider the case where $\delta = 0$. It is apparent from Figure 1 that the rent maximizing allocation of labor $L^*(p)$ must occur at a point to the left of the maximum sustainable yield (MSY) allocation of labor ($r/2\alpha$). But if condition (1.29) is satisified, the incentive constraint will only be satisfied if more than the MSY level of labor is allowed into resource harvesting (that is, $L^C > r/2\alpha$). Hence once p rises above p^+, the best that the manager can do is to keep the labor allocation at the point where the incentive constraint just binds (L^C). In this situation both the costs and benefits of cheating rise proportionately with p, and the regulator holds labor in harvesting constant to balance these incentives. Rents rise linearly with p.

When the regulator's discount rate δ is positive, the planner adopts a more aggressive harvesting policy and S^* is reduced in order to raise the return on the resource stock. However, as long as $\delta < r$ (so that extinction is not optimal), a similar argument to that given above applies except that the first best level of labor L^* is higher than the

[21] Using the same parameter values as assumed before and setting δ to zero shows that if it takes less than two years to catch a cheater but more than 10 months, then this is a *Ostrom economy*.

MSY level. As the resource price approaches infinity, one can show that the first best allocation of labour approaches $(\delta + r)/2\alpha$. If condition (1.29) holds, then then incentive constraint requires that the regulator always allow more labour time in the resource sector than would support the first best. Hence the first best cannot be supported. But since the incentive-constrained level of labour L^C is below the open access level of labor when price are high, the regulator can do better than open access and generate some rents by setting $L = L^C$.

Finally, there is a third category of countries where the incentive constraint is easier to satisfy and it is possible to achieve the first best allocation of labor when the price of the resource is sufficiently high. We call these countries *Clark economies*, and they satisfy:[22]

$$0 < \left[\frac{q+d}{q+d+r}\right] N \leq \frac{d+r}{2a}, \tag{1.30}$$

When (1.30) holds there exists some resource price p^{++} such that for $p > p^{++}$, $L^*(p^{++}) > L^C$ and the first best solution L^* can be sustained while meeting the incentive constraint. We have already depicted such a solution in Figure 1. *Clark economies* will exhibit open access and only limited protection for low resource prices, but for sufficiently high prices full rent maximization will result.

Proposition 4. For every Clark economy there exists finite prices p^+ and p^{++} (which depend on country characteristics) such that in steady state:

(i) for $p \leq p^+$ there is *de facto* open access, with $L^*(p) = L^O(p)$, and no rents;

(ii) for $p^{++} > p > p^+$ harvesting restrictions are successful, $L^*(p) = L^C$ and rents are positive;

(iii) for prices $p > p^{++}$, the first best harvesting is supported;

[22] We name these after the mathematician Colin Clark of U.B.C. whose book *Mathematical Bioeconomics* has played a major role in the teaching and study of resource economics. While Clark's book also considers the open access case, most of it is devoted to study of various control problems that implement the first best. See Clark (1990).

Proof: see Appendix

Clark economies have either very productive resources (high r), small numbers of people with access to the resource, good detection technologies, or unproductive harvesting technology. To understand why full rent maximization can be achieved in these countries, consider again the case with $\delta = 0$. If (1.30) is satisfied, then the incentive-constrained minimum labor allocation L^C would be to the left of the MSY level of labor r/α. Since the rent maximizing level of labor approaches the MSY level as the resource price approaches infinity, the incentive constraint will not bind for sufficiently high prices.

3.3 A Measure of Effective Property Rights

To compare the three types of countries, it is useful to have a tool to assess the extent to which a country is able to enforce property rights. To do so, we define a measure of effective property rights (EPR) as follows:

$$EPR = L^*(p) / L(p), \tag{1.31}$$

where L* is the first best allocation of labor to the resource (given in (1.18)), and L is the labor actually employed in the resource sector, L. If the first best is achieved, then EPR = 1; but if the incentive constraint binds, then EPR < 1.

Figure 2 depicts graphs of effective property rights for the case where δ approaches zero. Hardin economies have open access for all resource prices. Since the open access allocation of labor L^O is proportional to the rent maximizing level when $\delta = 0$, EPR does not vary with p and is a horizontal line.

Ostrom economies are in open access for $p < p_{II}^+$, and hence these countries have identical EPR with Hardin economies over the $[0, p_{II}^+]$ range. But when prices rise further, the incentive constraint binds, and labor is held fixed at $L = L^C$. And since L*(p) rises with p to reach a maximum at $r/2\alpha$, the EPR locus for Ostrom economies asymptotes as

