Governing the Resource: Scarcity-Induced Institutional Change[*]

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Abstract

This paper provides a dynamic model of natural resource management where the institutional structure that governs resource use optimally changes with resource depletion. Previous studies (e.g. Copeland and Taylor 2009) analyze how characteristics of a natural resource determine whether its steady-state management regime is open access, communal property, or private property. We extend these studies to analyze how and when resource governance may change on the transition path to the steady state, taking into account the fixed costs of institutional change and the variable costs of enforcement/governance. Assuming that governance cost is increasing in the difference between open-access and the actual harvest, we show that open access can be optimal if the resource is abundant relative to its demand or if governance costs are high. Once open access is rendered inefficient due to increased resource scarcity, further depletion may justify institutional change. Given the cost of institutional change, optimal resource use implies non-monotonic resource dynamics. These findings explain the co-evolution of resource scarcity and property rights — from open access to common property and beyond. We also extend the Demsetz-Taylor theory that price induced scarcity may or may not be sufficient to induce institutional change by adding dynamics to the steady state conditions of Taylor (2008).
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1. Introduction

What explains emergence of property right regimes? Demsetz (1967) has suggested that they emerge when the benefits of reduced rent-dissipation exceed the costs of a new property institution. Thus tribal hunting rights for beaver in Quebec were established when trade with Europe increased the effective demand for beaver pelts beyond the point where the gains of internalization became larger than the costs of internalization. In contrast, Native-Americans in the Southwest did not establish private hunting rights over bison, due in large part to the high costs of internalization resulting from the migratory patterns of the animals.[1] This seminal paper left many questions unanswered. What should be included in benefits and costs? When will an institution change from one form to another? Is it current benefits and costs that are critical to the timing of institutional change or the present value thereof? Is it possible to classify resources according to which institution will be optimal for each resource? Are there conditions under which property or the lack thereof will always be more efficient than other institutions? What kind of property?

The first of these questions has been largely answered by assumption. Most of the literature on the economics of property rights after Demsetz has equated the costs of institutional change with monitoring and enforcement costs.[2] North and Thomas (1971) and Davis and North (1971) are exceptions in this regard, comparing the net benefits of institutional change with the political costs of changing the rules.[3] In what follows, we abstract from the political costs of change and restrict our attention to enforcement and information costs.[4]

The question of timing has been partially answered. Albeit for a one-time fixed-cost investment, Anderson and Hill (1990) showed that private property would efficiently emerge when the present value of reduced rent dissipation net of enforcement costs is maximized. This helped to concretize the costs of institutional change and bring some dynamics into the picture.

Demsetz (1967) cited anthropological evidence showing that the "Indians of the Labrador Peninsula had a long-established tradition of property in land," but did not clearly distinguish between private and common property. Ostrom (1990 and 1998) helped to cast the "common property resource" problem as one of comparative institutions (as had been encouraged by Coase, e.g. 1988 and 1998) by noting that neither private property nor Hardin's (1968, 1978) Leviathan (state control) should be viewed as "the only way" and by advancing community management as a third alternative.

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[1] See also Lueck (2002) and Taylor (2007) for further analysis of the fall and rise of the bison population in the American West.

[2] Anderson and Hill (1975 and 1990) consider the fixed cost of property enforcement (fencing). Deininger (2003) and Copeland and Taylor (2008) focus on the variable costs of enforcement and monitoring. See also Eggertsson (1990) for a comprehensive review and several examples.

[3] Accordingly, institutional change is said to come about when the benefits thereof exceed the (political) costs to the primary action group.

[4] In the early days of the *New Institutional Economics*, Demsetz (1967) and North and Thomas (1973) viewed institutional change as the spontaneous product of benefit-cost calculus. Later, North (e.g. 1981) spelled out the role of the state in fomenting appropriate or inappropriate institutional change.

Alston and Mueller (2003) have suggested that open access and private property are fully equivalent if land is sufficiently remote from the market and if enforcement costs are zero. For land closer to the market, property will be worthwhile if the increased value associated with the instillation of high-powered incentives brings benefits greater than the enforcement costs of enforcement. They further note that the intermediate form of common property may be preferred in situations where its benefits net of organizational costs (including enforcement) are higher than private property. Libecap enumerates factors that contribute to the success (or failure) of common property relative to other institutions such as homogeneity of potential group members.[5]

The comparative institutions literature regarding the evolution of property rights from open access to private property and comparisons across resources is aimed at explaining why different management regimes prevail for different natural resources (wildlife, land, non-renewable resources, and renewable resources) at different times, places, and for resource characteristics. A branch of literature is referred to as the *economics of common property resources* or the *economics of common property regimes* (e.g. Bromley, 1992). Despite the fact that this literature is overwhelmingly oriented to renewable resources (especially forests, fisheries, water and grazing land, Ostrom, 1990), it rarely if ever incorporated the dynamics of resource economics until the current decade.

Lueck (2002) considered the evolution of property rights in the American West. He models bison as a renewable resource and shows that the transition from open access to property rights would occur sooner if the rents from resource use are higher and if the exogenously fixed cost of resource governance is lower. The resource economics is incomplete, however, inasmuch as resource extraction is not allowed as a control variable, changes in resource scarcity do not play a role in regime switching, and governance costs are modeled as a one-time fixed cost of switching from one institution to another. Taylor (2008) takes hide prices as set by the European leather market and finds that open-access depletion closely tracks actual depletion rates up to the near extinction of the species.

Copeland and Taylor (2008) provide a more general model of resource management with explicit costs of monitoring harvests in their comparison of “Hardin” (open access), “Clark” (private property), and “Ostrom” (common property)” management regimes. They limit their analysis to steady state comparisons. This makes it possible to classify combinations of resource characteristics according to the institution that governs each resource in its steady state. They abstract from transitional issues of how and when resource governance changes en route to the steady state.

In the current paper, we explore how property right regimes that govern resource use evolve over time. While open access characterizes the organization of some common pool resources for long periods, some resources experience shifts in their property-right regimes as resource scarcity changes over time. A large number of examples demonstrating such transitions include:

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[5] See Dixit (2004) for a concise summary of Libecap’s (1989) discussion of preconditions for successful and unsuccessful group cooperation regarding mineral rights in California, oil fields in Texas, fisheries, and federal land policies in late nineteenth century western U.S.

- Rural land use in Switzerland and Germany (Netting 1981);
- Enclosure of open/common fields in England (McCloskey 1976, Allen 1983);
- Groundwater use in Southern California: from open access to restricted access (Ostrom 1965);
- Use of forest land (*Iriaichi*) in rural villages in Japan: from commons to private (McKean 1986);
- Fishing cooperatives in Japan (Platteau and Seki 2000) ;
- Watersheds (Ahupua`a) in Hawaii (La Croix and Roumasset 1990); and
- Lobster fisheries in Maine (Acheson 1988).

The lobster fishery in Maine provides an illustrative example. Back in the colonial period, lobsters were abundant and managed as an open access resource. As an Economist article documents, servants used to be fed with lobster so often that a group of them protested to their landlords against lobster meals. As the demand for lobster increased, local lobstermen started to organize themselves (the "lobster gangs" in Maine, Acheson 1988) in order to exclude outsiders from lobstering and restrict their own harvest, thereby avoiding rent dissipation due to open access.

