From Rites to Rights:
The Co-evolution of Political, Economic and Social Structures

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Abstract

We attempt to illuminate both the nature and causes of growth and institutional change by using both archeological and historical evidence from natural resource use during the settlement and modernization of the Hawaiian economy to develop a candidate theory of the natural co-evolution of production systems, organizational forms and authority structures. Hawaii's resources are first controlled by hierarchy, which intensifies over time, until decentralization occurs after Western contact (1778). Changes in relative governance requirements over time inform a more general theory of second-best resource use in a dynamic setting that allows for institutional change to minimize governance costs.

Keywords: natural resource dynamics, institutional change, governance of the commons, Hawaiian economic development.

1. Introduction

In the beginning of his Nobel lecture, Douglass North opined that "The object of the field [of economic history] is not only to shed new light on the economic past, but also to contribute to economic theory by providing an analytical framework that will enable us to understand economic change." In paleoeconomics, the roles of theory and evidence may appear even more indeterminate. Note only can sparse evidence provide stylized facts that result in theory that applies both to the case in question and elsewhere, but theory may help to provide an account of what happened that is internally consistent as well as being consistent with the sparse evidence. To this end, we attempt herein to illuminate both the nature and causes of growth and institutional change by using both archeological and historical evidence from natural resource use during the settlement and modernization of the Hawaiian economy to develop a candidate theory of the natural co-evolution of production systems, organizational forms and authority structures.

We focus our search by summarizing the physical evidence brought forward by Kirch and his interdisciplinary team of researchers on Hawaiian pre-history. As we do, these researchers choose Hawaii because:

> “the archipelago… presents an ideal region for understanding complex interactions between human populations and their environments. In Hawaii such interactions can be tracked over a time frame of about 1200 years. During this period between the discovery and colonization of the archipelago by humans and the arrival of Europeans, archaeological research reveals the emergence of a highly complex island civilization which by A.D. 1700 had approached the level of an “archaic state.” In Hawaii, historical anthropologists and natural scientists have the opportunity to study the emergence of such complexity in the context of dynamic coupling with natural systems.” (Kirch, 2007)

We present sparse evidence in support of stylized facts about Hawaiian economic development, and expand the discussion into the historic era, where Hawaiian economic development shifts rapidly, though not uniformly, from hierarchical control to decentralized decision-making. We use this history to inform a dynamic model of natural resource governance. The model incorporates changes in resource values and enforcement costs for common property resources to explain the co-evolution of governance structures and resource pressures.

2. Archaeological and Historical Record

Over Hawaiian history, social organization went from family to hierarchy to more complex and larger hierarchy (vertical and horizontal expansion) to more decentralized private property. Transitions were gradual, e.g. with some private property coexisting with hierarchies. Even the great Mahele, often historically billed as a quick transformation in 1848 from hierarchy to private property, took many years to settle, and was incomplete, i.e. it left much land and marine resources as common property.

The standard division in Hawaiian history between the pre-historic record (until Western Contact in 1778) and the historic record masks the underlying pressures affecting the rapid institutional change that occurred following Western Contact. We divide the timeline with a slight distinction, first focusing on the evolution from the colonization of the islands to the monarchy and then investigating the switch to decentralized decision-making that evolved over the course of the 19th Century. This distinction helps drive the theory of institutional adaptation and its co-evolution with economic development as a function of the underlying economic pressures presented by factors that include resource use (intensification, capital formation, and abandonment) and relative price shifts from changes in supply and demand.

The co-evolution of governance and property with respect to resource scarcity can be clearly illustrated by considering these two distinct periods in Hawaiian history. The first period is further divided into sub-periods wherein property structures, governance, and scarcity pressures changed. The first period, encompassing all of Hawaii's pre-history, is divided by anthropologists into 4 eras: (1) Colonization, (2) Developmental, (3) Expansion, and (4) Proto-historic, which we link to their corresponding economic interpretations: extensive growth, intensive growth, and capitalization, and add (5) Unification, and (6) Independent kingdom, during which new opportunities for trade are introduced under an intensifying system of hierarchical control of a diminishing native population. The second period consists of the decline of the kingdom and the evolution to decentralization as a U.S. territory/state, categorized by increasing opportunities for trade and marked by differences in decentralization of common property resources as a function of their value.

2.1. Co-evolution of Specialization and Hierarchy before Private Property

Figure 1 summarizes available archeological and proto-historic evidence on the timing of Hawaiian cultural development until just after Western Contact. We reclassify these stylized anthropological periods for Hawaii (Kirch, 1985) until unification under Kamehameha I (the inception of the monarchy) to depict stages of economic growth. During this time, the institutional framework evolved from family networks to an intensive hierarchy though the overall *ahupua'a* and *kapu* systems operations maintained a defining continuity.[1] These systems of production and enforcement could be, and were, intensified or relaxed, within limits, to accommodate population growth and capital formation.