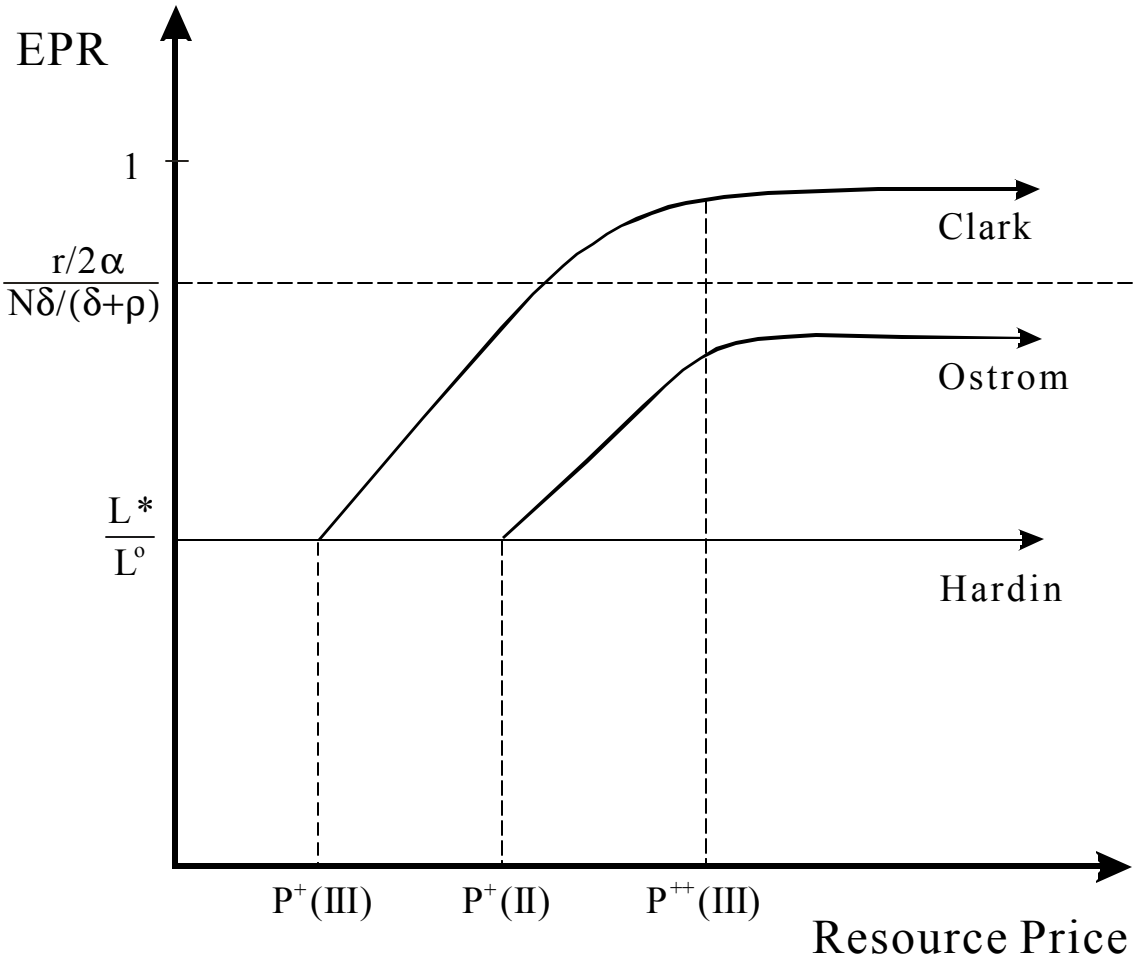

Figure 2. Effective Property Rights

shown. Note that effective property rights over the resource are rising even though the labor allocation to the resource sector is held constant. The reason for this is that as p rises, the optimal effort is rising and hence the extent of "excessive harvesting" falls with p.

Finally, consider Clark economies. They also have an open access component from $[0, p^{+}_{III}]$.[23] As prices rise above p^{+}_{III}, effective property rights increase and eventually this country is able to support full rent maximization. At this point, EPR = 1 and remains there.

While we have illustrated this heterogeneity across countries under the assumption that δ approaches zero, qualitatively similar results hold more generally:

Proposition 5. Assume a group of Hardin, Ostrom and Clark economies exist, and let them share the same minimum price $p^{min} = 1/\alpha K$ 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 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.

Our analysis indicates we should expect to find a great degree of heterogeneity in property rights protection worldwide, even without accounting for differences in government objectives. While political economy motivations and corruption may well be the dominant forces governing resource use in some situations, these results force us to ask what part of the observed variation in property rights protection worldwide is consistent with utilitarian governments doing the best they can under difficult situations.

Our results also useful in thinking about the implications of domestic resource policy reform. Suppose we think of starting from a point where there is no management system in place (in which we would expect the open access outcome to obtain) and introducing a domestic policy reform that brings in an element of enforcement and monitoring. Such an initiative will always fail in some countries (Hardin) whereas it will

[23] Recall that p^{+} depends on country characteristics: it is straightforward to show that $p^{+}_{III} < p^{+}_{II}$.

be at least partially successful in others (Ostrom and Clark). Moreover for both Ostrom and Clark countries, international trade at higher world prices may be a necessary precondition for successful policy reform. This suggests that the idea of making environmental policy reform a precondition for trade liberalization can be counterproductive. Instead, the relative price changes induced by freer trade may make viable a previously unviable environmental policy reform.

4. Market Integration

In this section, we consider the implications of increased integration with foreign markets. As discussed in the introduction, previous work has mostly focussed on cases where the effective property rights regime is exogenous. In this section, we show how endogenizing the management regime has important and novel implications.

Our model has numerous policy and empirical implications because we could consider the effects of different types of market integration (trade, technology transfer, factor mobility, etc.) for each of our three types of economies, each starting with different levels of effective property rights. Rather than producing a large catalogue of results, we focus on four results that highlight the importance of allowing the effectiveness of resource management to be endogenous.

4.1 Trade liberalization: Resource Exporters

Much of the concern about the effects of globalization on the environment centers on the case where a country that lacks an effective management regime opens up to trade and exports renewable resource-intensive goods. Brander and Taylor (1997) and Chichilnisky (1994) have shown that such a country will experience increased resource depletion and may experience a decline in steady state real income. This is because the trade-induced increase in the price of the harvest good attracts entry into the resource sector and exacerbates the open-access externality.

Once we allow for endogenous management, we obtain a much richer set of

predictions, and these results can be reversed. First, a straightforward application of the results from the previous section implies that trade liberalization can lead to the emergence of an effective management regime. This is because the increased price of the harvest good arising from trade liberalization in a resource-exporting country 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 steady state real income.

Second, our model predicts heterogeneity across resource-exporting countries in the impact of trade liberalization. Hardin economies will always experience resource depletion and a decline in steady state income; Clark economies may experience a transition to first best resource management, and Ostrom economies will fall somewhere in between. Moreover, we can link the likely effects of trade to observable characteristics of countries (or resource sectors within countries). Those most vulnerable to trade-induced resource depletion and real income losses are countries with slow growing resources, large numbers of people with access to the resource, good harvest technology, poor monitoring, and harvesters with high discount rates (which might be driven by low life expectancy).

More formally, to facilitate comparison with Brander and Taylor (1997), we consider the effects of trade for a resource-exporting country where the manager has a discount rate that approaches zero.[24] Suppose there are initially trade frictions (such as transportation costs) that drive a wedge between domestic and foreign goods prices because they introduce real resource costs of trading.[25] We consider "iceberg" trading costs. Let $\gamma \leq 1$ be the fraction of a good that arrives at its destination. The fraction $1-\gamma$ lost in transit is the trading cost. If the world price is p, then if home exports H, then a domestic agent must ship $1/\gamma$ units to the foreign market to receive a price p. Equilibrium

[24] We discuss the case where the manager discounts the future in a footnote below.
[25] Modeling trade barriers as frictions rather than revenue-generating taxes (tariffs on manufactures or export taxes on resources) allows us to focus on the pure effects of trade without the complication of the trade barrier also being a second-best harvest tax. Export taxes are discussed in Section 4.3.

requires that the domestic price p^d satisfies $p^d = \gamma p < p$. Trade liberalization corresponds to an increase in γ, and this will lead to an increase in the domestic price of H. Then the following result summarizes the discussion above:

Proposition 6. Suppose the planner's discount rate approaches zero and the country exports the harvest good.

1. A fall in trade frictions will reduce steady state real income in a Hardin economy.

2. For a Clark or Ostrom economy,[26]

(a) If $\gamma p \geq p^+$, then a fall in trade frictions will increase steady state real income.

(b) If $\gamma p < p^+$, then a sufficiently small fall in trade frictions will reduce steady state real income, but there exists $\underline{p}$ such that if $\gamma_1 p > \underline{p}$, then a fall in trade frictions from γ to γ_1 will lead to the emergence of a management regime and to an increase steady state real income.

3. For a Clark economy, if $\gamma p < p^+$, and $p \geq p^{++}$ then elimination of all trade frictions will result in a transition from de facto open access to fully efficient management. Steady state real income will rise.[27]

Proof: See appendix.

4.2 Correlated Characteristics and Comparative Advantage

One of the standard assumptions in the literature on trade and the environment is that poor countries have weaker property rights than rich countries. This seems an

[26] Note that the p^+ referred to in what follows depends on country characteristics and so will differ depending on whether we have a Clark or Ostrom economy.