We should probably add a sentence or two on each of the other cases.

Our objective is to focus on the evolution of resource governance up to and including its steady state. The same framework is suitable for comparing the evolution of property rights for resources with different characteristics. Building on the above literature of endogenous property rights, we develop a dynamic resource-use model that takes into account the cost of institutional change in order to address how governance of a resource evolves over time depending on resource scarcity and changes in the surrounding economic environment. We solve the model for the second-best allocation in the presence of governance costs.[6] The second best solution is then contrasted with the first best and the competitive (open-access) outcome.

Here we summarize the main findings of the paper. For a small open economy (or a local resource) with an exogenous price of harvest, the following holds.

- When resource is abundant, allowing open access is the second best given costly governance. Eventual institutional change from open access to governance is the second best if and only if the costs of governance are small. If institutional change requires a positive investment cost, and if governance is the second best, then overshooting occurs: open access is allowed until the resource stock falls below the steady-state level, and then harvest is restricted so that the stock recovers to the steady state.
- When adopting governance is the second best, the steady state stock is lower than the first best level (that would prevail in the absence of governance costs) if the marginal governance cost is positive.
- The optimal timing of institutional change is delayed if the harvest price is larger or if the cost of governance is larger.

More generally, with downward sloping demand of harvest, the following holds.

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[6] We use "second best" in the sense of Dixit (2004), i.e. optimal in the presence of transaction costs, albeit with either a single principal or united principals.

- Open access resource extraction always exceeds the first best level regardless of resource scarcity level.
- With governance costs, open access can be the second best when resource is plentiful—as resource scarcity increases, the second best may converge to the first-best steady state.
- With governance costs high enough, open access is the second best at all resource stock levels.

Thus the model explains how resource scarcity is related to property rights and how this relation depends on governance costs. When the governance cost is negligible, the second best outcome generates positive rents at all stock levels. Given large governance costs, open access (i.e. zero-rent) is the second best when resource is abundant. In this case, the second best resource management implies that governance (or escapement from the tragedy of the commons) can start as resource is depleted—a story consistent with the Maine lobster and the examples cited above. With the governance cost sufficiently large, it becomes too costly to restrain harvest below the open access levels: in this case, open access is the second best regardless of resource scarcity.

By characterizing institutional change as the constrained optimal outcome given governance costs, this study also contributes to the literature on the emergence of organization. Most existing studies on this topic assume non-rational resource users in evolutionary-game frameworks. Our model explains that escaping the tragedy of the commons is possible and is a second-best rational response against changing resource scarcity.

We also aim to supplement Taylor's (2008) dynamic, open-access model of bison depletion. For the most parts of our analysis, we follow Taylor's assumption of an exogenous world price of the resource (e.g. bison hides), and solve for conditions under which the efficient property rights regime would remain in open access. We also solve for the optimal switch time from open access to governance in the event that open access eventually becomes inefficient.

In what follows, section 2 describes a general, dynamic model of natural resource use with explicit costs of resource governance. Section 3 explains the main results of the paper regarding the evolution of resource governance over time. In particular, section 3.1 characterizes the second best resource use given governance costs using a model with exogenous price of harvest. Section 3.2 discusses if and when it is optimal to transition from open access to either common property or private property—the two major institutions differentiated by the governance cost structures. We also discuss how the results found in section 3 carries over to the case with endogenous harvest prices. Section 5 concludes the paper with suggestions for further research.

2. Model

Consider a renewable resource management problem with an exogenous demand for harvest and governance costs. Without governance, the resource would be open access and experience eventual rent dissipation. The resource manager's objective is to maximize the present value of the resource rents by choosing the dynamic harvest profile, taking into account the cost of restricting harvests under the open access level. This section presents the assumptions of the model.

Resource dynamics

Let S_t be the stock of a renewable resource at time t. Without harvest, the growth of the resource stock at time t is given by $F(S_t)$ where $F(S) > 0$ for all $S \in (0, K)$, $F(0) = F(K) = 0$, and $F'' < 0$. The parameter $K > 0$ represents the carrying capacity of the resource. Without harvest, K would be the long-term steady-state stock whenever the initial stock is positive.

Net benefits of resource use

Let x_t>0 represent the harvest at time t. Given x_t, the net (flow) benefit of resource use for the society at time t is given by the consumer surplus associated with the resource good minus the cost of harvesting:

$$NB_t = \int_0^{x_t} P(\omega)d\omega - c(x_t; S_t)x_t,$$

where P is an inverse demand function and c the unit harvesting cost function. The inverse demand P is continuously differentiable with $P' \leq 0$. We assume that P is stationary over time. (We will also consider cases where the demand curve shifts over time.) The unit harvesting cost function c may be increasing in harvest and decreasing in stock.

Costs of Constitutional Governance

Without enforcement or governance, the resource is open access: harvest will continue to the point where the rent diminishes to zero. The associated harvest x_{oa} satisfies

$$P(x_{oa}(S)) = c(x_{oa}(S), S).$$

Open access harvest x_{oa} at time t depends on the stock level at time t as long as unit harvest cost c is stock-dependent.

The model explicitly takes into account the costs of governance, i.e. of limiting harvests to a level below x_{oa}. Governance includes the negotiation, information processing and enforcement regarding harvesting rules (what, who, when, and how); decision-making; monitoring, bonding, and sanctions; and conflict resolution. For example, homogeneity of group membership lowers the costs of designing and enforcing harvesting rules in accordance with member differences in harvesting capacity (Libecap, 1989; Dixit, 2004).

While some of the governance costs are recurrent in nature, implementing governance (or institutional change) involves a one-time investment. In many cases governance involves a lumpy investment, and the timing of investment determines the evolution of institutions. In fact, many previous models of institutional change focused on the timing of investment (e.g. Anderson and Hill 1990, Lueck and Miceli 2007). Hence, we consider both the fixed and the variable costs of governance. Let $C \geq 0$ be the investment cost of institutional change. Let G be the variable (or recurrent) governance cost. Once investment is made at time T, the variable cost G at each time $t \geq T$ depends on the difference between the open-access harvest level and the actual harvest at time t. We also assume that G is a linear function:

$$G(x_t; x_{oa}) = g(x_{oa}(S_t) - x_{oa}),$$

where $g > 0$ is a constant. The further the resource manager restricts the harvest, the larger the governance cost. The present value of the total governance cost, evaluated at time 0, is given by

$$e^{-\rho T}C + \int_T^\infty e^{-\rho t} g(x_{oa}(S_t) - x_t)dt.$$

3. Second-best resource governance

3.1 Institutional change in a model with exogenous prices

The second best problem

We first consider a case with a constant harvest price—an assumption applicable to a small-open economy or a local small-scale natural resource taking the market price of harvest as given. The assumption of constant price simplifies the analysis significantly. However, as we will see below, the analysis generates rich results regarding if and when institutional change is the second best given the cost of governance.

