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) that divide the world's set of resource rich countries into three categories. Category I countries will never be able to effectively manage their renewable resources. Category II countries exhibit *de facto* open access for low resource prices, but can maintain a limited form of resource management at higher prices. Category III countries can implement fully efficient management and obtain the unconstrained first best outcome for some range of resource prices. For Category III countries *de facto* open access and the limited management are but transitory phases they pass through

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1. Introduction

Concern over the sustainability of major renewable resource stocks has emerged as a significant international policy issue. There have been widely publicized claims that forests in countries such as Brazil, Canada and Indonesia are being harvested excessively, and other renewable resources, including fish, wildlife stocks and the biosphere, are also alleged to be under threat. There is now considerable interest in incorporating trade rules focused on resource management into the World Trade Organization (WTO) and other international arrangements. Since natural resources and their raw material products constitute a significant fraction of merchandise exports for much of the developing world, this is a potentially serious matter.[1] Unfortunately there is at present a large gap between what we know about the relationship between international trade and renewable resource management, and what we would need to know to evaluate policy proposals, design new international treaties, or amend WTO obligations.

The purpose of this paper is to take a first step towards a better understanding of the impact of international trade on renewable resource use by developing 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.[2] Not all countries can follow this path of institutional reform and we identify key country characteristics (mortality rates, resource growth rates, technology) that divide the world's set of resource rich countries into three categories.

Category I countries will never be able to develop control over access to their renewable resources. These are countries with large numbers of agents who have access to the resource,

[1] For example, in 1995 raw materials represented 73% of merchandise exports for Argentina, 55% for Brazil, 75% for Columbia, 39% for India, 22% for the Phillipines, and 95% for Zambia, etc. See Table 1.1 in Ascher (1999) for a list of these figures for over 30 countries. Raw material exports does include some non-renewables, but the property rights issues raised here are relevant to non-renewables as well. Since the proper management and exploitation of these resources must play an important role in their development and growth, it is important to understand how access to international markets affects resource management.
[2] It has been well established (starting with the classic paper by Gordon (1954)) that resource over-exploitation may occur when a common property resource is subject to no control on entry or harvesting efforts. "Open access" refers to this no-controls case.

short life spans, resources with a low intrinsic growth rate, and a poor monitoring technology. Category II countries exhibit open access for low resource prices, but can maintain a more limited form of resource management at higher prices. Category III countries are those for which the first best can be obtained. For Category III countries open access and limited management are but transitory phases they pass through.

The model we develop has 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. Second, we use a general equilibrium model because one of the major effects of trade liberalization can be the reallocation of workers across sectors. And third, we explicitly model the incentives of individual resource harvesters to comply with attempts by a regulator to manage the resource.

We adopt a relatively simple renewable resource model taken from Brander and Taylor (1997). There are two sectors: resource harvesting and manufacturing; and there is a group of agents who have the right to access the commons and harvest the resource. Agents choose how to allocate their time across the two activities. If harvesting in the commons is not regulated, then rents in the resource sector will be dissipated and the resource stock will be depleted. The government can manage the resource by limiting the time that agents can spend harvesting. However, there is imperfect monitoring and so cheating may occur. If cheating is excessive, the management system collapses. The resource manager's problem is modeled in much the same way as an efficiency wage problem. The resource manager allows agents to earn rents, but punishes those caught cheating by denying them further access to the commons. Agents then compare the short-term benefits of excessive harvesting with the long term risks of losing access to a flow of resource rents. Throughout, we focus on the link between country characteristics and management regimes in steady state. An examination of the transition between regimes is studied in a companion paper.[3]

Previous work on this issue has concluded that the effect of trade depends on how well

[3] See "Transition, Reform and Collapse: the Creation and Destruction of Property Rights Institutions", Copeland and Taylor (in process).

resources are managed. If property rights are fully assigned and perfectly enforced, then there are no market failures, and so the usual gains from trade results apply.[4] Trade may lead to resource depletion, but only if such depletion is efficient. On the other hand, if there is complete open access in the renewable resource sector, then trade liberalization can be devastating to both resource stocks and real incomes in resource-exporting countries.[5]

While this work has led to some important insights, its major weakness is that the policy regime is taken to be exogenous. As a result, a change in prices or market size brought about by international trade cannot alter the efficacy of policy. This exogeneity limits the ability of the existing theoretical literature to be a guide for current policy debates, or a stepping-stone to empirical work.

As Ostrom (1990), Baland and Platteau (1996) and others have documented, the success of resource management regimes varies both across communities and over time. A change in the trade regime may therefore be expected to alter the efficacy of the resource management regime. Some have argued that access to international markets may disrupt traditional norms that have supported resource management and possibly lead to a collapse of the management regime. Others, such as Demsetz (1967) have argued that resources will be better managed when they become more valuable, and hence this raises the possibility that a trade-induced increase in resource prices could lead to the emergence of better management.

An approach where the strength of regulation is endogenous has a number of advantages. It allows us to develop an understanding of the characteristics that determine whether trade liberalization will allow a country to improve its resource management, and the circumstances under which existing management regimes may lose their viability. Recent work on trade and the environment suggests that the endogeneity of policy is very important in explaining how environmental quality responds to trade. Many researchers have found a strong relationship between income gains and tighter pollution regulation; and this evidence is highly suggestive of a

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[4] 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 in the Handbook of International Economics, Vol I. (1984).

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

strong link between trade-inspired income gains and endogenous changes in regulation.[6] If a similar effect is present for renewable resources, then assuming policy is unresponsive to these income gains may yield misleading results.

As well, a model with endogenous management will allow us to draw a much needed distinction between the impact of a change in world prices brought about by trade and the impact of a whole set of other possible changes brought about by "market integration". Our model predicts that increases in resource prices tend to improve the viability of resource management in some countries. However, market integration can also mean access to new goods, improved technologies or more attractive outside options for those working in the resource sector; and in our model these changes tend to weaken the viability of resource management. This suggests that the debate over the effect of globalization on renewable resource use can only be answered by careful empirical work isolating the role of price changes from other confounding influences.

Finally by employing an explicit resource model we produce insights not found in related literatures in industrial organization, trade theory etc. For example, in contrast with typical intuition we show how *higher discount rates* can lead to equilibrium outcomes where effective property rights are stronger and resource management closer to the first-best. We also find that while giving agents better harvesting technologies raises their temptation to cheat because it is now more productive; in equilibrium the outcome can be quite different. Better technologies can instead bring forth a limited management regime and positive resource rents in situations that were previously open access. These two results follow from features of the model directly linked to its renewable resource structure.

There have been some previous papers investigating endogenous regulation in the context of renewable resources. There are many papers on enclosure, some of which discuss incentive schemes to limit over-grazing in 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)).

[6] See Pargal et al. (1996), Grossman and Krueger (1995) and Antweiler, et al. (2001).

Hotte et al. (2000) is the closest to our work because it examines the implications of international trade for renewable resources. They develop a model of poaching from a renewable resource stock where the incumbent owners allocate effort to building fences to enforce property rights. Poachers are static optimizers, there are no punishments for poaching and no monitoring occurs. The main result of the paper is that free trade may be welfare-reducing even when the level of enforcement is affected by trade. While this immizerizing trade result is of some interest, the paper does not shed light on the conditions determining when free trade may lead to better or worse resource management; nor does it allow for an examination of how discount rates, the size of punishments, and improvements in monitoring technology may affect the consequences of freer trade.

The rest of the paper is organized as follows. In Section 2, we set out the model. In section 3 we examine the steady state equilibrium of the model, define our categories of countries, and link management regimes to world prices, population size, mortality, resource growth rates, etc. In Section 4, we consider the effect of trade liberalization. Section 5 concludes. An appendix contains all 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 (such as a fish or forest stock) held in common by all agents.[7] Agents are endowed with one unit of labor per unit time. Labor may be allocated to either harvesting from the renewable resource or production of an outside good (manufactures).

[7] We assume that outsiders can be costlessly excluded from access to the resource. We also assume that agents with rights to the resource cannot credibly commit to renounce those rights (perhaps in return for a payment). In practice, excluding outsiders can be difficult, and this has been explored in poaching models. Expanding the model in this direction may lead to important insights but we leave it to future work.