[27] More generally, if the planner does discount the future, long run harvest rates (and steady state real income) need not increase even with full management in place. In this case, however, we can ask whether free trade leads to resource stock depletion in an economic sense. That is, define an index of stock depletion as $D(p) = 1 - S(p)/S^*(p)$, where S is the actual steady state resource stock, and $S^*(p)$ is the unconstrained socially efficient steady state resource stock given the discount rate δ of the planner. With no economic depletion, $S(p) = S^*(p)$ and hence $D(p) = 0$. With full depletion, $S(p) = 0$, and hence $D(p) = 1$ (since we have assumed that extinction is not socially efficient, so that $S^*(p) > 0$). For a Clark economy, the index of stock depletion falls to zero with trade liberalization (if the world price is sufficiently high). However, for a Hardin country, stock depletion can increase with free trade; and if the world price is sufficiently high, the depletion index will approach 1.

innocuous assumption and one that is easily verified with an examination of cross-country survey data on the rule of law and protection for contracts. It played a key role in Chichilnisky's (1994) North-South model where two otherwise identical countries differed in their property rights regimes: one had perfect protection and the other none whatsoever. These exogenous differences in property rights led to a Southern comparative advantage in natural resource products and Southern losses from trade.

In a model of endogenous property rights it is impossible to generate two countries identical in all respects except for their success in resource management. Instead we are forced to take a stand on where these differences have come from, and whether these differences also have an independent effect on comparative advantage. If the same features generating poor property rights also work against a comparative advantage in resource products, then associating weak property rights with natural resource exporters may be in error; and the positive and normative effects of trade liberalization can be radically different.[28]

To investigate further we can use our model to consider two countries which differ in some exogenous characteristic. This will then lead to differences in both the property rights regime and in comparative advantage. To make our point, we work through the effects of differences in one key characteristic - the intrinsic rate of resource growth, r - however, similar results are obtained for other characteristics, such as differences in population density.

Recall that low values of r yield Hardin economies, with higher values giving rise to both Ostrom and Clark economies. Assume that two countries differ only in their rate of resource growth, as is likely to occur naturally from variation in geography and weather around the globe. To make matters concrete let one be a Hardin economy and the other a Clark economy as a result of this difference. Then, in obvious notation, we

[28] While many developing economies are heavily reliant on natural resource exports, so too are many rich developed countries. Canada is by far the largest exporter of forest products in the world, followed by Sweden and Finland. Germany exports a greater value of forest products than does Brazil and Columbia combined, while New Zealand is heavily reliant on natural resource exports from both fisheries and forests. These are not countries we typically associate with weak or non-existent property rights.

have $r^H < r^C$.

To determine comparative advantage, we compare relative supply curves across the two countries. If the Clark economy produces a ratio of H/M greater than that of the Hardin economy at all possible world prices, then autarky resource prices must be lower in the Clark economy.[29] Relative supply in either economy, H/M, can be written as:

$$\frac{H}{M} = \frac{aL_H S}{N - L_H} \tag{1.32}$$

For low resource prices, both economies would be in open access. At higher prices only the Hardin economy is in open access. By comparing relative supplies across all possible prices, we obtain:

Proposition 7. Consider Hardin and Clark economies that differ only in their intrinsic rate of resource growth. Then in free trade, real income in the Clark economy is greater than or equal to that of the Hardin economy; and the Clark economy has a comparative advantage vis-à-vis the Hardin economy in the resource product.

Proof: See Appendix.

Proposition 6 demonstrates how a positive correlation between a country characteristic that is important to property rights enforcement – a high rate of resource growth – may be correlated with a country characteristic important to determining comparative advantage in resource products – a large output of the harvest good. In this case the correlation of attributes is perfect as a fast growing resource base is conducive to both large rents and a large output of the resource good. When this occurs, poor and rich countries do differ in their strength of property rights but this difference is swamped by the direct effect of faster growth of the resource. As a result, the country which is both rich and has well-enforced property rights has a comparative advantage in the resource intensive good.[30]

[29] Recall that we have assumed that relative demand is the same in all countries - this is a standard assumption in trade models which isolates the role of supply-side factors in influencing trade patterns.

[30] This possibility is related to the result in the pollution and trade literature where rich but capital-intensive developed countries can have a comparative advantage in dirty good production despite the stringent regulation brought about by their high incomes. See the discussion of correlated characteristics in Copeland and Taylor (2003, chapter 6).

This role reversal has several implications. For one it means that trade between our Clark and Hardin economies can only strengthen property rights protection in the Clark economy and is likely to bring it gains from trade as well. If its autarky relative price exceeded p+ then gains in real income are assured. And although trade has no effect on property rights protection in the Hardin economy, it will bring real income gains there as well: harvesting will fall and the resource stock will rebuild. If we now call the rich Clark economy North and the poorer Hardin economy South, then trade between two countries that differ in properties rights has a trade pattern and welfare result directly opposite to those in Chichilnisky (1994).

Correlated characteristics may or may not be an important feature of the real world. We have demonstrated how one such characteristic can lead to a reversal of trade patterns and welfare results.[31] Other parameter changes may not provide such clear-cut results. For example, neutral improvements in manufacturing and harvesting technologies make enforcement more difficult and lead to a comparative disadvantage in harvesting, but also raise incomes. In this case, the poorer country may both have better enforcement and export resources. Our point is not that country characteristics are always correlated in a manner that make the strong property rights country both high-income and resource-exporting, but merely to point out that the typical exogenous assignment of property rights regimes across countries has serious pitfalls.

4.3 Export Taxes and Resource Exporters

Export taxes on natural resource products are common in the developing world. They are a practical means to generate revenue and they can act as a second-best harvest tax. Many development economists, however, argue that export taxes are rarely employed for resource management reasons. They are instead used to protect processing industries, and allow predatory central governments to raid the natural resource base of

[31] Population differences yield similar results. High population makes enforcement difficult, and also yields more manufacturing output (and hence a lower H/M ratio) and lower income per capita.

the hinterland. In a world with endogenous property rights there is a further argument against export taxes – they destroy the incentive for better resource management. Export taxes can be the cause of resource management problems rather than their cure.

Suppose there is an ad valorem export tax at rate t levied on the resource good. Then the domestic price relative price of H is p/(1+t). It is easy to show that a small export tax has to be welfare improving for a Hardin economy. But consider a Clark economy and let p > p++. Then the imposition of an export tax is welfare decreasing in this economy since at current world prices it can already obtain the first best via the enforcement mechanism alone and the export tax would introduce a consumption distortion. From a outsider's perspective it is clear which policy is best for which country: an export tax may be a reasonable policy for the country with open access, while it is a bad policy for the one with strong harvest controls in place.

But in situations where property rights are endogenous it is far more difficult to match policy prescriptions to countries. For example, any export tax that satisfies (1+t) > p/p+ produces a situation of open access in the Clark economy. To an outside observer the export tax might appear to have merit *ex post.* With open access in the resource sector, the export tax while not perfect has some merits as a second best harvest tax.

Ex ante, the situation is entirely different. A system of local control over resources has been destroyed by the imposition of the export tax at the state level; rents are diverted from local agents to the central government; and overall national welfare is reduced because of the consumption distortion created by the lower than optimal domestic price. Therefore, a policy that has some merit in a world with fixed and immutable property rights can be counterproductive in a world where property rights are malleable. And policy evaluation based on ex post observable variables may tell us little about the ex ante optimal policies.