Let p>0 be the constant harvest price. Suppose the unit harvesting cost function c is independent of harvest but depends on the stock: $c'(S) < 0$, $c''(S) > 0$ for all S, and $\lim_{S\to 0} c(S) = \infty$. Let $K > 0$ be the carrying capacity of the resource. Assume that $p - c(K) \geq 0$, that is, harvesting can generate positive rents at a resource stock level sufficiently large. The social planner's objective function is the present value of the flow of rents from resource use minus governance costs:

$$\int_0^\infty e^{-\rho t}\left[\{p - c(S_t)\}x_t - g(x_{oa} - x_t)\right]dt$$

Suppose that the maximum harvest rate $\bar{x} > 0$ is given at each instant (perhaps due to the finite number of resource users even under open access). We assume that $\bar{x}$ exceeds the maximum sustainable yield (MSY, $\max_{0\leq S\leq K} F(S)$). Let $\underline{S}$ be the steady-state stock level associated with open access: $p - c(\underline{S}) = 0$. The open-access harvest x_{oa} depends on the current stock level and satisfies the following.

$$x_{oa}(S) = \begin{cases} 0 & if\ S < \underline{S}; \\ F(S) & if\ S = \underline{S}; \\ \bar{x} & if\ S > \underline{S}. \end{cases}$$

Because $\bar{x}$ exceeds the maximum sustainable yield, continued open access implies that the stock converges to $\underline{S}$, where complete rent dissipation occurs. Given governance costs, the social planner's second-best problem is to maximize the present value of resource rents by choosing the timing of investment and a time path of harvests if governance is adopted:

$$\max_{x,T} \int_0^T e^{-\rho t}[p - c(S_t)]x_{oa}(S_t)dt - e^{-\rho T}C + \int_T^\infty e^{-\rho t}\left[\{p - c(S_t)\}x_t - g(x_{oa}(S_t) - x_t)\right]dt$$

$$s.t. \quad S_t = \begin{cases} F(S_t) - x_{oa} & for\ 0 \leq t \leq T; \\ F(S_t) - x_t & for\ t > T, \end{cases}$$

$$0 \leq x_t \leq x_{oa}(S_t) \quad for\ all\ t,$$

given $S_0 \in (0, K]$. In the remainder of the analysis, we assume that $S_0 \approx K$ in order to describe the second best resource allocation starting at a time when the resource is untouched.

The first term of the objective function represents the rents while open access is allowed. The second term is the present value of the investment cost when institutional change occurs at time *T*. The last term represents the present value of rents upon governance. We say that (transition to) governance is the second best (given costly governance) if the timing *T** that solves the above problem is finite.

If C=G=0 (no governance costs), this problem admits a bang-bang solution because the objective function is linear in harvest x_t. The solution would be the most rapid approach path to the steady state where *g*=0. In what follows we demonstrate that (1) the nature of the second-best solution given *g*>0 is similar as long as the investment cost C is zero; (2) however, the second best solution is not a most rapid approach path and generates a non-monotonic resource stock transition in the presence of the investment cost *C*.

Case 1: No fixed cost

First suppose *C*=0 (no fixed cost for institutional change). Observe that the integrand can be rewritten as

$$\{p + g - c(S_t)\}x_t - gx_{oa}.$$

Hence, the marginal governance cost g has two effects: (1) it effectively increases the marginal benefit (or the marginal revenue) of harvesting (from p to $p+g$); and (2) it decreases the instantaneous rent (by gx_{oa}).

The singular solution S^* satisfies the following equation:

$$\Phi(S^*) \equiv -c'(S^*)F(S^*) - [\rho - F'(S^*)][p + g - c(S^*)] = 0.$$

There is a stock level S' at which $p + g = c(S')$ due to the assumption on c, and hence $\Phi(S') > 0$. Because Φ is continuous and $\Phi(K) < 0$, a solution to $\Phi(S^*) = 0$ exists between S' and K. With the additional assumption $\Phi''(S^*) < 0$, there is a unique solution.[7] If S*<$\underline{S}$, then S* is not approachable even under open access and hence the second best solution is open access with no governance at all *t*.

If S*≥$\underline{S}$, then the second best solution is one of the following two that generates the larger present value.

1. (With governance) Choose x_{oa} as long as $S_t > S^*$ and $x^* \equiv F(S^*)$ when $S_t = S^*$. That is, choose $\bar{x}$ until the stock decreases to S^*, and then choose x^* forever.
2. (Without governance) Choose x_{oa} at all t. That is, choose $\bar{x}$ until the stock decreases to $\underline{S}$, and then choose x_{oa} forever.

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[7] The function Φ has a negative second-order derivative if functions c and F take commonly assume functional forms (c(S)=c/S and F is logistic (F(S)=rS(1-S/K)) or is a Gompertz growth function F(S) = rS log(K/S)).

The present value with governance (the first case) is

$$\Pi_g = \int_0^{\tau(S_0,S^*,\bar{x})} e^{-\rho t}\{p - c(S_t)\}\bar{x}dt + e^{-\rho\tau(S_0,S^*,\bar{x})}\frac{[p - c(S^*)]x^* - g(x_{oa} - x^*)}{\rho}.$$

where $\tau(S_0, S^*, \bar{x})$ is the time it takes the resource of size S_0 to reach the open-access level S^* given harvest rate is $\bar{x}$:

$$\tau(S_0, S^*, \bar{x}) \equiv \int_{S_0}^{S^*} \frac{1}{F(w) - \bar{x}} dw.^{8}$$

The present value with no governance (the second case) is

$$\Pi_{ng} = \int_0^{\tau(S_0,\underline{S},\bar{x})} e^{-\rho t}\{p - c(S_t)\}\bar{x}dt \quad where\ \dot{S}_t = F(S_t) - \bar{x},\ S_o = S^*,$$

Therefore, the present value under the second best solution is given by $\max\{\Pi_g, \Pi_{ng}\}$.

Proposition 1

In the constant price model, suppose C=0. Given any initial stock $S_0 \geq S^*$, the second best involves positive governance costs if and only if

$$\frac{[p - c(S^*)]x^* - g(x_{oa} - x^*)}{\rho} \geq \int_0^{\tau(S^*,\underline{S},\bar{x})} e^{-\rho t}\{p - c(S_t)\}\bar{x}dt \quad where\ \dot{S}_t = F(S_t) - \bar{x}.$$

If the inequality holds, then (i) the optimal investment timing for institutional change from open access to governance is given by $\tau(S_0, S^*, \bar{x})$; (ii) the resource stock decreases monotonically to the steady state; and (iii) the steady state S is smaller than the first best level that would prevail if g=0.*

Figure 1 describes a case where the above condition holds. The figure assumes a simple unit harvesting cost c(S) = c/S. The resource growth function is given by a logistic function:

$$F(S) = rS\left(1 - \frac{S}{K}\right),$$

where $r > 0$ is the intrinsic rate of resource growth and $K > 0$ the carrying capacity of the resource.

Under the second best with governance in Figure 1, harvest is restricted to the steady-state level *x** before the stock reaches the open access level $\underline{S}$. The stock is maintained at the singular solution S^*, and generates positive rents.