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 subject to 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 sector, 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:

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

where δ is the pure rate of time preference. In writing (1.1) we have exploited the fact that when 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} = 1-F(t) and 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, the government's regulations, and the benefits and costs of complying with the 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 model for harvesting we have:[8]

$$H = \alpha L_h S \tag{1.3}$$

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 the incentives for over harvesting by agents. Each agent is allocated a fixed amount of harvesting time to exploit the commons.[9] The government monitors compliance with this rule, and agents

[8] See Schaefer (1957).

[9] 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 as the regulators choice variable since this is the most common form of

who cheat are detected with probability ρdt. If the agent follows the rules or is not caught cheating, then he or she can keep all of the harvest produced. On the other hand, an agent caught cheating is subject to a penalty. We assume that the maximum penalty available to the resource manager is to terminate the agent's right of access to the resource. 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.[10]

The mechanism that deters cheating here is similar to that at work in an efficiency wage model.[11] 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. The resource managers can at least partially alter the size of available rents by increasing or decreasing harvesting as this drives changes in the resource stock and harvesting productivity.

Denote the relative price of the harvest by p, and denote by $l^* \leq 1$ the amount of labor time an individual is authorized to allocate to harvesting. An agent who complies with the rules obtains a harvest equal in value to:

$$ph^* = p\alpha l^* S \, , \tag{1.6}$$

and, in addition, earns an income of (1-l*)w in the manufacturing sector. On the other hand, an individual who cheats will allocate all of his or her effort to harvesting the resource, yielding a harvest in the current period with value:

$$ph^c = p\alpha S \tag{1.7}$$

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regulation.

[10] 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.

[11] See Shapiro and Stiglitz (1984).

If the agent is caught cheating (which occurs with probability ρdt), then he loses access to the resource stock and must work full time in the manufacturing sector earning a return of w.

The decision to cheat is an investment decision. Since the agent is risk neutral, and prices are fixed in our small open economy, this decision will rest on a comparison of the expected present discounted value of the income stream earned by each activity. To render this decision interesting, we assume it is not desirable for agents to produce only manufactures in steady state.[12]

Let V^C represent the expected present discounted value of the income stream of an agent who is currently cheating. Let V^{NC} be defined similarly for an agent who is not cheating, and let $V^R(t)$ be the max over these two options at time t. An agent who can work only in the manufacturing sector has an discounted income stream given by $V^M(t)$. Consider the returns to cheating over some small time interval dt. The agent earns the cheating level of harvest, $ph^c dt$. If the agent is caught cheating (which occurs with probability ρdt), he loses access to the resource and achieves a continuation value of $V^M(t+dt)$. With probability $1-\rho dt$, the villager is not caught and remains in the industry. In this case the villager 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 moreover the agent dies over the interval, with probability θdt. The expected present discounted value of being in the resource sector and cheating at time t, $V^C(t)$, can be written as:

$$V^C(t) = ph^c dt + [1 - d dt][1 - q dt]\Big[r\, dt V^M(t + dt) + [1 - r\, dt]V^R(t + dt)\Big], \qquad (1.8)$$

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

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

$$V^{NC}(t) = [ph^* + (1 - l^*)w]dt + [1 - d dt][1 - q dt]\Big[V^R(t + dt)\Big], \qquad (1.9)$$

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[12] This requires p be sufficiently high (i.e. p>w/αK) so that resource harvesting is lucrative. Agents may find it advantageous to specialize in manufacturing during the transition between steady states.

The value of being in resource sector at time t is given by the maximum over the cheating and not cheating options. That is:

$$V^R(t) = \max[V^{NC}(t), V^C(t)]\,. \tag{1.10}$$

To simplify first assume $V^C(t)$ is the maximum in (1.10). Then equate $V^R(t)$ to the right hand side of (1.8) to find the value of being in the resource industry under this assumption. To simplify, use the Taylor series approximations:

$$\begin{aligned} V^R(t+dt) &\approx V^R(t) + \dot{V}^R(t)dt \\ V^M(t+dt) &\approx V^M(t) + \dot{V}^M(t)dt \end{aligned}\,, \tag{1.11}$$

cancel common terms, and let dt approach zero. To find the prospective value of the not-cheating option, assume $V^{NC}(t)$ is the maximum in (1.10) and follow a similar procedure.[13] Finally, substitute these values into (1.10) to find:

$$V^R(t) = \max\left[\frac{ph^* + (1-l^*)w + \dot{V}^R(t)}{d+q}, \frac{ph^c + rV^M(t) + \dot{V}^R(t)}{d+q+r}\right]. \tag{1.12}$$

The agent will not cheat at time t when the first argument in (1.12) exceeds the second. Manipulating this condition yields:

$$\left(\frac{r}{d+q}\right)\left[ph^* + (1-l^*)w + \dot{V}^R - w\right] \geq \left[ph^c - [ph^* + (1-l^*)w]\right]. \tag{1.13}$$

The right hand side is the flow benefit of cheating. This is simply the difference between the flow rewards under the two options. The left hand side is the expected present discounted value of the penalty to cheating. An agent who cheats loses his share of resource rents (and capital gains) with probability ρdt. Therefore the left hand side of (1.13) is the expected present discounted value of the penalty to cheating. To prevent cheating, the resource manager must

[13] A complete derivation of (1.12) is in the appendix.

choose l*(t) to ensure this constraint is met at all times.

It is useful to rearrange the incentive constraint to highlight the role played by resource rents. To do so, let $\Pi^* = H^*-L^*[w/p]$ be the aggregate resource rents when the rules are followed, where H*=Nh* and L*=Nl*. Then rearrange (1.13) to write the incentive constraint as:

$$\frac{\Pi}{N} + \dot{V}^R / p \geq \left[\frac{d+q}{d+q+r}\right]\left[[h^c - w/p] + \dot{V}^R / p\right] \tag{1.14}$$

which says that current plus future expected rents per agent must be sufficiently high for the incentive constraint to be met. Rents are composed of both current period returns measured in terms of the harvest good, Π/N, but also capital gains reflecting expectations regarding future returns in the harvesting sector.

In steady state there are no ongoing capital gains or losses. This implies $\dot{V}^R$ in (1.14) is zero, and it simplifies to:

$$\frac{\Pi}{N} \geq \left[\frac{d+q}{d+q+r}\right][h^c - w/p] \tag{1.15}$$

To determine the implications of this constraint for the harvesting regulations, use (1.6), (1.7) and the definition of rents to write (1.15) as:

$$L^*[p\alpha S - w] \geq \left[\frac{d+q}{d+q+r}\right]N[p\alpha S - w] \tag{1.16}$$

This constraint can be met in one of two ways. First, if resource rents are positive, then $p\alpha S - w > 0$ and in this case (1.16) requires:

$$l^* = \frac{L^*}{N} \geq \left[\frac{d+q}{d+q+r}\right] \tag{1.17}$$

The fraction of time each agent spends exploiting the resource has to exceed some threshold for the incentive constraint to hold. A greater time allocation satisfies the incentive constraint by reducing the gap between the allowed and cheating effort levels, and by reducing the productivity of cheating by lowering the resource stock. Using (1.6) and (1.2) it is easy to show the steady state resource stock is a monotonically declining function of L*. Therefore raising L*, lowers the productivity of effort given (1.7). The threshold itself reflects impatience, the expected lifetime of agents (which is $1/\theta$) and the probability of being caught.

An alternate solution occurs when L* specified in (1.17) is inconsistent with positive rents in the resource sector. We need to ensure that L* does not exceed the open access level of labor since this level eliminates all rents leading to the equality $p\alpha S = w$. Setting unit labor costs equal to the resource price, and solving for the open access level of labor, L^0, we find:

$$L^0 = (r/\alpha)\left[1 - w/p\alpha K\right]. \tag{1.18}$$

Taking this qualification into account, the incentive constraint is met, in steady state, when:

$$L^* \geq \min\left[L^0, L^C\right], L^C \equiv \left(\frac{\delta + \theta}{\delta + \theta + r}\right)N \tag{1.19}$$

Although the aggregate allocation of labor to the resource stock must be below L^0 to generate resource rents, this may not always be consistent with the incentive constraint. In some cases, the manager will not be able to do better than simply allowing agents to harvest all they want, producing a situation we refer to as *de facto* open access. Therefore, the management regime is flexible, reflecting resource conditions and the realities of imperfect monitoring and self-interested behavior.

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 assume that the regulator maximizes a utilitarian objective function developed by Calvo and Obstfeld (1988) that aggregates across the utility levels of representative agents from different generations and leads to time-consistent optimal plans.