[1] See Appendix 3

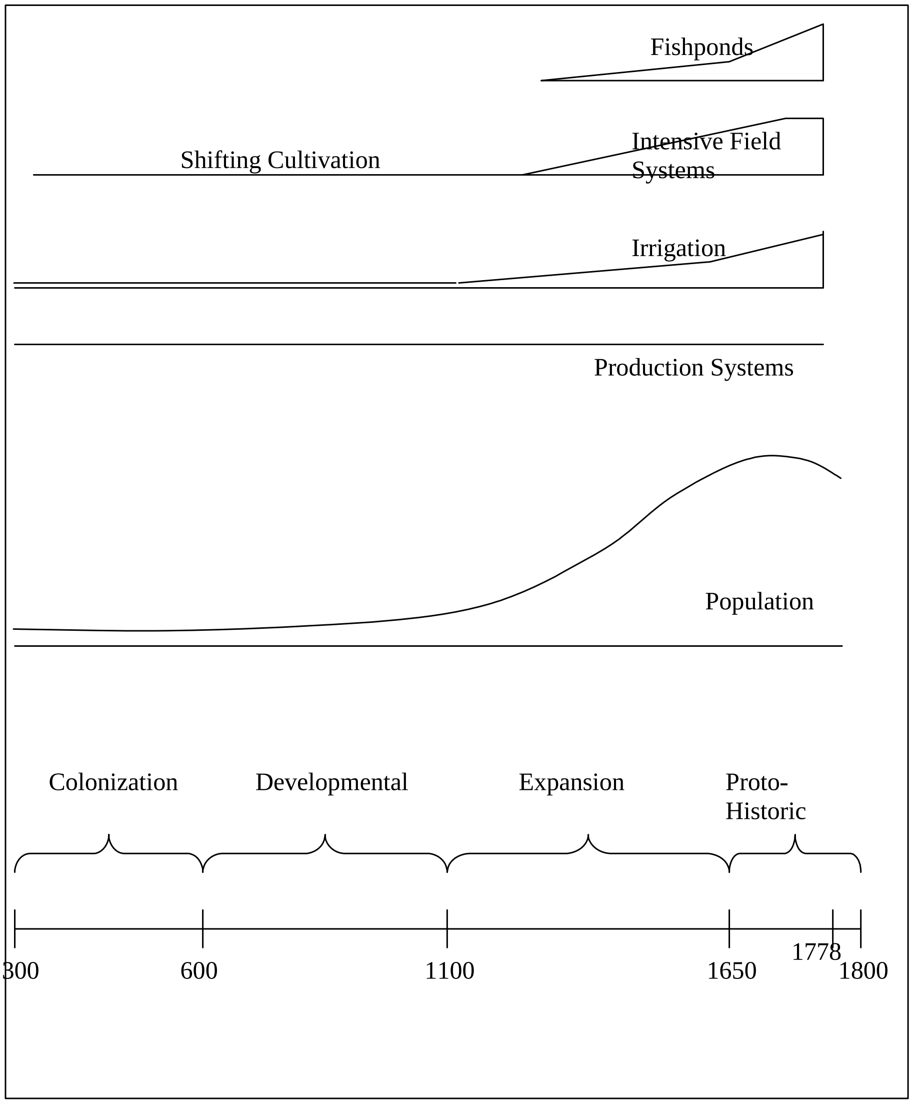

Figure 1: Timeline for Hawaiian resource use and development (Adapted from Kirch (1985), p. 300-1

Colonization and development are combined as a period of extensive growth as Polynesians arrive and sparsely settle coastal areas, moving slowly upland. Populations may have been very small, perhaps 100 people in an extended ‘*ohana* (Kirch, 1996). Governance for some time after the Polynesians arrived in Hawaii (roughly 400 A.D.) developed under an ´*ohana* (community management) system wherein the patriarchs of each extended family determined production and enforcement. Extremely low populations, the introduction of new agricultural products (e.g., pigs, taro), and the slow subsequent transformation of the most fertile valleys (wet, windward areas), adjacent to superior fishing grounds, grew into populated communities. Marine and terrestrial resource pressures were low,[2] and though societal institutions to govern resource scarcity, particularly the *kapu* (taboo) system, had traveled to Hawaii with the earliest Polynesian settlements, implementation and enforcement were low (Kirch, 1996).

From these beginnings, we see continuous evidence of increasing intensification of production both on land and at sea. Technology becomes standardized, evidence of intermediate goods produced by a rising class of specialized adze-makers and fishhook producers (Kirch, 1985, p. 184).