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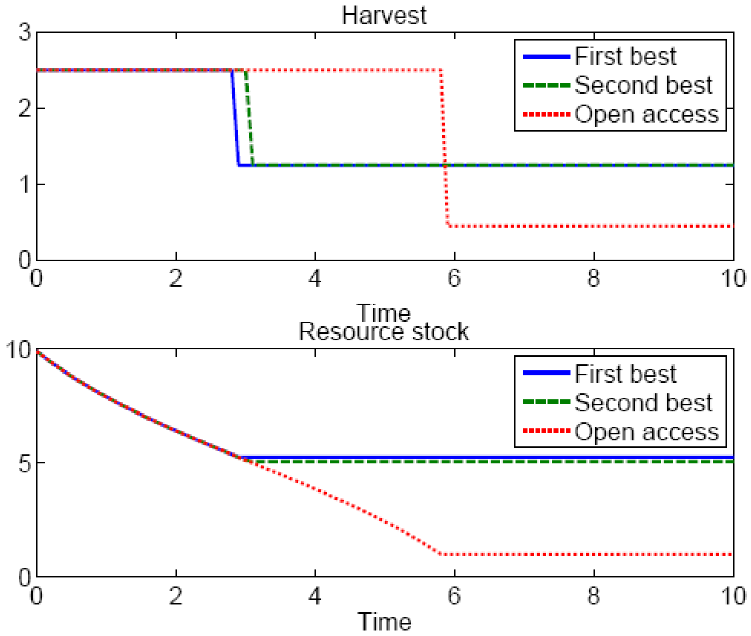
[8] This equality holds because $dS_t/dt = F(S_t) - \bar{x}$ implies $dt = dS_t/(F(S_t) - \bar{x})$, and hence $\int_0^{\tau} dt = \int_{S_0}^{S^*} \frac{1}{F(w) - \bar{x}} dw$.)



Note: The figure is based a constant-price model in section 3.1. The parameter values are ρ= 0.03, $c(S) = 1/S$, p=2, r=0.5, K=10, $\bar{x}$ = 2.5, g= 0.5, and $S_0 = 9.9$.

Figure 1. Second best resource use for a constant-price model.

Case 2: Positive fixed cost

In the presence of fixed investment cost, the most rapid approach path is not optimal.

Proposition 2 *In the constant price model, suppose* $S_0 > S^*$ *and adopting a governance structure involves a fixed-cost investment* C. *For any* $C > 0$, *the optimal timing of investment implies non-monotonic stock path: the resource stock falls below* S^*, *increases to* S^*, *and stays at the level.*

Proof. Suppose governance involves fixed cost C and zero variable cost. (The proof holds when the marginal governance cost g is positive.) Let T^* be the optimal timing of investment (to switch to governance). Let $\tau^* \equiv \tau(S_0, S^*, \bar{x})$. If $C = 0$, then the optimal harvest rule is given by

$$x_{FB}^*(S) = \begin{cases} \bar{x} & \text{if } S > S^*; \\ x^* & \text{if } S = S^*; \\ 0 & \text{if } S < S^*. \end{cases}$$

Because the optimal harvest equals the open-access level $\bar{x}$ for any t where $S_t > S^*$, it follows that $T^* \geq \tau^*$ (i.e. it is never optimal to invest when open access is optimal). The present value of governance with timing T between τ^* and $\tau_{oa} \equiv \tau(S_0, S_{oa}, \bar{x})$ (i.e. the time when stock reaches the open-access steady state level when open access is allowed at all time) is given by

$$V(T) = \int_0^T e^{-\rho t}[p - c(S_t)]\bar{x}dt - e^{-\rho T}C + e^{-\rho(T+\tau(S_T, S^*, 0))}\frac{[p - c(S^*)]x^*}{\rho}.$$

The first term represents the present value of harvesting until governance is adopted during which $\dot{S}_t = F(S_t) - \bar{x}$. The second term is the present value of the investment cost. The third term is the present value of rents under governance. The discount factor $e^{-\rho(T+\tau(S_T,S^*,0))}$ involves two time periods, T and $\tau(S_T, S^*, 0)$. (After investment occurs at time $T > \tau^*$, the resource stock is below the optimal steady state S^*. Once governance is adopted, the optimal harvesting rule is given by x^*_{FB} specified above, and hence zero harvest is chosen until the stock recovers to the level S^*. The time it takes for S_T to build up to S^* is given by $\tau(S_T, S^*, 0)$.)

The first order derivative of V is

$$V'(T) = e^{-\rho T}[p - c(S_T)]\bar{x} + \rho e^{-\rho T} C - \rho\left(1 + \frac{\partial \tau}{\partial S_T}\frac{dS_T}{dT}\right)e^{-\rho(T+\tau(S_T,S^*,0))}\frac{[p-c(S^*)]x^*}{\rho},$$

where

$$1 + \frac{\partial \tau}{\partial S_T}\frac{dS_T}{dT} = 1 + \frac{\partial}{\partial S_T}\int_{S_T}^{S^*}\frac{1}{F(S)}dS \cdot [F(S_T) - \bar{x}] = 1 - \frac{F(S_T) - \bar{x}}{F(S_T)} = \frac{\bar{x}}{F(S_T)} > 0,$$

for all T (because $S_T \in (0, K)$). It follows from $F(S^*) = x^*$ and $\tau(S^*, S^*, 0) = 0$ that the derivative evaluated at time τ^* satisfies

$$V'(\tau^*) = e^{-\rho T}[p - c(S^*)]\bar{x} + e^{-\rho T}\rho C - e^{-\rho T}[p - c(S^*)]\bar{x} = e^{-\rho T}\rho C > 0.$$

This inequality implies that the present value is larger when investment occurs at a time later than τ^*. ■

Hence, if C>0 and if governance is the second best, then the second-best resource transition exhibits non-monotonicity: the resource is driven down to a level below the steady state, investment for governance is made and harvest is restricted to zero until the stock recovers to the steady-state level, and then the harvest is controlled at the steady-state level $F(S^*) = x^*$ thereafter. Thus, even without exogenous priced shocks, it is optimal to allow the stock to fall below the steady-state level—there is a benefit from delaying governance due to the investment cost for institutional change.