Let λ denote the rate at which the regulator discounts the utility of future generations. Recall the size of each new cohort is θN. In this situation, Calvo and Obstfeld's objective function yields social welfare at time t=0 given by:

$$\begin{aligned} SW &= \int_0^{\infty}\left\{\int_v^{\infty} U(R(t))e^{-(\theta+\delta)(t-v)}dt\right\}\theta N e^{-\lambda v}dv \\ &+ \int_{-\infty}^{0}\left\{\int_0^{\infty} U(R(t))e^{-(\theta+\delta)(t-v)}dt\right\}\theta N e^{-\lambda v}dv \end{aligned} \tag{1.20}$$

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.[14]

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 (1.20) 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:

[14] We are weighing each generation similarly over time, despite the fact the size of any generation is falling exponentially at rate θ with time. This implies that the objective function is taking generations as the unit of account to weigh equally in utility. If we adopt a stricter utilitarian interpretation where social welfare is written over an equally weighted sum of individual's utility, then we need to account for the size of the surviving population from vintage v at time t. This adds to the complexity of the expression but in the end only adds a constant to our welfare function.

$$
\begin{aligned}
SW &= \int_0^{\infty} U(R(t)) \left\{ \int_{-\infty}^{t} Nq \bullet e^{-(q+d-l)(t-v)} dv \right\} e^{-lt} dt \\
&= \left[\frac{Nq}{q+d-l} \right] \int_0^{\infty} U(R(t)) e^{-lt} dt, q+d > l
\end{aligned}
\qquad . \qquad (1.21)
$$

where $q + d > l$ is required for the integral in (1.21) to be well defined. It is apparent from (1.21) that the individual specific risk of death, θ, only appears as a constant in the expression leaving utility flows discounted by the planner's pure rate of time preference. This implies social welfare is proportional to the utility of a hypothetical infinitely lived representative agent with real income path R(t). This feature simplifies the planning problem tremendously despite the generational structure and allows us to consider the very useful simplifying case where the planner's discount rate approaches zero but agents remain impatient.

The resource manager maximizes (1.21) by choosing a ceiling $l^*(t)$ on the amount of labor each agent can allocate to harvesting in each period t, subject to technologies given in (1.3), (1.4), full employment in (1.5), biological growth in (1.2), and the incentive constraint (1.14).

3. The Steady State Economy

The solution to the regulatory problem depends on whether the incentive constraint is binding or not. To determine when, if ever, the incentive constraint binds it is useful to start by considering the three possibilities in steady state. The first occurs when the incentive constraint is not binding. In this case we ignore (1.14) and proceed to solve a standard optimal control problem using L_h as the control. Denote the steady state allocation of labor to harvesting as L* and steady state stock as S*. Then routine calculations show that L* and S* are determined by:[15]

$$
l = G'(S^*) + \frac{aL^*}{paS^* - 1}, \quad S^* = K(1 - \frac{aL^*}{r}), \qquad (1.22)
$$

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

A second possibility is that the incentive constraint binds in steady state, but the resource manager is still able to maintain a degree of protection for the resource. This occurs when the first best labor violates (1.19). Accordingly, agents who cheat would obtain a great windfall. To offset this incentive, the planner distorts the first best allocation and drives the resource stock downwards. When the incentive constraint binds in steady state, (1.15) holds with equality. The steady state harvest must also equal the natural growth and hence using (1.2) and (1.3) we find that in a constrained steady state:

$$L^C = \left(\frac{q+d}{q+r+d} \right) N, \quad S^C = K \left(1 - \frac{a L^C}{r} \right) \tag{1.23}$$

We refer to these solutions as the constrained optimum.

Finally, the manager may have no ability whatsoever to limit resource harvesting. This occurs when the constraint continues to bind as the labor in the resource sector approaches the open access level. In this case, open access obtains and we have:

$$L^O = \frac{r}{a} \left(1 - \frac{1}{paK} \right), \quad S^O = K \left(1 - \frac{a L^O}{r} \right) \tag{1.24}$$

Since these are the only possible steady state solutions, 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.

3.1 The Infinitely Patient Regulator

[15] See the appendix for a derivation.

To examine which of the three possibilities emerges in any given situation it is useful to consider the limiting case where the government's discount rate λ approaches zero. We can employ (1.22) to show that S* is always falling in λ. Therefore, the stock is at its highest and hence labor in harvesting at its lowest, when λ approaches zero. Moreover, when λ is exactly zero, the solution to (1.22) replicates that of the *static problem* of maximizing resource rents.

This case is simple to present graphically and highlights the role the incentive constraint plays in altering behavior. It does so because when λ approaches zero, the first best solution is the furthest it can be from open access; therefore, if we find a result of *de facto* open access it must arise from the incentive constraint alone and not from impatience on the part of regulators.

When λ approaches zero, the solution to our optimal control problem mimics that of the static problem of maximizing sustainable surplus subject to (1.15). Surplus, in units of the harvest, is given by:

$$\Pi = H(L) - [w / p]L \tag{1.25}$$

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

$$aLS = rS(1 - S / K) \tag{1.26}$$

Solving (1.26) for S as a function of L we obtain:

$$S = K(1 - \frac{aL}{r}) \tag{1.27}$$

Employing (1.27) in (1.6) yields H(L) as follows:

$$H(L) = aLK[1 - aL / r] \tag{1.28}$$

Therefore our possible steady state solutions can be found by maximizing (1.25) subject to (1.15) and (1.28).

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 (1.28). 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 (1.14) (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. Using (1.27) to solve for S, N times the right hand side of (1.14) becomes:

$$N\left[\frac{q+d}{q+d+r}\right][aS(L)-w/p]=N\left[\frac{q+d}{q+d+r}\right][aK-w/p-a^2KL/r] \qquad (1.29)$$

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 the IC constraint 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 (1.19).

3.2 Country Characteristics and the Management Regime

The incentive constraint given in (1.19) relies on a relatively small number of parameters: world prices, population size, mortality rates, etc. To illustrate how the model works, we start by considering the impact of changes in population size because such changes are often linked to the collapse of informal property rights arrangements and deforestation.[16]

The harvest function H(L), the sustainable rent locus and the rent-maximizing labor allocation L* are all unaffected by changes in N. The aggregate incentive constraint does, however, depend on N. This is because each individual agent's allocation of harvesting time must satisfy the incentive constraint (1.17). Each additional agent must receive at least this allocation to avoid cheating, and therefore as N rises, the amount of labor the regulator must allow into the resource increases.

Figure 1 illustrates the incentive constraint for a relatively low level of N. The incentive constraint curve IC does not bind and the regulator chooses the rent-maximizing labor allocation L*. As N rises, the incentive constraint rotates downwards. 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*. From (1.27), it is apparent that this leads to a decline in the resource stock. Finally, 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:

$$N\left[\frac{q+d}{q+d+r}\right] \geq \frac{r}{a}\left[1-\frac{w}{pa\,K}\right]. \tag{1.30}$$

Note that the right hand side of (1.30) is positive for any resource capable of generating rents.[17] Our model thus predicts that when the population is small, rent-generating resource

[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] If the right hand side of this equation were negative, no agent would have an incentive to harvest at all, and restricting access would not be a concern. For the resource to generate rents, the value of the marginal product of labor must exceed the wage. Using (1.3), this requires $p\alpha S > w$ for some S, and since S cannot exceed K, we require $p\alpha K > w$.

management is possible; but for high levels of population, the resource will be subject to open access and not protected. From (1.30), the threshold population at which open access prevails depends on the market price, the biology of the resource, the monitoring technology and discount rates. For example, even in small communities (with low N), a resource will be unmanageable if its intrinsic growth rate (r) is sufficiently low.

3.3 From Open Access to the First Best

Our primary interest is in how developing countries may adjust their resource management practices with greater access to international markets. Greater access to international markets or "market integration" can mean many different things, including changes in relative goods prices, the possibility of technology transfer, and factor mobility. However, since relative price changes are a key aspect of trade liberalization, we start by examining how the management regime in our model responds to changes in goods prices.

First, note that an increase in the relative price of the resource makes it easier for the resource manager to sustain at least some rent in the resource. That is, increases in p make it more likely that (1.30) is satisfied (assuming for now that it can be satisfied at all). The reason for this is that at higher prices, the resource is capable of sustaining rents even with relatively high allocations of labor to harvesting. Since the incentive constraint places a lower bound on the amount of labor that each agent must be allowed to devote to harvesting, a higher price makes it more likely that rent-sustaining allocations can be supported.