As populations grew and became more permanent in the Developmental era and into the expansion era, governance by family eventually extended to governance of the entire *ahupua´a* valley, under a single chief or *ali´i*. During the Expansion Period (1100-1650) population estimates increase to several hundred thousand, with some estimates as high as 800,000 (Kirch, 1985; Kame´eleihiwa, 1992). The acceleration of population growth, particularly from 1200-1650, was followed by the intensification of food production, including capitalization. Soil analyses of dryland agriculture indicate that virtually all arable lands were brought under cultivation (Kirch et al, 2004). The chief allocated land and labor within a valley to their uses and began to take advantage of the top-down power to achieve economies of scale and increased production intensity through specialization, eventually building large-scale irrigation projects and fish ponds in particular. Governance also accelerated, particularly at the end of the period. The archaeological record shows increased temple-building, consolidated control, and expansion of territory on both Maui and Hawaii from 1570-1630 (Kirch, 2005).

Other indications of intensified governance come from fish pond management. Strict limited access to the ponds controlled rent dissipation, and governance measures increased accordingly.[3] With little trading between *ahupua´a*, and the ability of the *ali´i* to reserve the catch for themselves, fishponds produced considerably greater sustenance for the higher levels of

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[2] It is clear from bone pile analyses that pig and dog populations were growing rapidly over the time period and increasingly supplementing the fish protein collected from the sea, and resources were increasing as transplanted food species took hold in the new environment.

[3] Only 30% of ahupua´a had associated fishponds (ponds never crossed ahupua´a borders), and the ponds' total area of about 6650 acres would have produced somewhere between 1.75 million and 2 million pounds of fish per year – about 6 to 9 pounds per person per annum at the time of contact (Kikuchi, 1985; Hammon, 1975). Population in the islands has been conservatively estimated at 200,000-225,000 in 1778, at contact.

the social hierarchy with little direct benefit to the commoners, though indirect benefits stemmed both from reduced fishing pressure on the coastal fisheries and from the increased fish population overall. Further details regarding coastal fisheries management are presented in Appendix 4.

The hierarchical *ahupua´a* system allowed the capture of the economies of scale necessary to develop these fishponds while the complementary *kapu* system provided the mechanism by which efficient harvesting could be enforced. Inasmuch as the ali´i captured the rents, this exemplifies a case in which the *primary action group* (Davis and North) undertakes the institutional innovation in question.

This system of control evolved into an extensive hierarchy during the Expansion era and eventually crystallized during the proto-historic period (1650-1785), at the height of the islands' population, exhibiting a much higher degree of social hierarchy, specialization, and governance structure than in other parts of Polynesia (Abbott, 1992; Handy and Handy, 1991).

Within this growing hierarchy, decision-making and authoritative duties begin to be addressed by different parties acting for the chiefs. "Low-level" *konohiki* resource managers[4] develop increasingly sophisticated irrigation[5] and communal fishing techniques, and fishponds are developed and evolve into true aquaculture,[6] a unique Hawaiian development amongst Polynesian cultures, to increase productivity. Kinship networks give way to specialized skills in fishing and farming, managed by the *konohiki*. Without external trade, hierarchical stratification increases, as do efforts at resource extraction for the benefit of the *ali'i*. The commoners produce for the *konohiki*, who controlled the water supply, determined the land allocations for the commoners, determined fishing rights, and allocated *ahupua'a* resources for production, especially labor for communal projects. The *konohiki's* duty to the *ali'i* was to meet an expected production goal to be presented during the *makahiki* festival, at which time the *ali'i* divided the tribute amongst his supporters in the chiefly class, including the *konohiki*. Increased governance came from the parallel development of a large priesthood and increasing use of the *kapu* to

[4] For illustration of Hawaiian hierarchy, see Kirch 1985.
[5] In particular, increased use of Type III irrigation systems, consisting of an irrigation canal running along the periphery of the field complex, allowing more sophisticated control of water distribution than was used in earlier Type II systems, where small groups of fields were watered by a single ditch that fed directly into the uppermost field.
[6] True aquaculture means that fish are bred and nourished in captivity; other Polynesian fishponds were holding pens fed by ocean tides.

restrict resource use and population. This mechanism supported an increasingly stratified society.

This stratification appears to have steepened more rapidly on marginal lands than on lands that produced large surpluses easily (Kirch et al., 2004, Vitousek et al, 2004). Without additional trade opportunities to increase economic growth, the proto-historic period also experiences increased warfare over increasingly scarce resources, mainly initiated by chiefs controlling these marginal lands. Appendix 3 summarizes in table form.