4.4 Technology Transfer and the Collapse of Property Rights Regimes

Market integration affects a country in many ways other than simply via changes in relative prices. One commonly voiced concern is that market integration brings new

harvesting technologies to agents that alter their incentives to participate in management regimes. New technologies will of course raise real income in a world with perfectly enforced property rights: marginal improvements in harvesting technology have only beneficial impacts in a Clark economy that can already obtain the first best. However, a sufficiently large improvement in harvest technology will make it impossible to enforce the incentive constraint and lead to a collapse in the management regime and a fall in steady state real income.

Perhaps the most interesting and relevant case may be an Ostrom economy where some semblance of property rights is being enforced but the first best is not attained. In this Ostrom economy, real income falls with even small improvements in harvest technology. For small increases in α, we have:

$$\frac{dI}{da} = p\frac{\partial H(L^c;a)}{\partial a} = pL^cK\left(1-\frac{2aL^c}{r}\right) < 0$$

where the inequality follows because $L^c > r/2\alpha$ in an Ostrom economy. The rationale is straightforward: increased labor productivity in harvesting puts more pressure on the resource. The manager would like to reduce harvest time to compensate for this, but the incentive constraint prevents it. Because over-use of the resource is reinforced by the new technology, the harvest levels and rents from the resource fall in the long run.

This result follows from a specific type of technology transfer that is biased towards resource harvesting. But even with neutral technological progress that improves the productivity in manufacturing, harvesting, and monitoring equally, we are still pushed towards open access and a dissipation of rents.

Proposition 8. Consider neutral technological progress that raises α, ρ and the productivity of labor in manufacturing uniformly, then: (i) the range of parameters satisfying a Hardin economy expands; and (ii) if $(\theta+\delta)/\rho > r/\alpha N$, then neutral technological progress of sufficient magnitude transforms all economies into Hardin economies.

Proof: See Appendix.

An improvement in harvesting technology alone is destabilizing because it raises harvests for a given labor allocation, and sufficiently great technological progress will make any fixed labor allocation inconsistent with positive rents. All economies revert to Hardin economies. Our only hope in salvaging rents is if the monitoring technology improves as well. The proposition says that if the incentive problem is severe to begin with (because agents discount the future highly or N is large, etc.) then neutral technological progress leads to open access. The incentive constraint cannot be tightened up fast enough to offset the direct productivity effect on labor and all economies become Hardin economies. In contrast, if the incentive problem is less severe, then the productivity-adjusted labor force approaches a constant that does not extinguish the resource. This implies that for sufficiently high prices, rents can be obtained. [32]

5. Extensions

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

5.1 Monitoring

We have assumed that the probability of being caught and punished is fixed. We did so because in many situations self-monitoring by other agents is important. This assumption also had the benefit of rendering our classification of countries quite simple. More generally, the government can invest resources in monitoring. In this section we develop a simple extension to our model in which the intensity of monitoring is endogenous and argue that our main conclusions continue to hold.

[32] Although we have illustrated this result using a simple example of technology transfer, similar results could be obtained via goods trade in an expanded model. Suppose that harvesting production function required intermediate goods (such as gasoline engines and electronic fish finders) that would enhance the marginal product of labor for any given level of the resource stock. Then a trade liberalization that lowered the price of these intermediate goods relative to the price of the resource stock could also lead to the collapse of the management regime and real income losses.

Assume that 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.[33] 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.

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. We now write it to emphasize the role of ρ.

$$p(r) = \max_{L_H} \left\{ pH(L_H) - L_H : \; L_H \geq \min(L^o, L^c) \right\}$$

The optimal choice of ρ is given by:

$$r^* = \text{argmax} \left\{ p^N = p(r) - C(r) \right\}$$

We illustrate the government's optimization problem in Figure 3. The cost of monitoring is linear, and we have drawn two different cost functions: $c^1(\rho)$ and $c^2(\rho)$, where the monitoring technology is more efficient in the case of c^2. The rent function π is non-decreasing function of ρ. When ρ is low (for $r < \underline{r}$ in the figure), open access obtains and $\pi(\rho) = 0$. For sufficiently high ρ (for $r > \bar{r}$ in the figure), the first best is achieved and further increases in ρ do not raise π. For ρ between these values, the incentive constraint binds. Rents increase in ρ in this region because

[33] ρ is the rate at which you catch cheaters over the interval dt and can be greater or less than one depending on enforcement and the productivity parameter ρ_0. The underlying random variable is the time until the successful capture of a cheater. This is distributed exponentially with the probability of a capture at τ less than or equal to t given by $1-\exp\{-\rho t\}$. Therefore the probability of a successful capture at any time t is zero, the expected time to being caught is $1/\rho$, and for any finite effort in enforcement the expected time to a successful capture is strictly greater than zero. In this sense monitoring can never be perfect.

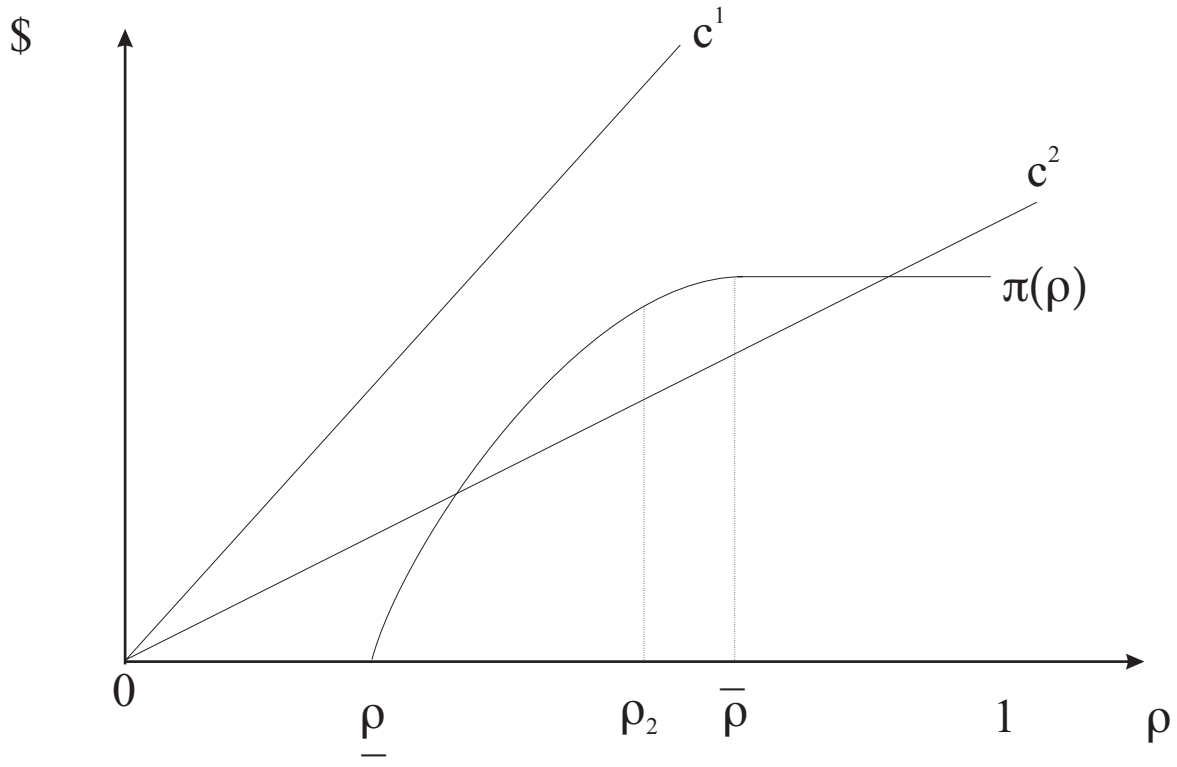

Figure 3. Choice of monitoring intensity

harvesting can be reduced as the probability of being caught rises.