There are however some economies that 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 (1.30) as:

$$\left[\frac{q+d}{q+d+r}\right] \geq \frac{r}{aN} \tag{1.31}$$

In countries that satisfy (1.31), the resource manager is not able to restrict access to the resource stock and so open access is always the result. This parameter restriction defines an important category of countries and generalizes to the case where the manager's discount rate λ is positive. We define *Category I* countries as those satisfying (1.31), and we have:

Proposition 2. Category I countries will always exhibit *de facto* open access in steady state. For any finite relative price p of the harvest good, we have $L^*(p) = L^0(p)$ and no rents are earned in the resource sector.

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. Note the definition of Category I countries makes no reference to the social discount rate λ, and hence the patience or impatience of the planner is irrelevant to the definition and also to the result. This is true because when (1.31) holds, the minimum labor allocation needed to meet the incentive constraint, L^C, exceeds the first best choice of labor at any price. Therefore, the preferences of the planner are irrelevant and the incentive constraint fully determines outcomes.

The country and agent characteristics in (1.31) affect either potential rents earned by the resource, r, the sharing of these rents across agents, N, or the benefits and costs of cheating. Cheating is of course more attractive if being caught is less likely and likewise more attractive if expected future punishments are discounted heavily. Surprisingly, a better harvesting technology makes cheating more likely even though it raises potential rents from the resource. It does so because a better harvesting technology typically calls for less and not more labor in the resource sector. This lowers l^* and raises the incentive to cheat.

The condition given in (1.31) guarantees open access as an endogenous outcome rather than an assumption, and hence one justification for the earlier literature's exogenous assumption of open access is that a condition like (1.31) always holds. An advantage of the current framework is that while open access is a necessary outcome for a Category I country, it is not certain outcome for all countries. Consequently for countries other than those in Category I, observing *de facto* open access at one world price may be a poor guide to the management regime at higher world prices.

We now examine the impact of an exogenous increase in the price of the resource good starting from some existing low price for an economy that can maintain some control over its resources. To allow for a possible transition in the enforcement of property rights we must now assume that (1.31) fails. To start, note that for very low resource prices we must obtain the open access equilibrium. By lowering p sufficiently we make the resource sector very unattractive and this lowers $L^O(p)$ making it the minimum in (1.19).

Intuitively, when the price of the resource is very low, rent can be extracted only if agents are required to spend very little time in the resource. But 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. As p rises labor in the resource sector rises and the resource stock falls. Since labor in the resource sector rises monotonically with p, and since we assume (1.31) fails (or else we could never have a transition to even some limited protection for the resource), eventually for some p, which we denote by p+, we will have:

$$L^O(p+) = L^C \tag{1.32}$$

Note, for future reference that p+ is a function of country characteristics. The price increase brought more labor into harvesting, drove down the stock and relaxed the incentive constraint.

Now consider further 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. We call these Category II countries, and they have country characteristics that satisfy:

$$\frac{l + r}{2a} < L^C < \frac{r}{a} \tag{1.33}$$

Note Category II countries can only exist if $\lambda < r$. For Category II countries we find:

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

(i) for $p \le p^+$ 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.

Category II countries 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. It is straightforward to show that the transition price, p^+, is higher in economies with higher populations (N), lower life expectancy (1/θ), with better harvesting technologies, α, and higher rates of time preference, δ; it is lower in economies with a faster growing resource (r), a larger resource base (K), or a greater probability of detecting cheating (ρ).

To understand why the first best cannot be obtained rearrange the first element in (1.22) to stress the role of the resource stock as an asset:

$$l\left[p - 1/aS^*\right] = G'(S^*)\left[p - 1/aS^*\right] - \frac{\partial c^H}{\partial S} H^* \tag{1.34}$$

where $c^H = w/\alpha S$ is the unit cost of harvesting. One unit of the harvest can be sold at price p but costs w/αS to harvest; hence leaving it *in situ* is an investment of potential rents given by p-1/αS that must earn a rate of return of λ. This is the left hand side of (1.34). If left *in situ* the unit of harvest affects natural growth giving it the instantaneous physical marginal product of G'(S*) which has value p-1/αS times this amount. This is the first element on the right hand side. In addition, a greater stock *in situ* lowers harvesting costs by a magnitude given by the last element.

Consider the limiting λ = 0 case. When λ = 0, it is apparent from Figure 1 that the optimal allocation of labor L*(p) must occur at a point to the left of the maximum sustainable yield. Routine calculations show this implies L*(p) < r/2α and S* > K/2. This ensures that G'(S*) < 0 as the right hand of (1.34) has to equal zero. Hence if $L^C > r/2\alpha$, then as p rises above p+ entry into the resource sector is blockaded and labor in the resource industry remains constant.

Rents rise linearly with p. In this situation both the costs and benefits of cheating rise proportionately with p, and the regulatory regime holds labor in harvesting constant to balance these incentives.

When the regulator's discount rate λ is positive, the planner adopts a more aggressive harvesting policy and S* is lowered in order to raise the return on the resource stock. When the resource price rises, L* rises but if $\lambda < r$ the first best level of labor is bounded strictly below the extinction level of labor L^E. If L* is bounded, then from (1.22) S* bounded too and as p approaches infinity (1.22) requires $\lambda = G'(S^*)$. Therefore, there will exist an L^C below the extinction level of labor, that is above the first best; i.e. Category II countries can exist. Moreover, it is now clear that L^C must be higher in situations where λ is higher since optimality requires the planner lower S* to raise the resource's instantaneous marginal product. The restriction $\lambda < r$ is necessary for a Category II country because G'(S) is declining in S, and hence $G'(S^*) = \lambda$ can only be met if $r = G'(0) = \text{Max}\,[G'(S^*)] > \lambda$.

Finally lets turn to examine Category III countries. When the incentive constraint is easier to satisfy full rent maximization at some world price will be possible. We call these countries Category III countries, and they satisfy:

$$0 < L^C \leq \frac{l + r}{2a}, \tag{1.35}$$

When (1.35) holds there exists some higher resource price p++ such that for p > p++, $L^*(p{+}{+}) > L^C$ and the first best rent maximizing solution for L* can be sustained while meeting the incentive constraint. We have already depicted such a solution in Figure 1. Category III countries will exhibit open access and only limited protection for some resource prices, but for sufficiently high prices full rent maximization will result. And hence, for high resource prices Category III countries exhibit "optimal extraction" as in the earlier 1970s and 1980s literature. It is now straightforward to show:

Proposition 4. For every Category III country 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 $L^*(p) = L^0(p)$, 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;

Proof: see Appendix

Putting Proposition 2, 3 and 4 together it is now possible to identify the two roles played by the rate of time preference. On the one hand if agents have a high rate of time preference then expected future punishments are discounted heavily and this raises L^C making the enforcement of property rights difficult. In contrast, a high value for the planner's rate of time preference works to strengthen property rights because optimality calls for a small and very productive stock. A small stock calls for a large allocation of labor to harvesting and this raises l* for all agents. This reduces the incentive to cheat.

To understand which of these incentives dominates, assume $\lambda = \delta$ so social and individual rates of time preference are the same and start with a Category II country.[18] If (1.33) holds at δ close to zero (this is necessary for our country to ever satisfy the Category II definition) then it must fail at δ equal to or exceeding r. Our former Category II country must be reassigned to either Category I or III. It becomes a Category III country if (1.31) fails at $\delta = r$. This in turn means L^C must satisfy:

$$N\left(\frac{d+q}{d+q+r}\right) = L^C < \frac{r}{a},\ \ at\ r = d \qquad (1.36)$$

When (1.36) is true an increase in time preference changes our Category II country into a Category III country. The former can only exhibit limited property rights protection, the latter complete property rights!

When (1.36) fails, our former Category II country becomes a Category I country. No enforcement of property rights is possible. It is clear that (1.36) is true in situations where α is small and r is large. Less productive harvesting helps since this implies the extra time used in cheating is not very valuable in generating rents. It also means more labor is required to maintain

[18] For a Category I country increases in time preference can only reinforce the lack of property rights.

the desired stock level S*. Both work towards the enforcement of property rights. A higher rate of resource growth helps because S* must now be driven down further to equalize rates of return. This in turn requires more labor than previously. It also implies there are greater rents to share across agents. Again both changes alter the balance in favor of the change in time preference working towards stronger property rights.