Hierarchy lingered past Western contact and its institutions for private property, culminating in the Hawaiian kingdom formed under Kamehameha I in 1805. Most local resources experienced dramatic changes in value and governance needs after western contact, however. While rent extraction by the Hawaiian chiefs was expected and accepted as the way of life, the hierarchical authority included a mechanism for transferring these rents every generation in order to maintain consolidated support for the *ali´i nui*, or head chief. This mechanism, the *mahele*, was a redistribution of rights from top to bottom that occurred with every change of leadership. With consolidation into the Hawaiian kingdom under King Kamehameha I after western contact, rent extraction opportunities increased rapidly. Kamehameha I, however, was a conservationist, and under his reign, three major fishpond projects were undertaken, and sandalwood trading with Westerners was carefully managed.

Enforcement costs of the consolidated hierarchy increased under his successor, Liholiho. Unable to bring about a *mahele*, the chiefs gained power to extract greater rents of their own, with greater competitive pressures among them, and sandalwood resources quickly dwindled (LaCroix and Roumasset 1984). The introduction of new religious institutions (Christianity in particular) and the apparent impotence of the Hawaiian gods in protecting the population from Western diseases rendered the *kapu* system less effective and the system was officially abandoned in 1819. (Kame'eleihiwa, 1992, p 140ff). Sandalwood was depleted by 1850, leaving not only a void in tradable goods, but also considerable environmental degradation to watersheds. Thus the greater scarcity of extractable resources increased the benefits of conservation just as the hierarchical institution designed to protect them failed due to the increased costs of governance

The subsequent transition to private property, frequently portrayed as an overnight coup defined as the Great *Mahele* of 1848, was neither instantaneous nor complete. Neither fully-formed fences nor production and enforcement systems materialized overnight, though the relative cost of moving to private property, despite the large initial fixed costs of the Great *Mahele* and in establishing a series of constitutions, had become efficient. The scope and breadth of central government authority increased; these constitutions established a cabinet, a civil service, and an independent judiciary by 1847. Through this expensive investment government lowered per-unit costs of providing governance and ensured a higher level would be provided. At the same time, the move lowered informational costs by enabling decentralized decision-making through private property.

The native population decreased, perhaps by 90% in a generation, rapidly deflating the pressures that drove specialization, intensification, and the growth of governance before Western contact. New products were introduced driving fundamental economic shifts and reducing the effectiveness of *ahupua'a* management in meeting society's needs. The *kapu* governance system was soon in tatters, raising the enforcement costs of hierarchy.

The population decline after Western contact was not accompanied by a direct reduction in resource pressures, however. Resource pressure from population growth alone is therefore insufficient to explain increases in governance and intensification. Instead, relative prices for resources began to shift; for example, with respect to marine resources, benefits from coastal fisheries for local demands were reduced while benefits from ocean fisheries for trade expanded. Institutions shifted accordingly, and governance efforts did not abate, as the new judicial system and placed control over public goods, particularly education, in the hands of a representative legislature (Daws, 1974, p. 107), which over time imposed more stringent rights and governance on the increasingly valuable ocean fisheries and a return to less stringent and more local enforcement in less valuable coastal fisheries.

As a less costly governance mechanism available within the existing Hawaiian institutions, the *konohiki* maintained governance rights over these less valuable coastal, common-property fisheries. Private decision-making within the new property rights system for fisheries continued to balance enforcement costs against benefits as well. *Konohiki* sought to incur the costs of fishery registration when the asset was more valuable, leaving less valuable assets to open access. Enforcement declined across all coastal fisheries as the resource value decreased over time.

Opportunities for exchange also promote specialization and intensification by increasing the value of the resource base. As the consumption set expands to include gains from trade and as the number of potential transactions expands, centralization of decisions will face increased costs as the informational burden increases. Efficiency is likely to give way to rent-seeking. Centralization of authority, however, should increase in order to meet increased governance requirements. These governance costs will include the high fixed costs of transitioning to a rule of law and establishing rights to property.

2.2. Stylized Facts and Synthesis

We can conveniently summarize from this archaeological and historical record the stylized facts before and after Western contact.

Before contact: The increase in population before Western contact was associated with increasing horizontal specialization and intensification of agricultural production and resource use. Both the control and decision-making aspects of governance became more centralized. Social hierarchies were closely aligned with increasingly vertically specialized managerial structures. Specialization was primarily within *ahupua'a* hierarchies, not across hierarchies.

After contact: Slightly before Western contact, and increasingly after contact, population declined, but intensification and specialization continued due to the opportunities afforded by international trade. Private property developed and decision-making became decentralized. Specialization across hierarchies developed along with trade.