Open access outcomes can still exist. This occurs when the productivity of monitoring effort ρ_0 is low and is illustrated in Figure 3 in the case where the cost function is $c^1(\rho)$. In this case, the optimal investment in monitoring is zero.[34]

For more efficient monitoring technologies, it pays to invest in monitoring. In Figure 3, when the monitoring cost function is c^2, the optimal solution is $\rho = \rho_2 > 0$. In this case, the manager can successfully restrict harvesting, but the first best is not attained.

Differences in country characteristics (such as the resource growth rate, population, and technology) shift the profit function to the left or right, or up and down. 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. For example, an increase in the resource's growth rate r will shift the profit function to the left, increasing the likelihood of efficient management. Our earlier result that trade can induce transitions in the management regime also holds. Increases in the resource price shift up the profit function, which increases the likelihood of effective management.

Endogenous management does introduce some changes in model behavior. 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.[35] The reason is simply that increases in monitoring have a vanishingly small marginal benefit as the economy gets close to the first best. In

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[34] Note that the rent function is non-concave - rents are zero until a threshold level of ρ is reached. This is what yields the corner solution of no monitoring.

[35] This holds because, referring to Figure 3, we have $p'(\overline{r}) = 0$ 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 $\overline{r}$ and so although we may get close to a Clark economy as the monitoring technology becomes more efficient, we will never reach it. However, we can obtain a Clark economy if we alter the monitoring technology to allow for some fixed base line probability of being caught with zero monitoring (as in the specification in earlier sections of the paper)..

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 while the first best may not be obtainable, countries with resources easy to manage will come arbitrarily close to the first best and so are de facto Clark economies.

Overall these results complicate but do not offer any significant contradictions to our earlier analysis. The beneficial impact of higher resource prices remains, as does the destabilizing impact of better technology and higher population. And we will have heterogeneity across countries in their response to trade liberalization.

5.2 Fines

We have assumed that agents lose their right to harvest from the resource whenever they are caught cheating. This is equivalent to a permanent period fine $F \equiv \Pi/N$, where Π is aggregate resource rents measured in terms of the harvest good. Our analysis makes two assumptions about F. The first is that the utility cost of imposing the maximum fine is bounded. The second is that the value of the fine rises with resource prices starting from zero when rents are zero. Would a different fine structure alter our results greatly?

It should be clear from our analysis that the regulator wants to impose the maximum fine, but to have any incentive problem at all we need to bound the maximum penalty. In the body of the paper we have assumed the agent can always work in manufacturing if they are caught cheating. A larger fine would reduce the returns they would earn in manufacturing as well. Suppose in addition to ostracism the government levied a direct fine equal in value to some fraction of the cheating agent's future earnings in manufacturing. Let this fine lower the agent's lifetime income by reducing their continuation value when caught to $(1-\beta)V^M(t)$ for some positive fraction β. When β is zero we are back to our original formulation; as β rises more draconian penalties are imposed.

The new incentive constraint facing agents, in steady state, is then:

$$l^*(paS - w) \geq \left[\frac{d+q}{d+q+r}\right](paS - w) - bw\left[\frac{r}{d+q+r}\right]$$

If we compare this incentive constraint with (1.13), it is apparent that when $\beta > 0$, the planner has more latitude in reducing l^* towards the first best. But even if we allow for the most draconian punishment (shooting cheaters and setting $\beta = 1$) this will not guarantee the first best is obtained. This is because as rents rise and cheating becomes more attractive, the threat of losing future returns to work in manufacturing becomes less and less significant relative to the benefits of cheating. Indeed the additional component of the fine works most effectively in just those situations where rents are low.

It was a feature of our previous analysis (when $\beta = 0$) that the costs and benefits of cheating approach 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. Agents involved in resource industries typically have poor outside opportunities so that the loss of access to the resource may represent the strongest incentive authorities have in curbing over use. But if we instead assume $\beta > 0$, then some rents can be generated in the resource even when resource prices are low. This is because the attraction of earning cheating rents becomes vanishingly small while the potential cost of lost earnings in manufacturing remains finite. As a result, if monitoring is exogenous then 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 higher fines 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 and hence will be de facto Hardin economies. Moreover, if monitoring itself consumes resources as in section 5.2, then open access outcomes can again result because the benefits of monitoring are also small in low rent situations.

6. Conclusions

The purpose of this paper was to investigate the implications of international trade for countries with renewable resources when the management regime adjusts to the changed conditions brought about by access to international markets. We constructed a relatively simple general equilibrium model of harvesting and manufacturing where the resource managers set harvests to maximize the well being of agents while being cognizant of cheating incentives. Within this context we find that countries can be divided into three categories according to their potential for providing enhanced resource management as world prices rise. The model shows how cross-country heterogeneity in the effectiveness of resource management can arise quite naturally from heterogeneity in their access to world markets, technological sophistication, and the specific nature of their natural resources.

We have found that some countries may never escape the tragedy of the commons, but others will and our framework links the possibility of escape to a relatively small number of country characteristics such as population density, technology, resource growth rates, and expected life spans. By linking the strength of the resource management regimes to more primitive parameters we hope to facilitate empirical work linking these country characteristics to outcomes. With a theory of endogenous regulation in play, we have a far better chance of understanding the spectacular cross-country variation we observe in resource management.

While our primary interest has been the interaction of world prices and resource management regimes, our framework may shed light on several related questions. The role of property rights in development and growth is still an open question, as is the question of how property rights affect population growth and environmental degradation. Expanding our model to introduce a storable capital good or endogenous population size seems possible and likely fruitful. Other applications could include a discussion of how trade policy instruments affect resource management, how tropical timber bans and international transfers affect deforestation, and how the emergence of *de facto* property rights over our global commons may be facilitated.