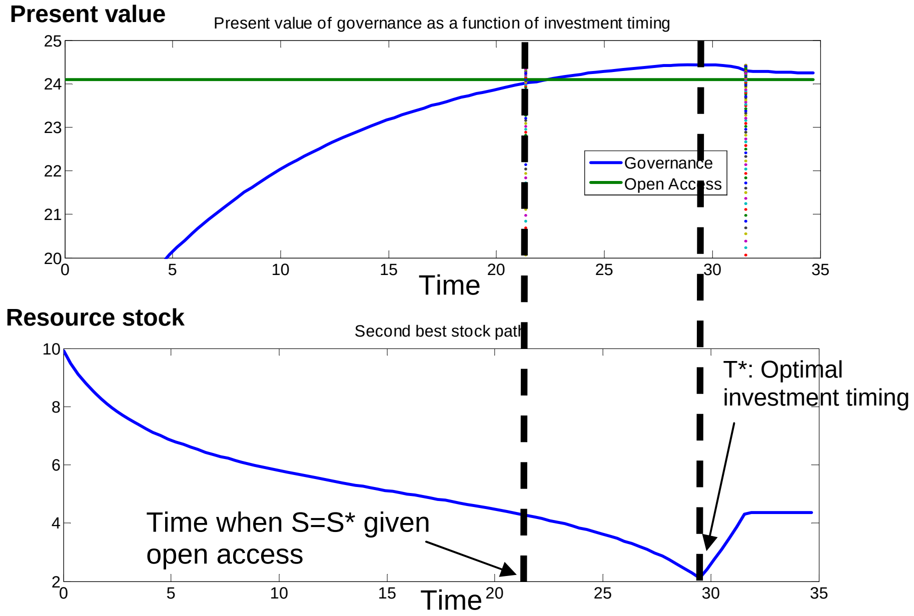


Figure 2. Overshooting given an investment cost for institutional change.

Figure 2 illustrates a case where governance is the second best. The top panel represents the present values of governance as a function of investment timing (blue color) and under open access (green color). Notice that the present value of governance increases even after stock reaches the steady state level (at t=21.3). The optimal investment timing is $T^*=29.5$, when it becomes optimal to restrict harvest (to zero) so that stock grows back to the steady state level. This example illustrates an interesting case where adopting governance when $S_t = S^*$ generates a lower present value than open access while adopting governance at the optimal timing T^* is the second best superior to open access.

3.2 Common and private property

So far, we study institutional change from open access to a generic governance structure with fixed and variable costs of governance. Here we distinguish two major forms of governance: common property and private property. We assume that the fixed cost is lower and the variable cost is larger under common property. While implementing private property is more costly than initiating collective action under common property, governance under private property is less costly.

To simplify the comparison, we assume that the fixed investment cost is zero for introducing common property and the marginal governance cost g is zero under private property (once it is introduced with fixed cost C>0).

What follows is a number of observations regarding if (Proposition 3) and when (Proposition 4) switching from open access to common or private property is the second best.

Proposition 3 *If transition to common property is the second best given* $\underline{g}>0$*, then it is the second best for any* $g<\underline{g}$*. If transition to private property is the second best given* $\underline{C}>0$*, then it is* *the second best for any C<$\underline{C}$. If transition to governance is the second best given $\underline{p}$ >0, then it is the second best for any p> $\underline{p}$.*

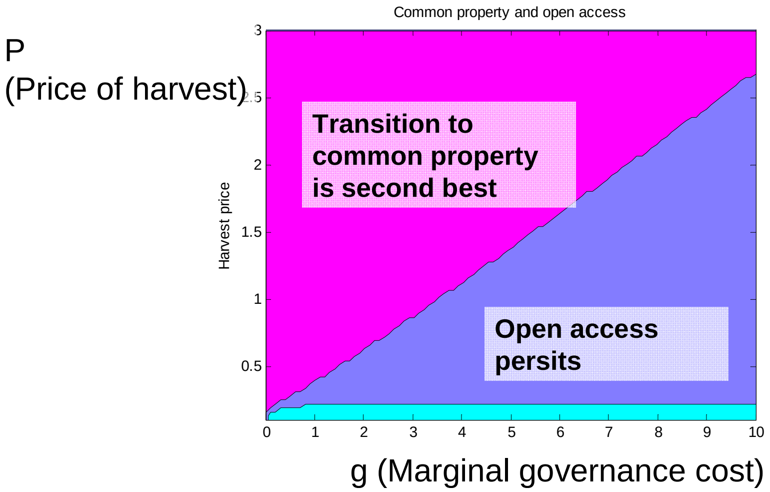


Figure 3: Open access and common property ($S_0 = K$)

Proposition 3 states that the gains from adopting governance is decreasing in the governance costs and increasing in the harvest price, as illustrate in Figure 3 and 4. Figure 3 compares open access and common property given different values of harvest price and marginal governance cost. Given S0=K, adoption of common property is the second best if the parameter values fall under the upper triangular region in the figure. The higher the harvest price and the lower the governance cost g, the larger the net benefit of common property over open access.

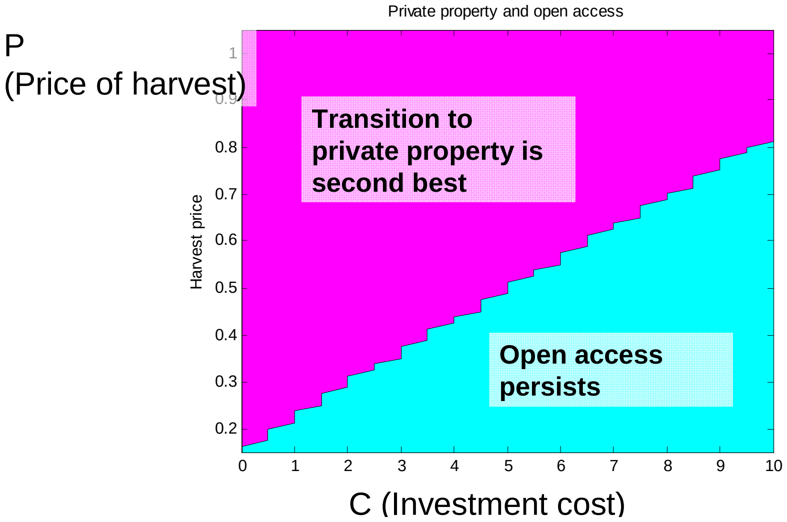


Figure 4: Open access and private property ($S_0 = K$)

Figure 4 compares open access and private property given different values of harvest price and marginal governance cost. Again, eventual transition to private property is preferred to open access if the harvest price is high or if investment cost is small.

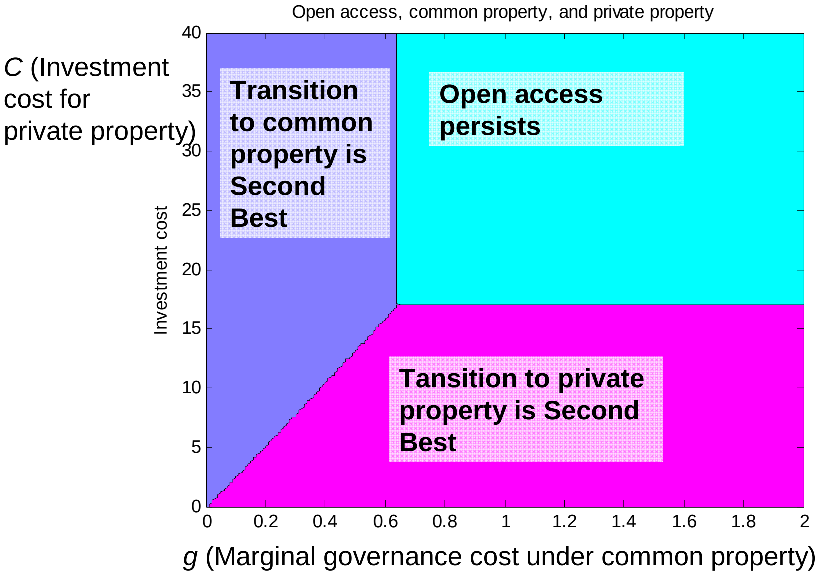
We obtain a monotonic relationship between harvest price and institutional transition. The optimal switching time to common property (when it is the second best) is later if harvest price is larger.