Category III countries present one further surprising difference in their response to parameter changes. In contrast to earlier results, the transition price p^+ sometimes rises and sometimes falls when the economy obtains better harvesting technology. When the resource is severely depleted prior to a transition, then L^O is relatively large, the resource stock is close to zero and below its maximum sustainable yield level. In this severe overuse case, an improvement in technology leads to less labor being allocated in the open access equilibrium. Therefore to make a transition, a higher price for the resource is necessary to raise open access labor above the constrained level. Therefore a better harvesting technology makes a transition to even limited management more difficult in severely depleted environments. Note that this was always true for a Category II country since $L^C > (r+\lambda)/2\alpha$.

In contrast, when open access is currently leading to mild overuse of the resource then L^O is small and a productivity improvement raises the level of labor employed under open access. With a Category III country it is now possible for $L^C < r/2\alpha$. Therefore, a now lower resource price will suffice to raise open access labor above that needed to generate a transition. Alternatively, it implies that for a given p an improvement in harvesting technology now leads to partial management of the resource whereas before it was open access. This result is in stark contrast with our previous results where an improvement in harvesting technology always worked against the enforcement of property rights. The difference arises because as the open access labor rises, it crosses the threshold of l* so that property rights can be enforced. Even though the productivity of labor has risen, the fraction of time left to cheat has fallen and this makes all the difference.

3.5 An Index of Effective Property Rights

We now illustrate how "effective property rights" vary with the resource good price for all three categories of countries. To create a unit-free measure of effective property rights, we divide the labor that would be employed in the resource sector with full rent maximization by the labor actually employed in the resource sector. Since open access or incomplete property rights brings in more labor than full rent maximization, this ratio is less than one for all partial property rights situations, but equals one when full rent maximization is possible.

Let $L^B(p)$ be the labor employed in the first best maximization solution when there is no incentive constraint. Then our index of effective property rights is given by:

$$EPR = L^B(p) / L^*(p) \tag{1.37}$$

In Figure 3 we have depicted a graph of effective property rights for all categories of countries for the case where λ approaches zero.

First consider Category I countries. These countries have open access for all resource prices, and since $L^* = L^O$ is proportional to L^B (when $\lambda = 0$), EPR does not vary with p and is a horizontal line.

Next consider Category II countries. These are countries for which open access is the outcome for prices less than p_{II}^+, and hence these countries have identical EPR with Category I countries over the [0, p_{II}^+] range. But when prices rise further, labor is held fixed at the corner solution discussed earlier. And since $L^B(p)$ rises with p to reach a maximum at $r/2\alpha$, this ensures the EPR locus for category II countries asymptotes as 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. Consequently, in terms of our EPR metric the corner solution leads to a continuous upgrading of effective protection as resource prices rise.

Finally, consider category III countries. They also have an open access component from

[0, p^+_{III}].[19] From Proposition 4 and the definition of Category III countries we can conclude that this open access portion is shorter than that for Category II countries. As prices rise above p^+_{III} effective property rights start to rise and eventually this country is able to support full rent maximization. At this point, our EPR metric reaches unity and remains there. As a consequence the EPR profile in qualitative terms is that shown in Figure 2.

While we have illustrated this heterogeneity under the assumption that λ approaches zero, the heterogeneity in effective property rights and its link to world prices is quite general. In general we can show:

Proposition 5. Assume countries of type Category I, II and III 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 below this mark, all countries exhibit de facto open access. There also exists a finite $p > p^{high} > p^{low}$ such that at this p 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.

Figure 2 and Proposition 5 are useful in mapping out the relationship between the de facto property rights regime and world prices. By doing so it generates three observations. The first is simply that we should expect heterogeneity across countries in their property rights protection. At a low level of world prices all countries exhibit open access in their resource sectors, but at higher prices only some will. Therefore, even without any allowance for political economy elements or the addition of corruption, we should find a great degree of heterogeneity in property rights protection worldwide. 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.

The second observation comes from the realization that with no regulation in place, all countries – even those that could generate some control over their resources given our mechanism - would be in open access at all world prices. Therefore, the figure illustrates how a (credible)

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

domestic policy reform (starting from a position with no regulation in place) that brings in an element of enforcement and monitoring of resource use will always fail in some countries (Category I) whereas it will be at least partially successful in others (Category II and III). Moreover for both Category II and III 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 may be entirely counterproductive. It may instead be that the higher prices that trade engenders may make viable a previously unviable environmental policy reform.

Finally the figure illustrates that if a trade liberalization affects the prices faced by domestic residents then it can have a large impact on the property rights regime. For example, if a trade liberalization raises the domestic relative price of the resource good – as it would for a resource exporting country with a positive import tariff on manufactures - then we are moving rightwards in the figure and this trade liberalization tends to strengthen property rights. Alternatively though if the trade liberalization also brought with it access to new technologies that raised harvesting productivity, then it is unclear how property rights and welfare respond because now both transition prices and a country's classification can change.

3.6 Trade liberalization

Resource Exporters

We now consider the effects of trade liberalization. Let us start with resource exporting countries and suppose there is a tariff at rate t on manufactures. Since manufacturing is the numeraire, the domestic relative price of the harvested resources is initially p/(1+t). Trade liberalization will lower t, and hence raise the relative price of resources.

It is clear from our previous analysis that the long run effects of tariff liberalization will depend on country characteristics. To illustrate, consider countries with planners whose discount rate approaches zero. Such managers attempt to maximize sustainable surplus from the resource. In Figure 3 and 4, we have plotted the steady state resource supply functions for two different small open resource-exporting countries with the domestic relative price of the harvest good p/(1+t) on the vertical axis (for comparative purposes, we assume the tariff t is the same in both countries). Figure 3 depicts a category I country with supply curve S^I, while Figure 4 depicts a category III country with supply curve S^{III}.

As is well known (see for example Clark (1973), Brander and Taylor (1997b)), the supply curve is backward bending for an open access resource. This can be seen by reference to Figure 1. For low relative prices, there is little labor in the resource, so output is low. As p rises, labor enters, eventually raising the harvest to its peak at the maximum sustainable yield (MSY) level of rK/4. Beyond that, further price increases encourage even more entry, which further depletes the stock and lowers yields. This yields the backward bending supply curve S^I in Figure 3.

On the other hand, a manager who maximizes sustainable surplus will never deplete the stock beyond the point at which yield is maximized. The supply curve can be constructed by referring to Proposition 4. For a low resource price, management is ineffective, and the supply curve behaves like the open access case. However, at some point the price is high enough to support a management regime that limits harvest effort. For intermediate levels of p, (that is, for $p^+ < p < p^{++}$), the incentive constraint binds and in steady state harvest remains constant. The supply curve is vertical in this region, as illustrated in Figure 4. Finally, for p sufficiently high ($p > p^{++}$), the incentive constraint will not bind, and the manager allows steady state supply to rise monotonically with p and asymptote to the MSY level.

Suppose we start off in a case where tariffs are high and there is little pressure on the resource in either country. In the example illustrated, both countries are initially at a *de facto* open access equilibrium at their domestic prices p/(1+t). Both countries respond similarly to small tariff reductions - a fall in the manufacturing tariff makes manufacturing less attractive and agents allocate more of their time to harvesting. Because the resource is underutilized, output will rise. However, the resource stock will shrink (because of increased harvesting), which raises steady state unit harvesting costs; and because both countries are in *de facto* open access, there are no steady state rents. As Brander and Taylor (1997a) show, this will lead to a decline in steady state per capita incomes in both countries.[20]

[20] To see this, note that in the short run, the model is Ricardian with a linear production frontier for any given level of the resource stock. The production frontier rotates inward as the stock declines; and as long

Now consider a large tariff reduction - suppose that the tariff is eliminated so that the domestic relative price of the resource rises to the world price p. The Category I country will continue to be in de facto open access. No resource rents will be generated, steady state real income will fall, and if the world price of the resource is sufficiently high, the severe pressure placed on the resource can lead to a decline in steady state harvest rates as shown in Figure 3. On the other hand, the Category III country will undergo a transition from *de facto* open access to full management in free trade. Although increased pressure is placed on the resource, the stock is not depleted in an economic sense, because of the transition to full management.