7. Appendix

7.1 Derivation of Incentive Constraint

To find the incentive constraint use the Taylor series approximations:

$$\begin{aligned} V^R(t+dt) &\approx V^R(t)+\dot{V}^R(t)\,dt \\ V^M(t+dt) &\approx V^M(t)+\dot{V}^M(t)dt \end{aligned}, \tag{1.33}$$

Recall that

$$V^R(t)=\max[V^{NC}(t),V^c(t)] \tag{1.32a}$$

If V^{NC} is the max, then we have:

$$\begin{aligned} V^R(t) &= [ph^*+(1-l^*)w]dt+[1-ddt][1-qdt]\left[V^R(t+dt)\right] \\ V^R(t) &\approx [ph^*+(1-l^*)w]dt+[1-(d+q)dt+dqdt^2]\left[V^R(t)+\dot{V}^R(t)dt\right] \\ V^R(t) &\approx \frac{1}{(d+q)dt}\begin{bmatrix}[ph^*+(1-l^*)w]dt+\dot{V}^R(t)dt \\ +[dqV^R(t)dt^2-(d+q)\dot{V}^R(t)]dt^2+dq\dot{V}^R(t)dt^3\end{bmatrix} \end{aligned} \tag{1.34}$$

Cancel dt terms, and let dt go to zero. This yields the first element in the max of (1.36). Now start with (1.9). If V^C is the max in (1.32a), then we have:

$$\begin{aligned} V^R(t) &= ph^c dt+[1-ddt][1-qdt]\left[rdtV^M(t+dt)+[1-rdt]V^R(t+dt)\right] \\ V^R(t) &\approx ph^c dt+[1-(d+q)dt+dqdt^2]\begin{bmatrix}rdt[V^M(t)+\dot{V}^M(t)dt] \\ +[1-rdt][V^R(t)+\dot{V}^R(t)dt]\end{bmatrix} \end{aligned} \tag{1.35}$$

Cancel dt terms and let dt go to zero. An atomistic agent views the time derivatives of $V^R(t)$ as equal under the two options. Finally, substitute these values into (1.32a) to find:

$$V^R(t) = \max\left[\frac{ph^* + (1-l^*)w + \dot{V}^R(t)}{d+q}, \frac{ph^c + rV^M(t) + \dot{V}^R(t)}{d+q+r}\right]. \tag{1.36}$$

The agent will not cheat at time t when the first argument in (1.36) exceeds the second. Manipulating this condition yields (1.11).

7.2 Derivation of the Objective Function

Recalling that new cohorts come in size θN, and assuming the government's rate of time preference is λ, we can write Calvo and Obstfeld's (1988) as:

$$\begin{aligned} SW = &\int_0^{\infty}\left\{\int_v^{\infty} U(R(t))e^{-(q+d)(t-v)}dt\right\}qNe^{-lv}dv \\ &+\int_{-\infty}^{0}\left\{\int_0^{\infty} U(R(t))e^{-(q+d)(t-v)}dt\right\}qNe^{-lv}dv \end{aligned} \tag{1.37}$$

This objective function has two components. The first bracketed term is the expected discounted value of lifetime utility for agents yet to be born as of t=0. Agents of vintage v have their utility flows discounted to their birth date v, by the sum of their pure rate of time preference, δ, and their instantaneous probability of death, θ. Hence the innermost bracket in this first component is the expected discounted utility for an agent of vintage v given in (1.1). We then integrate over all future vintages accounting for the fact that they are each of size θN. The second component consists of the utility of generations already alive at t=0. These agents were born sometime in the past, came in cohorts of size θN, and we likewise discount their utility streams by the sum of their own pure time preference and their probability of death. Discounting is again to their birth date v, but only utility flows from time t=0 onwards of course count. The planner again aggregates over the living generations taking into account their size θN and puts individual utility in social terms by reverse discounting to time t=0. Equation (1.37) aggregates over time first and generations second. By changing the order of integration, and noting that all

agents alive at time t have the same real income we obtain the simpler form:

$$SW = \int_0^{\infty} U(R(t)) \left\{ \int_{-\infty}^{t} Nq \bullet e^{-(q+d-l)(t-v)} dv \right\} e^{-lt} dt$$
$$= \left[\frac{Nq}{q+d-l} \right] \int_0^{\infty} U(R(t)) e^{-lt} dt \qquad (1.38)$$

where $q+d > l$ is required for the integral in (1.38) to be well defined. When λ equals δ, the objective function simplifies to that given in the text.

7.3 Stability

We have focused on steady states throughout and employed comparative steady state analysis. There are interesting issues introduced by a consideration of dynamics with the most important of these being the impact of announced policy reforms and the dynamics surrounding a collapse or transition of property rights regimes. These will be investigated in a follow-up paper. The reader may however want some assurance that a full consideration of dynamics would not render our comparative steady state analysis in error. Since the stability of first best and open access equilibria has already been examined extensively we consider only the limited property rights steady state.[36]

To do so take an Ostrom or Clark economy at an existing steady state where p is greater than the relevant p+ for the economy so that either would be at a constrained steady state with $L=L^C$. The dynamics of the system are governed by two differential equations that we now derive. Since the planner chooses $l^*(t)$ to deter cheating, we have $V^R(t)=V^{NC}(t)$ which we will henceforth denote by V(t). Using (1.10) the evolution of V(t) is given by:

$$\dot{V} = (d+q)V - [paS\ell + (1-\ell)w] \qquad (1.39)$$

[36] See for example Clark (1990) for stability of the unconstrained first best and Brander and Taylor (1997) for an examination of stability in the open access case.

At the constrained steady state the incentive constraint binds with equality and we can use (1.11) and (1.33) to solve for *l(t)*. Using this solution for *l(t)* in the differential equations for V(t) and S(t) yields a standard two equation system suitable for examination with planar methods.

$$\dot{V} = (d+q+r)V - pa\,S - r/(d+q)$$
$$\dot{S} = rS(1-S/K) - a\,NS\left[\frac{1-r[V-1/(d+q)]}{pa\,S-w}\right]$$

V(t) is a jump variable as it is an asset price, while S(t) moves slowly. Setting both time derivatives to zero and solving yields our steady state solutions for V and S. It is now easy to establish that the limited property rights steady state exhibits saddle path stability.

7.4 Proofs of Propositions

Proof of Proposition 1. In a steady state, all time derivatives are zero; therefore the optimal choice for L* must satisfy (1.16) in the text. That is, it must satisfy:

$$L^* \geq \min\left[L^O, L^C\right] \text{ where } L^C \equiv \left[\frac{d+q}{d+q+r}\right]N \text{ and } L^O \equiv (r/a)\left[1-w/paK\right]. \qquad (1.40)$$

There are only three possibilities. Two of these arise when (1.16) holds as an equality. In this case L* equals either L^C or L^O. The other possibility occurs when (1.16) holds as a strict inequality. When this is true, L* can be found by solving the manager's problem ignoring (1.11). This problem is given by

$$\underset{\{L_H\}}{Max}\ SW(t) = N\int_t^{\infty} U(R(t))e^{-d(t-t)}dt$$
$$\text{subject to:}$$
$$R = I/Nb(p) \quad I = pH + M \quad H = aL_H S \quad M = L_M \qquad (1.41)$$
$$L_M + L_H = N \quad \frac{dS}{dt} = rS(1-S/K) - H$$

The current value Hamiltonian for this problem is:

$$H = U\left(\frac{[paS-1]L_H + N}{b(p)}\right) + j\,[G(S) - aL_H S]. \tag{1.42}$$