Proposition 4

- *(i)* *The time at which common-property governance starts is increasing in g. For sufficiently large g, common property is not the second best.*
- *(ii)* *The optimal timing for investment in private property is delayed as C increases. For sufficiently large C, private property is not the second best.*
- *(iii)* *As harvest priced p increases, the timing of institutional transition increases monotonically.*

Hence, the optimal institutional switching time is delayed if the given harvest price is larger. This proposition holds because the second-best steady-state stock decreases and the time it takes for resource to reach the steady-state level increases as *p* increases. Similarly, the optimal switching time is later if *g* is larger because the steady state under governance is decreasing in the marginal governance cost. With *g* large enough, open access is the second best and governance never adopted.

The analysis so far deals with pairwise comparison of open access versus common property on one hand an open access and private property on the other. Figure 5 illustrates the second best institution when both common and private property regimes are available.



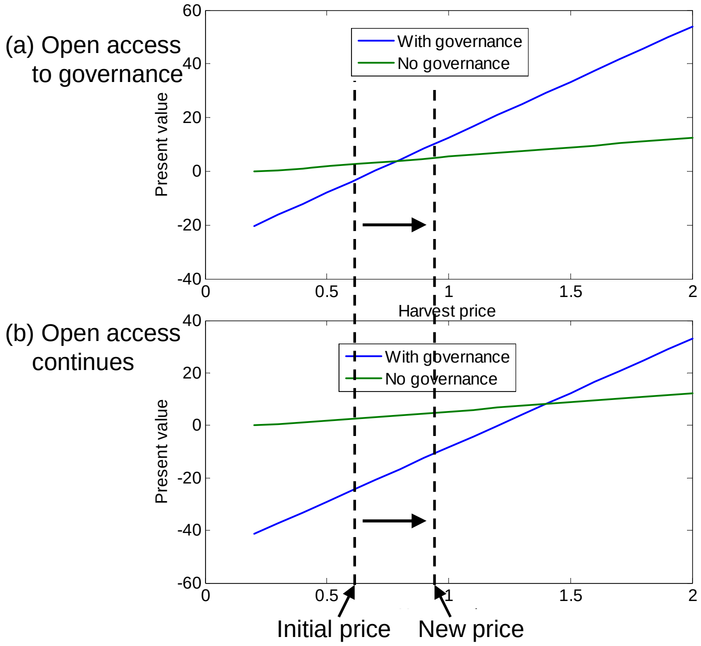
The figure assumes rho = 0.05, p=1, c(S) = 1/S, r= 0.5, K=10, xbar = 2*MSY =4, S_0 = K. Axes measure C (investment cost) between 0 and 40, and g between 0 and 2.

Figure 5 Open access, common property versus private property

Common property is preferred if its marginal governance cost g is small relative to the cost of investment for private property.

3.3 Institutional change due to price shocks

When unexpected changes in the harvest price occurs, it is possible for the second best institution to change. First, we illustrate that an increase in harvest price may induce common property to be the second best. Then we discuss the conditions under which sequential institutional transition, from open access to common property and then to private property, occurs.



Note: The figure is based a constant-price model in section 3.1. The parameter values are ρ= 0.03, r=0.5, K=10, $\overline{x}$ = 2.5. The marginal governance cost g equals 0.5 in panel (a) and 1 in panel (b).

Figure 6. The present value of governance and harvest price.

Figure 6 illustrates the effect of harvest price on the second best resource use (under the conditions where Proposition 1 holds). Case (a) assumes a lower marginal governance cost g than in case (b). An increase in the harvest price justifies governance in case (a) (as in the case of beaver discussed in Demsetz 1967) while open access continues to be the second best in case (b) (as in the case of bison discussed in Taylor 2007).

[Sequential transition from open access to common and private property: incomplete]

4 Resource scarcity and institutional change

The above model with constant harvest price involves a bang-bang solution. The result that open access is the second best when stock is abundant holds trivially in the model. Here we demonstrate that this result carries over to a more general, non bang-bang model with a downward-sloping demand curve. To simplify the analysis, we also assume linear, stock-independent harvesting costs and maintain linear governance costs. (The result that open access is the second best when S is large holds with nonlinear harvesting costs as well.)

Suppose the cost of harvesting x_t is given by

$$C(x_t) = cx_t,$$

where $c > 0$ is a scalar. The open-access harvest level x_{oa} satisfies

$$P(x_{oa}) = c.$$

With stationary demand and stock-independent cost, the open-access harvest level is unique and constant over time (provided $P' < 0$).

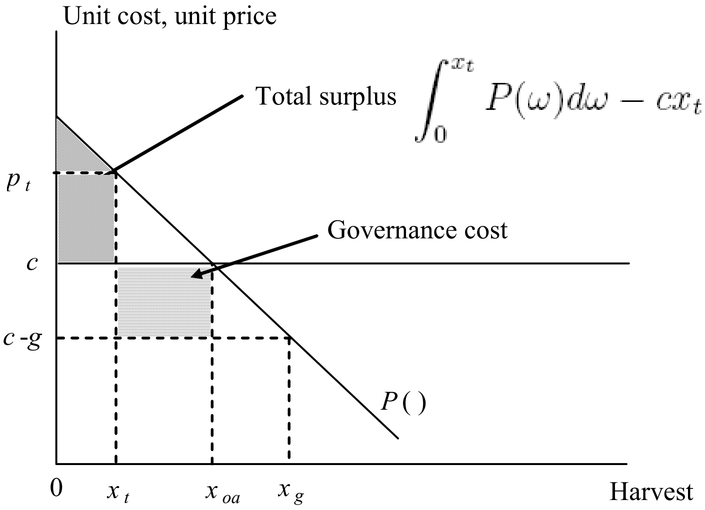


Figure 7 Resource rent and governance cost.

The social planner's problem is given by

$$\max_x \int_0^\infty e^{-\rho t}\left[\int_0^{x_t} P(\omega)d\omega - cx_t - g(x_{oa} - x_t)\right]dt$$

$$s.t. \quad \dot{S}_t = F(S_t) - x_t, \text{for all } t$$

given $S_0 \in (0, K]$. (Figure 7 illustrates the total surplus from resource use and the governance costs at an arbitrary time *t*.) The maximum principle implies the following conditions for optimality:

$$P(x_t) - (c-g) - \lambda_t \begin{cases} > 0 & \Rightarrow x_t = x_{oa}; \\ = 0 & \text{if } 0 < x_t < x_{oa}; \\ < 0 & \Rightarrow x_t = 0. \end{cases}$$

$$\dot{\lambda}_t - \rho\lambda_t = -\lambda_t F'(S_t).$$

Let S^* be the steady state that satisfies $F'(S^*) = \rho$. The following proposition addresses the second-best optimality of open access.