Figure 2 illustrates these stylized facts. As private property expands, governance costs and government responsibility increase. Private property does not obviate the need for government intervention. As decision-making is decentralized, growth and development require institutional support for voluntary contractual exchange as well as for resolving externalities and public good problems imposed by the conflicting goals of individual decision-makers. At low levels of scarcity and specialization, centralization of authority and decisions increase together, to reduce idiosyncratic risks through mutual insurance and diversification, and exploit economies of scale in production, e.g. large scale irrigation works. The goal of the theoretical development to follow is to explain these patterns.

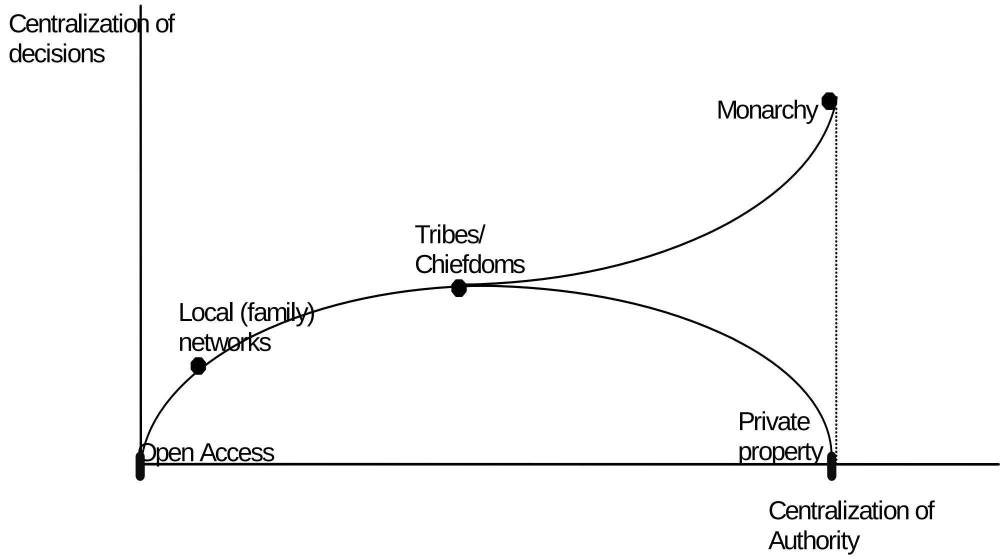

Figure 2: The Governmental Kuznets Curve

As resource pressures increase, returns to specialization, intensification, capitalization and governance require additional centralization of authority and decision-making, which can be developed in small populations, with limited opportunities for external economies of trade, through hierarchy. With larger populations or a change in opportunities for trade, hierarchy's relative inability to solve information problems may lead to institutional changes favoring decentralization of decision-making while increasing centralization of authority in the form of property rights.

At this point, the existing second-best theory suggests that institutions will change whenever the net benefits to doing so are positive. In particular, institutions that manage resources through common property, public property, or private property are perceived as comparable solutions to the open access problem, and comparing these institutions according to the extended Demsetz theory involves weighing known enforcement costs against the benefits that a particular institution delivers by reducing free-riding.

3. Dynamic Theory of Resource Use and Institutional Change

3.1. A Resource Capital Theoretical Base

The evolution of property has been at the heart of the New Institutional Economics since its inception. However, the theory is incomplete regarding the nature of agency costs and the lack of capital-theoretic foundations. We hypothesize that property coevolves with governance, which increases with the intensification and specialization of production; increasing scarcity of land and marine resources leads to more and broader governance and greater resource use restrictions, if enforcement mechanisms are also free to evolve. By drawing on the relatively short time span between settlement and modernization of the Hawaiian economy, we clarify at least one plausible mechanism for this co-evolution. As Hawaii moved from a Neolithic group of small isolated villages to a unified kingdom and finally to U.S. territorial status and eventual statehood, old and new institutions, some of which were imposed, overlapped. The experience provides an intriguing opportunity to study the natural co-evolution of decision and authority structures as resource scarcity, productivity, and trade increase, population fluctuates, production intensifies, and economic growth is characterized by both vertical and horizontal specialization.

In the Coasean paradigm, first-best efficiency, whether achieved through decentralized, centralized, or intermediate institutions, is only a point of departure for comparative institutional analysis. What is needed is a conceptual framework capable of generating propositions and explanations regarding which institution is second-best efficient under what circumstances.[7] The advocates of private property (Demsetz), public property (Hardin), and communitarianism (Ostrom) all implicitly agree that the relative efficacy of these institutions rests primarily on their ability to control the free-rider problem.

In what follows, we exploit resource economics in a generalized and dynamic setting to provide a theory that encompasses the full spectrum of Hawaiian economic development. In section 3.1.1 we recap the dynamics of optimal resource extraction to clarify the origins of the model, with a more complete exposition in Appendix 1. Then, in section 3.1.2, we describe the state of the literature and discuss what our general model adds in the context of the problems in achieving the first-best model. In section 3.1.3 we develop a second-best model that

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[7] This use of second-best follows Dixit (1996). He subsumes rent-seeking, corruption, and other elements of political economy is his theory of the 3rd-best.

incorporates the agency costs of achieving the first best resource levels, so that institutions can be compared according to their dynamic effects.