The first order necessary conditions are given by:

$$\begin{aligned} &Max_{L_H}\{H\} \\ &-\frac{\partial H}{\partial S} = \dot{j} - l\,j \\ &\frac{\partial H}{\partial j} = \frac{dS}{dt} \\ &\lim_{t\to\infty} j\,e^{-dt} S = 0 \end{aligned} \tag{1.43}$$

The Hamiltonian is linear in the control and hence our use of the Max operator. We assumed $L_H = N$ will drive the resource to extinction because $N > r/\alpha$. As well, $L_H = 0$ is inconsistent with meeting the incentive constraint in steady state. Hence, any steady state solution must be interior if p is finite – which we assume. Setting time derivatives to zero and manipulating yields:

$$d = G'(S) + \frac{aL_H}{paS - w} \tag{1.44}$$

$$L_H = \frac{r}{a}(1 - S/K) \tag{1.45}$$

(1.44) and (1.45) solve for L_H and S. Equation (1.45) 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 (1.44) 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 $L_H = ((\delta+r)/\alpha)(p\alpha K-1) > 0$. Therefore a solution exists with L_H non-negative. It is unique. Straightforward differentiation of (1.44) and (1.45) show $dL_H/dp > 0$ and $dS/dp < 0$.

Proof of Proposition 2. To show that a *Hardin economy* always exhibits open access in steady state, note from (1.16) that this requires $L^O \le L^C$ for any finite p. To prove this, note that L^O is increasing in p, and as p approaches infinity, L^O approaches its maximum r/α. Hence when (1.26), holds we have $L^O \le L^C$ for any finite p as required.

Proof of Proposition 3 Define

$$p^{+} = 1/aS \text{ where } S = K\left[1 - \frac{aL^{C}}{r}\right] \tag{1.46}$$

This is the price at which the open access labor allocation is $L^O = L^C$. We have already established that L^O is an increasing function of p bounded below by zero and above by r/α. Hence for $p \leq p^+$, we have $L^O \leq L^C$ and *de facto* open access is the steady state outcome. For $p > p^+$, $L^C < L^O$ and the planner can do better than open access. The first best level of labor and resource stock, which we denote L^B and S^B are defined implicitly by (1.44) and (1.45). We now show that for any p, we must have $L^B < L^C$ if (1.29) is satisfied. To do so, note L^B is increasing in p and that

$$\lim_{p\to\infty} L^{B}(p) = \frac{d+r}{2a}$$

provided $S^B > 0$. But S^B is decreasing in p, and as p goes to infinity, we have $\delta = G'(S^B)$. Because $G'(0) = r$, to ensure $S^B > 0$, it is sufficient that $\delta < r$, which must hold if (1.29) is satisfied. Since $L^B < L^C$ for any finite p if (1.30) is satisfied, we conclude that the unconstrained first best labor allocation is not feasible, and so the best the planner can do is to set $L^* = L^C$ in the steady state for all $p > p^+$.

Proof of Proposition 4. Define p^+ as in the proof of Prop. 3, except now L^C satisfies (1.29). Then for $p < p^+$, we have de facto open access by the same argument as above. Note $L^B(p^+) < L^0(p^+) = L^C$. Next, define p^{++} such that $L^B(p^{++}) = L^C$. From the proof of Proposition 3 note that as p goes to infinity, $L^B = (r+\delta)/2\alpha$ and a positive steady state stock S^B exists. Since $L^C < (r+\delta)/2\alpha$ if (1.30) holds, such a p^{++} must exist. Since L^B is increasing in p, we have $p^{++} > p^+$. For $p \in [p^+, p^{++}]$, we have $L^B(p^+) \leq L^C$, and hence the incentive constraint binds. Hence the regulator sets $L^* = L^C$ for p in this range. For $p > p^{++}$, we have $L^B > L^C$, and hence the incentive constraint does not bind and so the regulator sets $L^* = L^B$.

Proof of Proposition 5. If all categories of countries exist and we are considering $p > 1/\alpha K$, then we know that for any admissible p, *Hardin economies* have open access; and from Propositions 3 and 4 we know that Ostrom and Clark exhibit open access for prices below p^+_{II} and p^+_{III} respectively. Note $L^O(p)$ is increasing in p for any category of country. Then choose $p^{low} = \min [p^+_{II}, p^+_{III}]$. If this min is p^+_{II}, then we have $L^O(p^+_{II}) < L^O(p^+_{III}) = L^C_{III}$ and the Clark economy must have open access as well. If this min is p^+_{III}, then $L^O(p^+_{III}) < L^O(p^+_{II}) = L^C_{II}$ and the *Ostrom economy* must have open access as well. There exists such a p^{low} since some rents are possible in the resource i.e. $p > 1/\alpha K$. Let $p^{high} = \max[p^+_{II}, p^+_{III}]$. By definition, and the results of Proposition 4, p^{low} is less than p^{high}. p^{high} exists since both transition prices exist and are finite. Note if the max is p^+_{II}, then $L^B(p^+_{II}) > L^B(p^+_{III})$ for the Clark economy since L^B is increasing in p for all categories. Therefore, the *Ostrom economy* has limited management and the Clark economy has full rent maximization. If the max is p^+_{III}, then $L^O(p^+_{III}) > L^O(p^+_{II})$ for the *Ostrom economy* since L^O is increasing in p for all categories. Therefore, the *Ostrom economy* has limited management and the Clark economy has full rent maximization.

Proof of Proposition 6. Because of homothetic preferences, steady state real income is:

$$I = \frac{w + gpH(L_H) - wL_H}{b(gp)} = \frac{1 + p(gp, L_H)}{b(gp)}, \tag{1.47}$$

where π is steady state resource rents measured in terms of the numeraire, w=1 because we assume that parmeters are such that the economy is always diversified in production, and β is a price index increasing in p.

1. In a Hardin economy, $\pi = 0$, and so an increase in γ reduces I.

2 (a). for $\gamma p \geq p^+$ in a Clark or Ostrom economy then either the incentive constraint binds or the first best is obtained. Since I has the properties of an indirect utility function, we can use Roy's identity to obtain:

$$dI = \frac{pXdg - p_{L_H} dL_H}{b(gp)} \tag{1.48}$$

where X is exports of H. If the constraint binds, $dL_H = 0$ and so $dI/d\gamma > 0$. If the

constraint does not bind then $p_{L_H} = 0$, since rent is maximized, and so again $dI/d\gamma > 0$.

2. (b) If $\gamma p < p^+$ then $\pi = 0$, and so from (1.47), $dI/d\gamma < 0$. If $\gamma p < p^+$ but $\gamma_1 p > p^+$, then the change in γ 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 $I(\gamma p) \leq I^*(\gamma p) < I^*(\gamma_1 p)$, where I^* is first best real income and the second inequality follows since I^* is increasing in γ as shown in 2(a) above. If constrained management obtains, then the result follows since real income increases in γ without bound for given L_H.