Proposition 5 *Suppose* $S_0 > S^*$. *When the resource is relatively abundant (i.e. when the stock level is close to carrying capacity), open access can be the second best. As the resource becomes scarcer, the governance cost may increase and the second best allocation may involve positive resource rents.*

Sketch of the proof

A key to this result is that the second best solution may not be interior because:

1. Harvest cannot exceed the open access level: $x_t \le x_{oa}$ must hold; and
2. The governance cost should not exceed total surplus.

Step 1. A modified first-best solution given unit cost c-g

The necessary conditions for an interior second-best solution includes

$$P(x_t) - (c-g) = \lambda_t.$$

This is the necessary condition for the interior first best solution when the unit harvesting cost is $c-g$:

$$\max_x \int_0^\infty e^{-\rho t}\left[\int_0^{x_t} P(\omega)d\omega - (c-g)x_t\right]dt$$

$$s.t. \quad \dot{S}_t = F(S_t) - x_t \text{ given } S_0.$$

Let (x_t^{**}) be the solution. Let $x_{oa}(c-g)$ be the open-access harvest level associated with the unit harvesting cost $c-g$, i.e. $P(x_{oa}(c-g)) \equiv c-g$. Under some parameter values, the solution to the above problem x_t^{**} is sufficiently close to $x_{oa}(c-g)$ for small *t*.

Step 2. Unconstrained optimal harvest is increasing in stock

Step 3. Open access can be the second best when stock is large

Note that the second best harvest must satisfy the following condition:

$$x_t \le x_{oa}(c),$$

where $x_{oa}(c)$ is the open-access harvest level associated with the unit harvesting cost c, i.e. $P(x_{oa}(c)) \equiv c$. Note that $x_{oa}(c) < x_{oa}(c-g)$. Hence, the solution x_t^{**} for the above problem may exceed $x_{oa}(c)$ when stock is large. If it does, then the constraint $x_t \le x_{oa}(c)$ is binding and hence the second-best solution will coincide with the open access outcome for stock levels large enough. ■

Figure 8 illustrates Proposition 3. The phase diagram describes the loci $\dot{x} = 0$ and $\dot{S} = 0$ as well as the saddle paths for three cases: (1) the first best when the marginal extraction cost were *c*-*g* with zero governance costs, (2) the second best with marginal extraction cost *c* and marginal governance cost *g* (i.e. optimal given governance costs), and (3) the first best with marginal extraction cost *c* and zero governance costs. When stock is large, the constraint $x_t \le x_{oa}(c)$ for the second-best solution may bind. Hence, open access can be the second best when resource is relatively abundant.

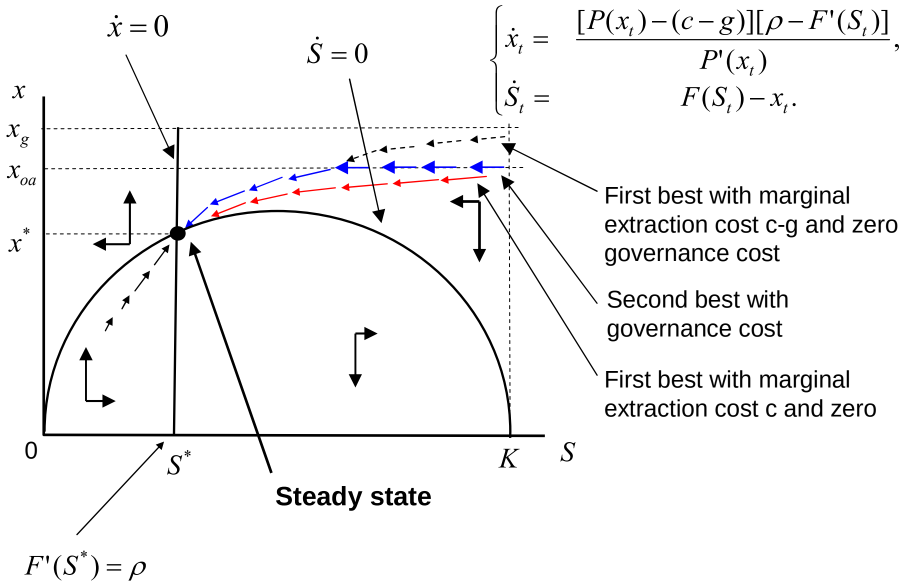


Figure 8 Open access may be the second best when stock is large.

3.3 Numerical example

To illustrate the above proposition, we present a simulation result based on a discrete-time version of the model. The stock transition is given by

$$S_{t+1} = (1+r)z_t\left(1 - \frac{z_t}{K}\right),$$

where $z_t \equiv S_t - x_t$ is the recruitment in period *t* given stock S_t and harvest x_t. With discrete time, harvest in each period is constrained by the existing stock: $x_t \le S_t$ for all *t*. The second-best problem is then given by

$$\max \sum_{t=0}^{\infty} \delta^t \left\{ \int_0^{x_t} P(\omega)d\omega - cx_t - g(x_{oat} - x_t) \right\}$$

subject to

$$S_{t+1} = (1+r)z_t\left(1 - \frac{z_t}{K}\right), \quad 0 \le x_t \le S_t,\ z_t = S_t - x_t,$$

for all t given S_0>0. The solution satisfies the following dynamic programming equation:

$$V(S) = \max_{0 \le x \le S} \int_0^x P(\omega)d\omega - cx - g(x_{oa} - x) + \delta V(S') \tag{1}$$

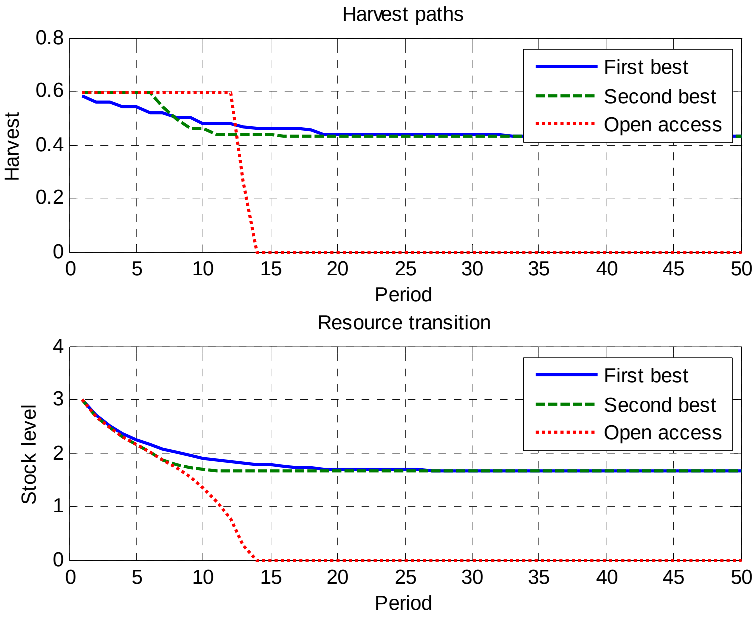
$$s.t. \quad S' = (1+r)(S-x)\left(1 - \frac{S-x}{K}\right). \tag{2}$$

The following simulation further assumes that the demand elasticity is constant:

$$P(x) = x^{-\gamma}. \tag{3}$$

In order to describe the dynamics of resource use starting with an untouched resource, the initial stock S_0 is set equal to the carrying capacity K.