Trade liberalization for resource exporters can lead to severe stock depletion and long run real income losses for Category I countries; while Category III countries will be able to conserve their resources, and can raise harvest rates and generate long run real income gains. The countries which are vulnerable to severe stock depletion from trade liberalization are those that satisfy the conditions for a category I country: slow growing resource, poor monitoring technology, large numbers of people with access to the resource, and high rates of time preference for resource harvesters. More generally, if the planner discounts the future, then the steady state supply curve for a Category III country also bends backward, and long run harvest rates 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 $D(p) = 1- S(p)/S^*(p;\lambda)$, 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 λ of the planner.[21] 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 category III country, the index of stock depletion falls to zero with trade liberalization (if the world price is sufficiently high). However, for a category I country, stock

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as the economy is diversified in production, the production frontier will rotate inward until its slope is the same as the new domestic relative price of the resource. Consequently, one can show that steady state real income falls.

[21] That is, S* is the efficient steady state stock for an economy in which there is no incentive constraint and the planner has full control over individual harvest rates.

depletion can increase with free trade; and if the world price is sufficiently high, the depletion index will approach 1.

Resource Importers

Now consider resource importers. Suppose there is initially a tariff t levied on resource imports so that the initial domestic relative price of the resource good is p(1+t). Again, compare category I and III countries and suppose the Category III country is initially fully managing its resource. A decline in the tariff will reduce pressure on the resource, since the relative return to working in the manufacturing sector will rise. In a category I country, the labor in the resource sector will fall, the steady state resource stock will rise, and steady state real income will rise as well. Intuitively, a tariff is a particularly bad policy for a resource importer that is not able to manage its resource. The tariff encourages more entry into a sector that already suffers from excessive harvesting. Consequently, eliminating such a tariff yields both conservation and economic benefits.

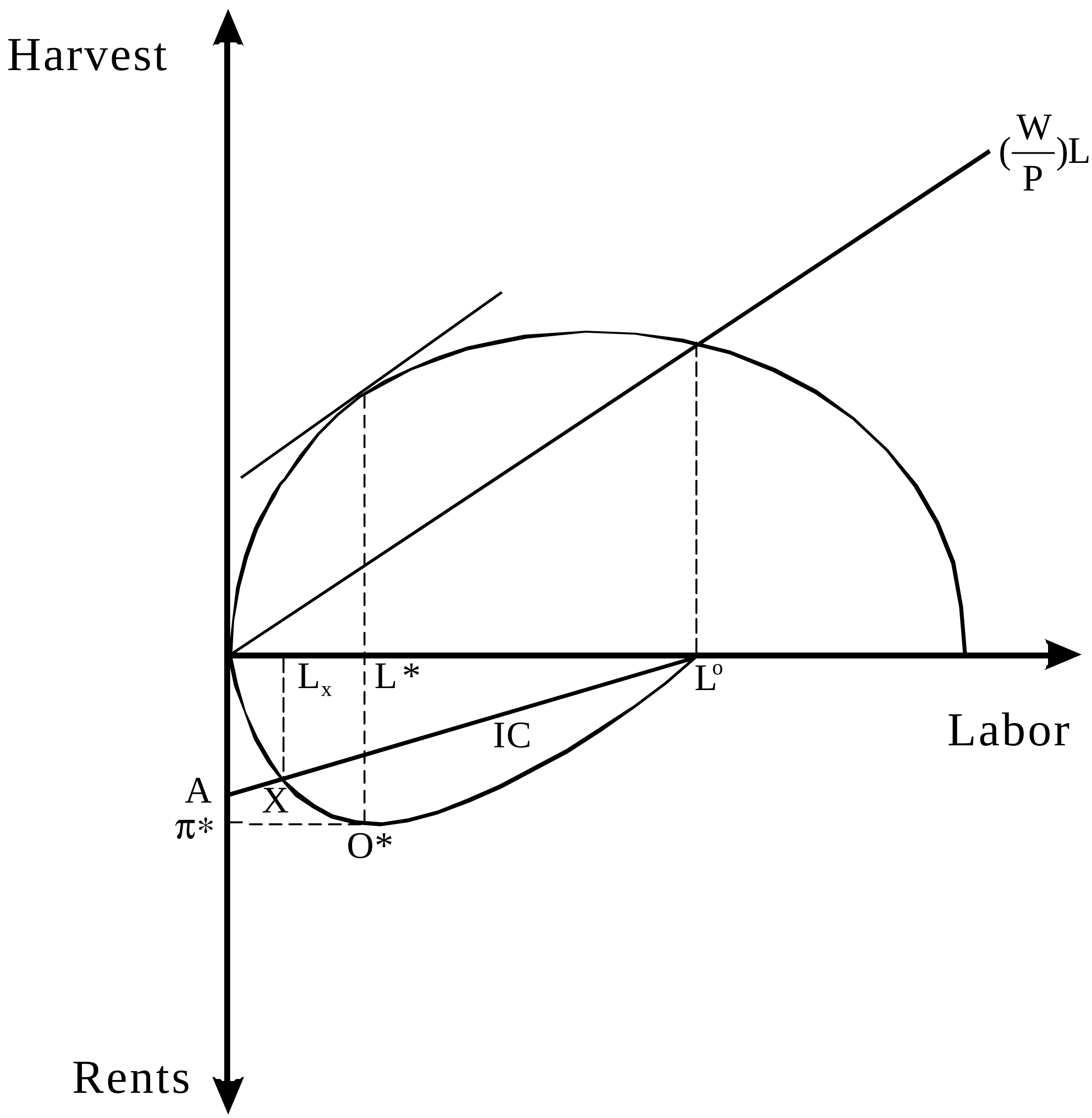
For a category III country, the fall in the domestic price that accompanies tariff liberalization can lead to a collapse of the management system. At low levels of the domestic price, the manager is not able to satisfy the incentive constraint at any level of labor below the open access level. Consequently, tariff liberalization can lead to an increase in the index of economic depletion of the resource. However, notice that even in the case where this occurs, the resource stock will rise because labor leaves the resource sector due to the lower domestic resource price. Consequently, although the index of economic depletion rises, there is less biological depletion. Moreover, because the stock rises, unit harvesting cost fall, and one can show that steady state real income rises. The erosion of the management regime therefore dampens, but does not reverse, the long run benefits of trade liberalization. Intuitively, in the price range where the country reverts to open access, the erosion of the management system is accompanied by a fall in the domestic price. This tends to drive people out of the resource sector, which prevents stock depletion.

4. Conclusions

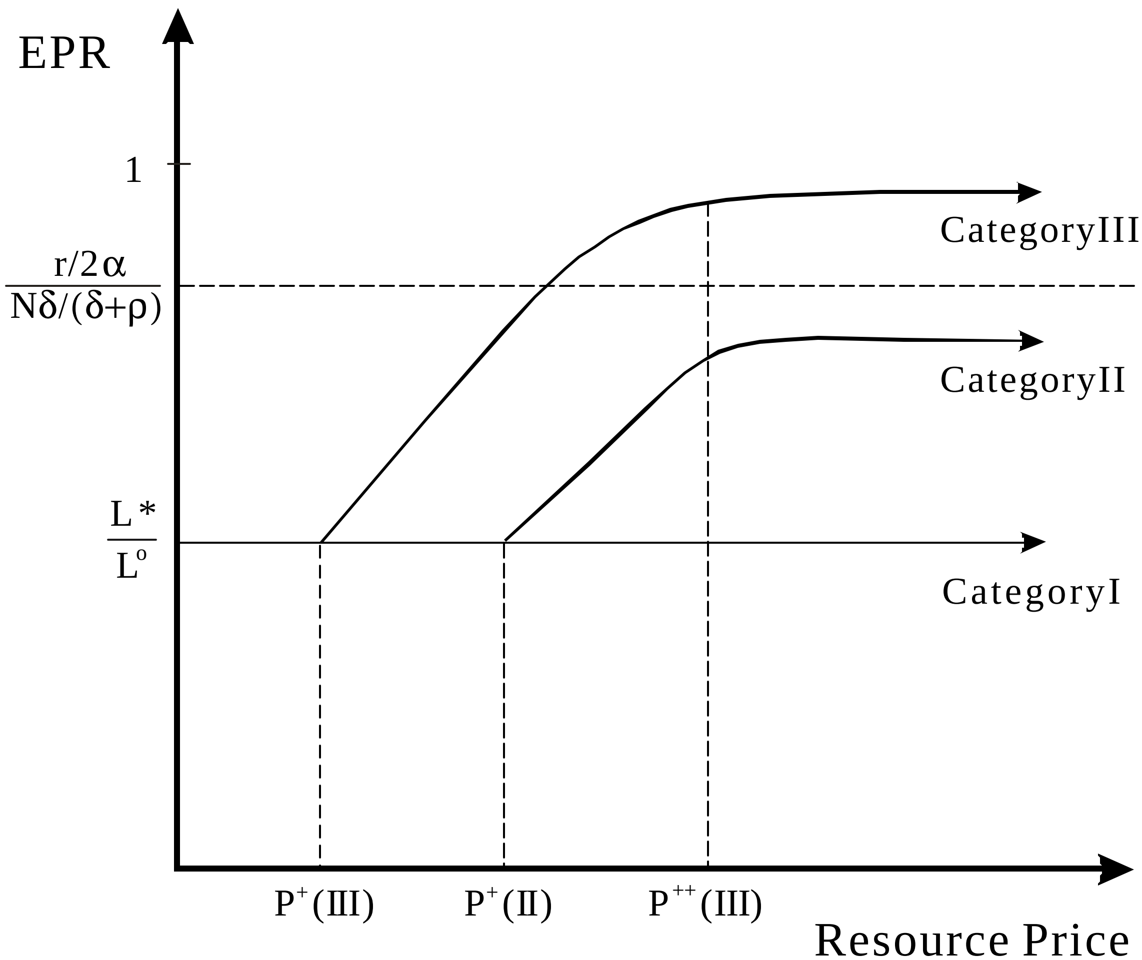
The purpose of this paper was to investigate the implications of international trade for countries with renewable resources when the management regime adjusts to the changed conditions brought about by access to international markets. We constructed a relatively simple general equilibrium model of harvesting 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. Our framework links these transitions 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, we have a far better chance of understanding the role trade and globalization play in explaining the spectacular cross-country variation in resource management practices worldwide.