3. Follows from the same argument in the first part of 2 (b) above.

Proof of Proposition 7. To prove the result on comparative advantage we need only to compare relative supplies. Relative supply is given in (1.32). To compare relative supplies first consider prices $p < p+$. When prices are this low both countries are in open access and $p\alpha S = w$. Use this relationship to substitute for αS, and find we require: $L^H/(N-L^H) < L^K/(N-L^K)$ where L^K is the labor in the Clark economy and L^H is the labor in the Hardin economy and we have suppressed their dependence on p. This condition is necessarily met if $L^K > L^H$, which from (1.20) holds since $r^K > r^H$ by assumption. Next consider $p{+}{+} \geq p \geq p+$, then we must prove that $wL^H/(N-L^H)p < \alpha S^K L^K/(N-L^K)$ where we have used $p\alpha S = w$ in the Hardin economy's relative supply. Note that $p\alpha S^K \geq w$ in the Clark economy for prices in this range, and hence the condition is again necessarily met if $L^K > L^H$. Over this range of prices this requires $L^H = (r^H/\alpha)[1-1/p\alpha K] < L^C = L^K$ since the Clark economy is constrained by the incentive constraint. This inequality is met for all prices, by the definition of a Hardin economy. Finally consider $p > p{+}{+}$. Following identical steps a sufficient condition becomes $L^K > L^H$ over this range of prices. But $L^K > L^C$ when $p > p{+}{+}$ and we have already shown that $L^C > L^H$. This completes the proof that the relative supply of the Clark economy lies everywhere outside that of the Hardin economy. Finally, consider real income. When $p < p+$, rents are zero in both countries, and real income is the same. When $p > p+$, rents are positive in the Clark economy and its real income must be greater.

Proof of Proposition 8. Let $\mu > 1$ index neutral technological progress. Then the incentive constraint in steady state (1.14) becomes $l^* \geq (\theta+\delta)/(\theta+\delta+\rho\mu)$. Hardin economies satisfy: $(\theta+\delta)/(\theta+\delta+\rho\mu) \geq r/(\alpha\mu N)$, which is equivalent to: $(\theta+\delta)/[((\theta+\delta)/\mu)+\rho) \geq r/\alpha N$. Increases in μ make this condition harder to satisfy. This proves (i). To prove (ii), take any economy that is not a Hardin economy to begin with. This economy must satisfy $l^* \geq (\theta+\delta)/(\theta+\delta+\rho\mu)$. Note how l^* goes to zero as μ goes to infinity, indicating that individual allocations shrink towards zero with technological progress. To determine whether this economy will ever become a Hardin economy we need to know whether there exists μ such that $(\theta+\delta)/[((\theta+\delta)/\mu)+\rho) \geq r/\alpha N$. Let μ goes to infinity. In the limit we need to ask whether $(\theta+\delta)/\rho > r/\alpha N$ is true. If it is, then all economies become Hardin economies when neutral technological progress is large enough.

8. References

Baland, J.M. and J.P. Platteau, *Halting Degradation of Natural Resources: Is there a role for Rural Communities?*, Clarendon Press, Oxford U.K. 1996

Barbier, E.B. and J.K.A. Benhim, "The Effects of Structural Adjustment Program on Deforestation in Ghana", *Agriculture and Resource Economics Review*, 30/1, April 2001, 66-80.

Barbier, E. B. "Institutional Constraints and Deforestation: An Application to Mexico", *Economic Inquiry*, vol. 40, No. 3, July 2002, 508-519.

Barbier, E. "Habitat loss linkages and mangrove loss in Thailand", *Contemporary Economic Policy*, Vol. 21, No. 1, Jan 2003, 59-77.

Besley, T. "Property Rights and Investment Incentives: Theory and Evidence from Ghana", *Journal of Political Economy*, 1995, Vol. 103, No. 5.

Blanchard, O., "Debts, Deficits, and Finite Horizons", *Journal of Political Economy* 93, 2 (April), 223-247.

Brander J.A. and M.S. Taylor, "International Trade and Open Access Renewable Resources: The Small Open Economy Case○, *Canadian Journal of Economics*, Vol. 30, No. 3 (August 1997a), 526-552.

Brander J.A. and M.S. Taylor, ○International Trade between Consumer and Conservationist Countries○, *Resource and Energy Economics*, Vol. 19, (May 1997b), 267-297.

Calvo, G. and M. Obstfeld, "Optimal Time-Consistent Fiscal Policy with Finite Lifetimes", *Econometrica*, Vol. 56, No. 2, March 1988, 411-432.

Clark, C. *Mathematical bioeconomics: the optimal management of of renewable resources,* 2nd. Edition, New York: Wiley, 1990.

Chichilnisky, G. "North-South Trade and the Global environment", *American Economic Review*, 84, 851-874.

Cohen, J. S. and M. L. Weitzman (1975). "A Marxian Model of Enclosures." *Journal of Development Economics,* 1: 287-336.

Deacon, R.T. "Deforestation and the Rule of Law in a Cross-Section of Countries" *Land Economics,* November 1994, 70(4): 414-430.

Hardin, G., "The Tragedy of the Commons," *Science*, 162(1968):1243-1248.

Hotte, L, Van Long N. and Tian, H.L, "International trade with endogenous enforcement of property rights", *Journal of Development Economics*, Vol. 62, No. 1, (2000), 25-54.

Kemp, Murray C. and Ngo Van Long, "The Role of Natural Resources in Trade Models", Chapter 8 in R.W. Jones and P.B. Kenen,eds.,*Handbook of International Economics*, Volume 1, North Holland, Amsterdam (1984).

Margolis, M. "Unprotected Resources and Voracious World Markets", mimeo, Department of Economics and Finance, University of Wyoming, (2001).

Mason, C.F, and Polasky S., "Entry Deterrence in the Commons", *International Economic Review*, Vol. 35, No. 2, (1994), 507-525.

McCarthy N., Sadoulet E. de Janvry A, "Common pool resource appropriation under costly cooperation", *Journal of Environmental Economics and Management,* Vol. 43, No. 3, (2001), 297-309.

Ostrom, E. *Governing the commons: The evolution of institutions for collective action*, Cambridge University Press, 1990.

Ostrom, E. "Collective Action and the Evolution of Social Norms", *Journal of Economic Perspectives,* Vol. 14, No. 3, (2000), 137-158.

Place, F. and K. Otsuka, "Population, Tenure and Natural Resource Management: The Case of Customary Land Area in Malawi", *Journal of Environmental Economics and Management*, 41, 13-32 (2001).

Schaefer, M.B. "Some considerations of Population dynamics and economics in relation to the management of marine fisheries", *Journal of Fisheries Research Board of Canada,* 1957, 14, 669-681.

Seabright, P. "Managing Local Commons – Theoretical issues in incentive design", *Journal of Economic Perspectives*, Vol. 7, No. 4, (1993), 113-134.

Shapiro, C. and J. Stiglitz, "Equilibrium Unemployment as a Worker Discipline Device**",** The *American Economic Review*, Vol. 74, No. 3. (Jun., 1984), pp. 433-444.

Weitzman, M.L. 1974. "Free access vs. private ownership as alternative systems for managing common property", *Journal of Economic Theory*, 8:225-234