3.1.1. First Best Resource Extraction

To understand the first best solution, suppose that a resource stock at time *t* is *s(t)* is extracted at rate *x(t)* at a cost of *c(s(t))* per unit to obtain benefits (consumer surplus). Assume that *P(z)* is the inverse demand function or price of the resource. The cost of extraction is assumed to be a decreasing function of its own stock, $c'(s(t)) \leq 0$. The stock increases with natural growth, *F(s(t))*, and decreases with harvest, *x(t)*. The natural growth function, *F(s),* is assumed to have the traditional properties; strictly concave and attains a maximum at a finite value of *s*. Over time, the rate of change in stock is then $\dot{s} = F(s(t)) - x(t)$. Given discount rate *r*, a hypothetical social planner chooses the resource extraction path, *x(t)*, to maximize the present value of net social welfare, which includes the consumer surplus from resource consumption minus the cost of extraction, i.e.,

$$\max_{x(t)} V = \int_{t=0}^{\infty} e^{-rt} \left[\int_{0}^{x_t} P(z)dz - c(s(t))x(t) \right] dt$$

$$s.t.\ \dot{s}_t = F(s(t)) - x(t), \quad \underline{x} \leq x(t) \leq \overline{x}, \quad x(0) \text{ given},$$

Where $\underline{x} \geq 0$ is the level of subsistence dependence on the resource, which may equal zero if the resource has substitutes, and $\overline{x}$ is the maximum harvest allowed using the existing technology. After describing the standard current value Hamiltonian, finding, and solving the first-order conditions together (see Appendix 1), we find the condition that:

$$F'(s(t)) = r - \frac{\dot{P}(t) - c'(s(t))F(s(t))}{P(t) - c(t)} \tag{1.1}$$

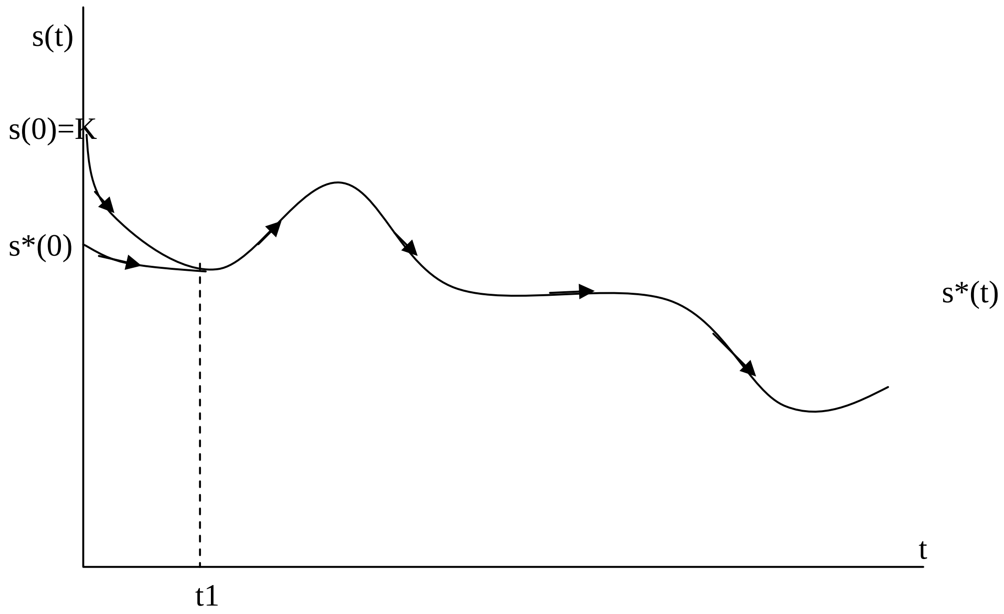
Equation (1.1) indicates that the change in the net natural growth rate of the resource stock equals the discount rate minus the percentage change in the resource value, i.e. a net growth rate of the value of the asset, including discounting. Equation (1.1) implicitly defines both the optimal stock (s*) and the optimal extraction (x*), at any point in time. Note that $F'(s(t)) > 0$ if $s < s_{msy}$ and $F'(s(t)) < 0$ if $s > s_{msy}$, where s_{msy} is the maximum sustainable yield stock level, or the stock level at which $F'(s(t)) = 0$.