Case 1: Low governance cost


Harvest paths

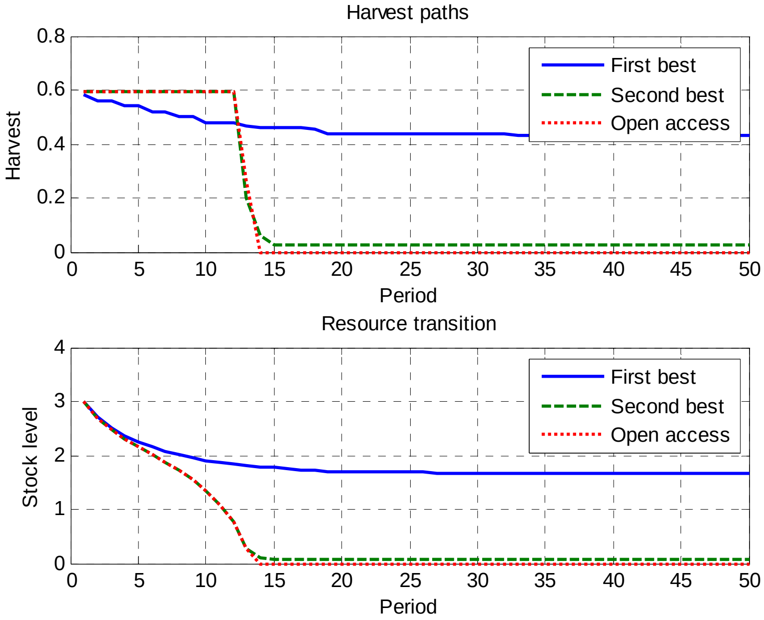
Resource transition

The simulation is based on the model (1)-(3) with the parameter values r=0.6, K=3, $\gamma = 0.5$, $c = 1.3$, δ= 0.9, $g = 0.7$.

Figure 9 Harvest and resource stock when governance cost is small.

In this case, open access is the second best when the stock is large. Until period 7, the open access and the second best outcomes coincide with each other. In later periods, as resource becomes scarcer, positive rents are generated. The second best stock level converges to the first best level (because the unit harvesting cost is stock independent; with stock-dependent costs, the second best steady state stock level may not be the same as the first best level).

Case 2: High governance cost



The simulation is based on the model (1)-(3) with the parameter values r=0.6, K=3, gamma = 0.5, c = 1.3, δ= 0.9, g = 2.9.

Figure 10 Harvest and resource stock when governance cost is high.

In this case, the second best outcome coincides with the open-access outcome throughout the periods because of high governance costs. This outcome will occur if the governance cost exceeds the total surplus at the steady state (see Figure 7).

These simulation results illustrate the dynamics of resource governance institutions that are consistent with many natural resources. In particular, case 1 indicates that the governance institution of a resource is not necessarily a fixture throughout the resource's life cycle. As we observe with many cases studies listed in section 1, institutional changes occur, and the changes involve transitions from open access with no governance to common property and to private property.

5. Discussion

We developed a dynamic model of natural resource management in order to illustrate how institutional change occurs over the life cycle of a natural resource. This model allows us to analyze not only what resource characteristics and economic conditions of harvested goods determine a resource's property right regime in steady state, but also how and when resource governance may change on the transition path to the steady state.

The resource manager incurs a cost of institutional governance in order to restrict resource use to a level below what would prevail under open access. We demonstrate that open access can be the second best outcome when resource abundance renders the gains of first-best resource management greater than the costs of governance. However, as resource extraction continues and scarcity increases, the marginal benefits of governance increase. Unless the governance cost is sufficiently large, it becomes optimal to switch from zero governance (with open access) to positive governance (with positive resource rents). If the governance cost is sufficiently large, the optimal resource management regime is open access at all resource stock levels. Inasmuch as extinction may be optimal even in first-best models (Spence, 1973), the presence of governance costs increases the likelihood of optimal extinction.

For a small open economy (or a local resource) with an exogenous price of harvest, we find the following regarding institutional change:

- When resource is abundant, allowing open access is the second best given costly governance. Eventual institutional change from open access to governance is the second best if and only if the costs of governance are small. If institutional change requires a positive investment cost, and if governance is the second best, then overshooting occurs: open access is allowed until the resource stock falls below the steady-state level, and then harvest is restricted so that the stock recovers to the steady state.
- When adopting governance is the second best, the steady state stock is lower than the first best level (that would prevail in the absence of governance costs) if the marginal governance cost is positive.
- The optimal timing of institutional change is delayed if the harvest price is larger or if the cost of governance is larger.

That the steady-state institutions differ for different resources has been discussed and explained in the literature of institutional economics (e.g. Copeland and Taylor 2009). Our model and simulation results illuminate efficiency and the timing of institutional change for a given resource according to governance costs and resource scarcity.

The model developed above can be extended in several directions. One step is to consider how changes in demand, harvesting costs, and governance costs over time influence institutional change.

We focused on explaining the optimal institutional changes given the cost of institutional governance. An analysis of how strategic interactions among resource users, and those between incumbent users and entrants, influence the equilibrium institutional changes is left for future research.

Appendix

Derivation of function τ with logistic growth

Recall the definition of function τ:

$$\tau(\underline{S}, S^*, \bar{x}) \equiv \int_{S^*}^{\underline{S}} \frac{1}{F(w)-\bar{x}}\,dw = \int_{S^*}^{\underline{S}} \frac{1}{rw(1-w/K)-\bar{x}}\,dw = \int_{S^*}^{\underline{S}} \frac{1}{-(r/K)w^2+rw-\bar{x}}\,dw.$$

Apply the following formula for integration:

$$\int \frac{1}{ax^2+bx+c}\,dx = \frac{2}{\sqrt{4ac-b^2}}\tan^{-1}\left(\frac{2ax+b}{\sqrt{4ac-b^2}}\right)+C.$$

Then

$$\tau = \frac{2}{\sqrt{4(-r/K)(-\bar{x})-r^2}}\tan^{-1}\left(\frac{2(-r/K)w+r}{\sqrt{4(-r/K)(-\bar{x})-r^2}}\right)\Bigg|_{S^*}^{\underline{S}}$$

$$= \frac{2}{\sqrt{4r\bar{x}/K-r^2}}\left[\tan^{-1}\left(\frac{2(-r/K)\underline{S}+r}{\sqrt{4r\bar{x}/K-r^2}}\right)-\tan^{-1}\left(\frac{2(-r/K)S^*+r}{\sqrt{4r\bar{x}/K-r^2}}\right)\right].$$

Similarly, with zero harvest rate, the time it takes for resource of size S_1 to grow to S_2 is given by

$$\tau(S_1, S_2, 0) = \frac{1}{r}\left[\log\left(\frac{S_2}{K-S_2}\right)-\log\left(\frac{S_1}{K-S_1}\right)\right].$$

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