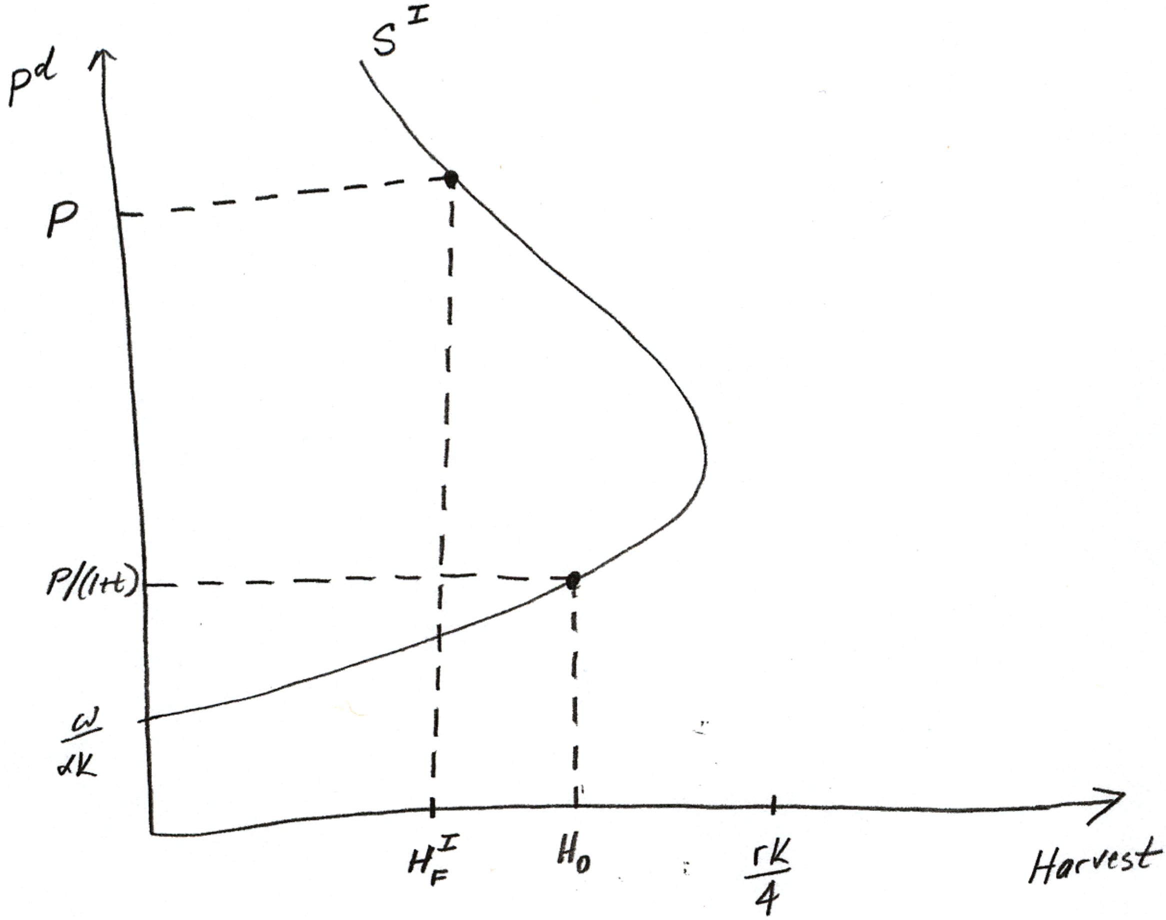
While our primary interest has been the interaction of world prices and resource management regimes, our framework may shed light on several related questions. The emergence and strength of property rights protection plays an important role in much of development and environmental economics. The role 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.



The Regulation Problem



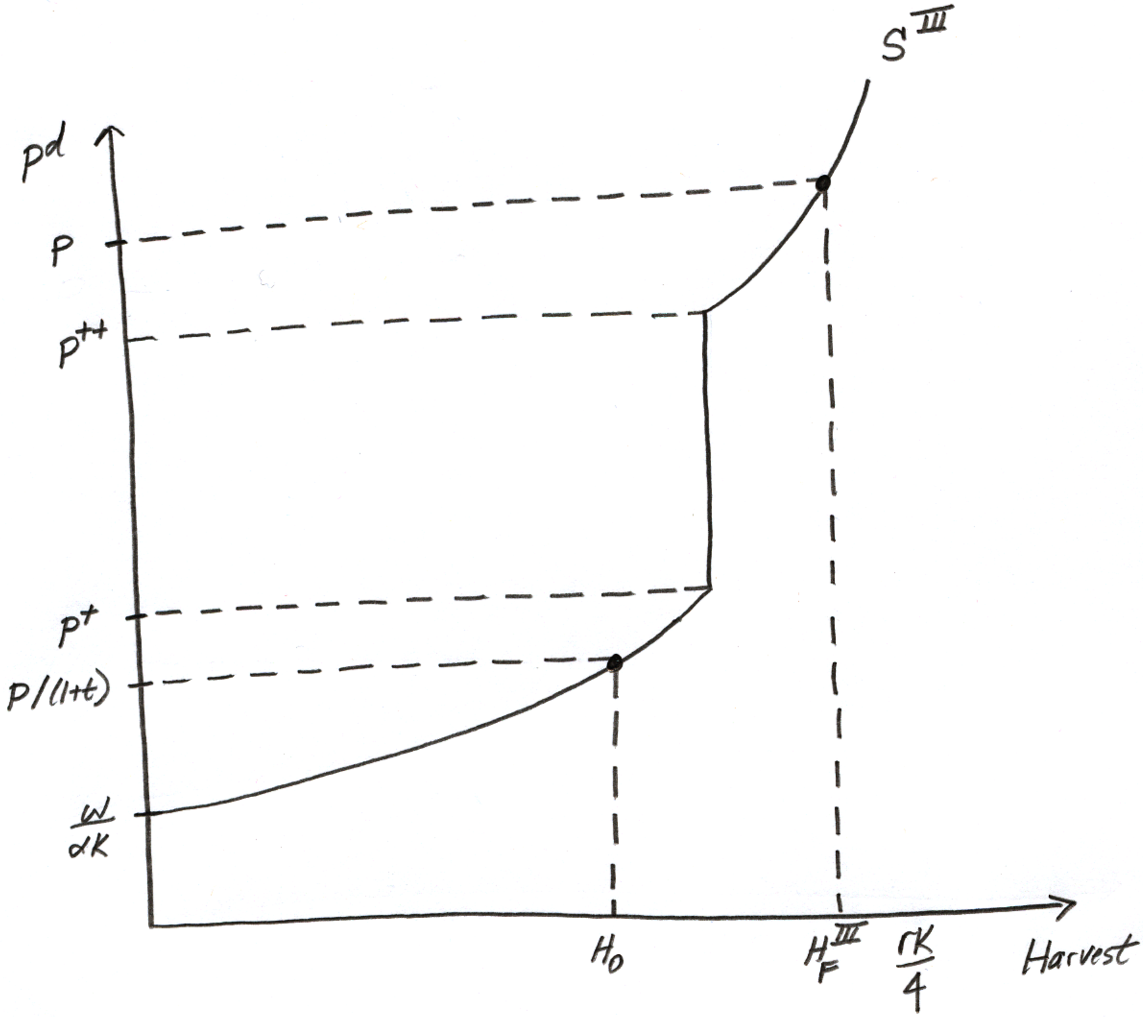
Effective Property Rights



Category I

Trade Liberalization

Figure 3



Category III

Trade Liberalization

Figure 4

5. Appendix

I. Derivation of Incentive Constraint

Start with (1.9). If the first element in (1.10) is the max, then we have:

$$
\begin{aligned}
V^R(t) &= [ph^* + (1-l^*)w]dt + [1-d\,dt][1-q\,dt]\left[V^R(t+dt)\right] \\
V^R(t) &= [ph^* + (1-l^*)w]dt + [1-(d+q)dt + dq\,dt^2]\left[V^R(t) + \dot{V}^R(t)dt\right] \qquad \text{(A.38)} \\
V^R(t) &= \frac{1}{(d+q)dt}\left[\begin{array}{l} [ph^* + (1-l^*)w]dt + \dot{V}^R(t)dt \\ +[dqV^R(t)dt^2 - (d+q)\dot{V}^R(t)]dt^2 + dq\,\dot{V}^R(t)dt^3 \end{array}\right]
\end{aligned}
$$

Cancel dt terms, and let dt go to zero. This yields the first element in the max of (1.12). Now start with (1.8). If the second element in (1.10) is the max, then we have:

$$
\begin{aligned}
V^R(t) &= ph^c dt + [1-d\,dt][1-q\,dt]\left[r\,dtV^M(t+dt) + [1-r\,dt]V^R(t+dt)\right] \\
V^R(t) &= ph^c dt + [1-(d+q)dt + dq\,dt^2]\left[\begin{array}{l} r\,dt[V^M(t) + \dot{V}^M(t)dt] \\ +[1-r\,dt][V^R(t) + \dot{V}^R(t)dt] \end{array}\right] \qquad \text{(A.39)}
\end{aligned}
$$

Cancel dt terms and let dt go to zero. This yields the second element in the max of (1.12) An atomistic agent views the time derivatives of $V^R(t)$ as equal under the two options.

II. Proofs of Propositions

Proposition 1.

Proof: In a steady state, all time derivatives are zero; therefore the optimal choice for L* must satisfy (1.19) in the text. That is, it must satisfy:

$$
L^* \geq \min\left[L^O, L^C\right] \;\; where\;\; L^C \equiv \left[\frac{d+q}{d+q+r}\right]N \;\; and\;\; L^O \equiv (r/a)\left[1 - w/paK\right]. \qquad \text{(A.40)}
$$

There are only three possibilities. Two of these arise when (1.19) holds as an equality. In this case L* equals either L^C or L^O. The other possibility occurs when (1.19) holds as a strict inequality. When this is true, L* can be found by solving the manager's problem ignoring (1.13). This problem is given by

$$
\begin{gathered}
\underset{\{L_H\}}{Max}\; SW(t) = N\int_t^\infty U(R(\tau))e^{-\lambda(\tau - t)}d\tau \\
subject\quad to: \\
R = I/N\beta(p) \quad I = pH + M \quad H = \alpha L_H S \quad M = L_M \\
L_M + L_H = N \quad \frac{dS}{dt} = rS(1 - S/K) - H
\end{gathered}
\quad . \tag{A.41}
$$

The current value Hamiltonian for this problem is:

$$
H = U\left(\frac{[p\alpha S - 1]L_H + N}{\beta(p)}\right) + \varphi\left[G(S) - \alpha L_H S\right]. \tag{A.42}
$$

The first order necessary conditions are given by:

$$
\begin{gathered}
Max_{L_H}\{H\} \\
-\frac{\partial H}{\partial S} = \dot{\varphi} - \lambda\varphi \\
\frac{\partial H}{\partial \varphi} = \frac{dS}{dt} \\
\lim_{t\to\infty} \varphi\, e^{-\lambda t} S = 0
\end{gathered}
\tag{A.43}
$$

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/α. 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:

$$
\lambda = G'(S) + \frac{\alpha L_H}{p\alpha S - w} \tag{A.44}
$$

$$
L_H = \frac{r}{\alpha}(1 - S/K) \tag{A.45}
$$

(A.44) and (A.45) solve for L_H and S. Equation (A.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 (A.44) gives L_H as a monotonically increasing function of S. At S=0, $L_H = (r-\lambda)/\alpha < r/\alpha$. At S = K, we have $L_H = ((\lambda+r)/\alpha)(p\alpha K-1) > 0$. Therefore a solution exists with L_H non-negative. It is unique. Straightforward differentiation of (A.44) and (A.45) show $dL_H/dp > 0$ and $dS/dp < 0$.

Proposition 2.

Proof: To show that a Category I country always exhibits open access in steady state, note from (1.19) that this requires $L^O \leq L^C$ 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 (1.31), holds we have $L^O \leq L^C$ for any finite p as required.

Proposition 3.

Proof: Define

$$p^{+} = 1/\alpha S \ \ where \ \ S = K\left[1 - \frac{\alpha L^C}{r}\right] \qquad \text{(A.46)}$$

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 (A.44) and (A.45). We now show that for any p, we must have $L^B < L^C$ if (1.33) is satisfied. To do so, note L^B is increasing in p and that

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

provided $S^B > 0$. But S^B is decreasing in p, and as p goes to infinity, we have $\lambda = G'(S^B)$. Because $G'(0) = r$, to ensure $S^B > 0$, it is sufficient that $\lambda < r$, which must hold if (1.33) is satisfied. Since $L^B < L^C$ for any finite p if (1.35) 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 $p > p^+$. Straightforward differentiation confirms p^+ has the properties stated in part (iii) of the proposition. Differentiation with respect to α yields $dp^+/d\alpha > 0 \ \ if \ L^C > r/2\alpha$.

Proposition 4.

Proof: Define p^+ as in the proof of Prop. 3, except now L^C satisfies (1.37). 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, $L^B = (r+\lambda)/2\alpha$ and a positive steady state stock S^B exists. Since $L^C < (r+\lambda)/2\alpha$ if (1.37) 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 $L^* = L^B$.

<u>Characteristics of transition prices.</u> The characteristics of p^+ have already been established in Prop. 3. To characterize the price p^{++} note that L^B and S^B are defined by:

$$l = G'(S^B) + \frac{a L^B}{pa S^B - w} \quad where \quad S^B = K(1 - \frac{a L^B}{r}) \qquad (A.47)$$

Denote the solution for the optimal labor force as $L^B = f(r,K,\alpha,\lambda,p)$. Equating this to L^C means p^{++} is implicitly defined by:

$$f(r, K, a, l, p++) = \frac{N(q+d)}{(q+d+r)} \qquad (A.48)$$

It is straightforward to show f is increasing in p, hence increases in N, in δ, and in θ, or decreases in ρ lead to a higher transition price. Similarly, it is easy to show that f is increasing in K; therefore, an increase in K decreases p^{++}. Finally, to determine the impact of α, λ and r we must differentiate (A.47) to characterize f and then employ that information in (A.48). Doing so shows a rise in λ always lowers S^B and raises L^B, and hence p++ has to fall.

Proposition 5.

Proof: If all category of countries exist and we are considering $p > 1/\alpha K$, then we know that for any admissible p, Category I countries have open access; and from Propositions 3 and 4 we know that Category II and III 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 Category III country 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 Category II country 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 category III country since L^B is increasing in p for all categories. Therefore, the Category II country has limited management and the Category III country has full rent maximization. If the max is p^+_{III}, then $L^O(p^+_{III})>L^O(p^+_{II})$ for the category II country since L^O is increasing in p for all categories. Therefore, the Category II country has limited management and the Category III country has full rent maximization.

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