Note that if the Hamiltonian expression (Eqn.(1.8)) is linear in the control variable, *x(t)*, as it is here, then the optimal solution will follow a most rapid approach path, where:

$$x(t) = \begin{cases} \underline{x} & \text{if } s(t) < s^*(t) \\ x^*(t) = F(s^*(t)) - \dot{s}^*(t)) & \text{if } s(t) = s^*(t) \\ \overline{x} & \text{if } s(t) > s^*(t). \end{cases}$$

Figure 3 illustrates a potential phase plane diagram for the optimal resource stock over time.

Figure 3: First Best Solution: Phase plane diagram for resource stock with optimal extraction over time. Here, a newly discovered resource moves to optimal levels along the most rapid approach path and is thereafter used optimally.



3.1.2. Theoretical Problems achieving the First Best Resource Levels

In the canonical theory (North and Thomas, 1973, and Demsetz, 1967), private property is thought to generate unambiguously higher benefits than open access to resources such as grazing or hunting lands. While it is now agreed that the first-best outcomes for resource use may be achieved by a variety of institutional forms for property (Ostrom (1990), for one, shows that it is theoretically possible that common property[8] can achieve efficient allocation and reviews substantial evidence suggesting that common property regimes were often effective at resource conservation), models of the tradeoffs among institutions in achieving these first-best outcomes remains vague and/or under-parameterized. This is due primarily to incomplete assessments of the second-best resource outcomes across institutional frameworks.

Without formal modeling, Demsetz (1967) argues further that once the efficiency benefits of the institutional change are greater than the enforcement costs, the institutional change will be effected, and private property will be adopted.

[8] Common property is distinguished from open access by its well-defined rules of access and management.

Field (1989) extends Demsetz's theory of institutional change in a useful but incomplete fashion. Field begins by noting that economic organization and growth of non-industrial economies can be classified into three stages. In the first stage, production is organized by families or small groups of families. In the second stage, these groups are consolidated into larger communal units. In the third stage, production devolves to family farms or other small production units, facilitated by private property. Accordingly, the evolution of property can be indexed by the number of commons. The marginal costs of exclusion are increasing in the number of commons, so that greater resource value is necessary to warrant the expense; complete decentralization under private property is achieved when the number of commons equals the number of firms (or families).

The theory is still incomplete, however, in a number of respects. The primary problem is that each institution is implicitly associated with a fixed value of benefits and costs. This is not Field's unique problem but the problem with the theory of institutional change generally.[9] Consider the marginal benefits of dividing the resource among more groups, each of which is responsible for its management. The proposition is that the costs of rent dissipation will go down with increased division. Field properly includes the costs of group contracting in with the costs of rent dissipation. The idea is that group contracting costs will go down in aggregate because of Olson's Law[10] and that rent-dissipation will go down because there is more accountability with smaller groups and the free rider problem will be better contained. But an optimization problem has been suppressed in this reasoning. For the group to manage its resources efficiently it will invest in group contracting and management until the marginal costs of so doing are equal to the marginal reduction in the value of rent dissipation that is achieved thereby.

Similarly, "exclusion costs" are at best a reduced form function of the number of commons. The suppressed optimization problem involves increasing exclusion expenditures until marginal value of reduced theft etc. equals marginal cost thereof. In section 4, we attempt to make these tradeoffs more transparent by exploiting the key insight of Jensen and Meckling (1976) that agency costs and residual departures from first-best efficiency are jointly determined. In addition, the potential economies of scale and opportunities for specialization need to be

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[9] Conventional theories treat different institutions as discreet entities. Field and Anderson-Hill (1975) implicitly index different institutions by a continuous variable.

[10] "Only a separate and 'selective' incentive will stimulate a rational individual in a latent group to act in a group-oriented way." Mancur Olson, The Logic of Collective Action (Cambridge: Harvard University Press, 1965).

incorporated in assessing that tradeoff. Finally, as the evolution of economic organization is fundamentally dynamic, the theory must rest on capital-theoretic foundations.

Inasmuch as government has a comparative advantage in some information and enforcement activities, we can extend these total system costs to include those of constitutional governance, e.g. defining and enforcing property rights (Libecap, 1978). In McChesney's (2002) consideration of the famous cattle-trampling of crops, enforcement is not limited to fencing but includes monitoring and enforcement activities by the state. In the efficient solution, governments and private actors each perform those information/enforcement activities in which they have a comparative advantage, much as the Coasean firm chooses to coordinate some production itself and subcontracts other production to outside suppliers. In this view property can arise through private enforcement efforts (e.g. Demsetz's (1967) Native American beaver trappers and Anderson and Hill's (1975) fencing farmers) or through Libecap's (1978) property-defining government.

One significant conceptual weakness of property rights theory is its overall lack of capital theoretic foundations. As an asset's value increases, it is natural to expect that investments in protecting or enhancing its value will increase over time. Anderson and Hill (1990) have provided a dynamic theory of a one-time investment in enforcement costs, e.g. building a fence, but have not considered the possibility of increasing governance-capital over time.

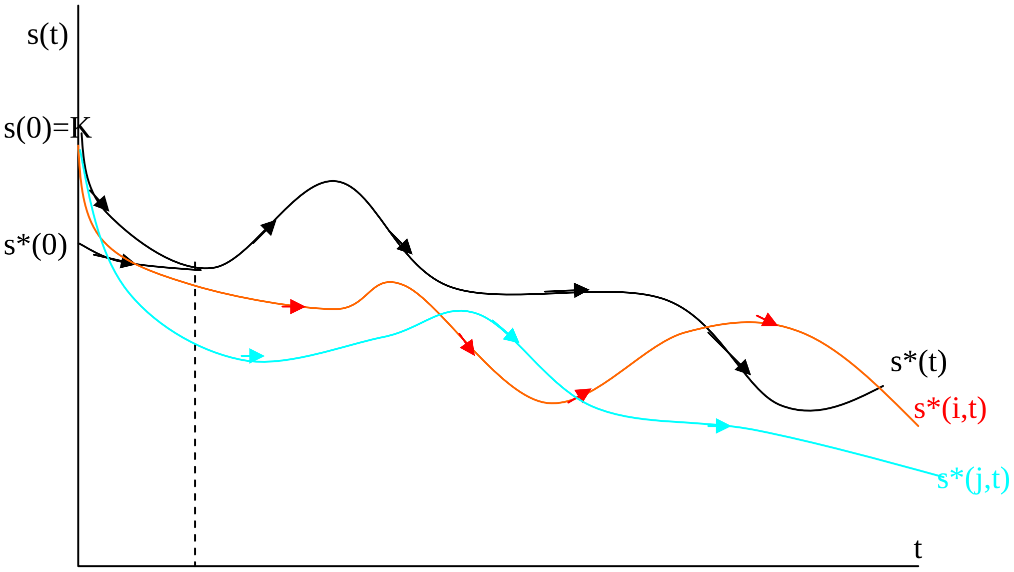
Even the extended theories of Anderson and Hill (1990) and Lueck (2002) are incomplete, however. First, they analyze only the steady-state institutional costs, wherein rents are fully dissipated under open access, fully captured under private property, and common property regimes lead to resource exploitation that lies between these steady states. Further, both implicitly assume that the enforcement costs of a particular institution are clearly defined. This in turn suppresses the problem of determining, for a particular organizational form, how much and what form of governance is optimal. For the case of common property management, for example, the community must determine the rights and responsibilities of members, and choose an incentive structure as well as its technology of enforcement. Until this governance structure is specified, neither the benefits nor costs can be determined.

3.1.3. Second Best Resource Extraction

Figure 4 illustrates the dynamic issues in the problem of the second-best. The red line, $s^*(i,t)$, and the blue line, $s^*(j,t)$ represent optimal paths given the constraints of possible institutional settings *i* and *j* respectively. These optimal paths differ from the first best socially optimal case because they have different "governance costs."

Figure 4: The problem of second-best resource conservation

$s^*(i,t)$



These governance costs have, in the property rights literature, come to include anything that is inefficient as a transaction cost, but this "deus ex machina" approach is more convenient than it is informative. We seek to make the components of our governance costs explicit, including transaction, agency, and enforcement costs. Thus, we first define governance costs *G(S(t)),* [where *S(t)* is the level of conservation of stock *s(t)* above the open access level of harvest (where $P(x(t)) = c(s(t))$), x_{OA}, so that $S(t) = x_{OA}(t) - x(t)$], as constitutional agency costs, including the actual resources used up in the enforcement and organizational effort plus the shirking costs that remain.[11] We elaborate further below, but it is instructive now, using this generic definition that is free from institutional form, to examine the impact of resource stock pressures on governance.

First, we incorporate enforcement (e.g. building fences, catching violators) and other costs of *administering* conservation into the problem. The open access harvest level, x_{OA}, is clearly a function of both the stock and the harvest levels. The level of conservation, thus, can be represented by the difference between open-access extraction (no conservation) and actual extraction, i.e. $x_{OA}\left(P(x(i,t)), c(s(i,t))\right) - x(i,t)$. We assume that the governance cost, *G*, is positive and an increasing function of conservation, $G'(S(t)) \geq 0$. More precisely, governance is non-decreasing in both the stock of the resource $\left(\frac{\partial G\left(x_{OA}\left(P(x), c(s)\right) - x\right)}{\partial s} \geq 0\right)$ and the harvest level of the resource $\left(\frac{\partial G\left(x_{OA}\left(P(x), c(s)\right) - x\right)}{\partial x} \geq 0\right)$. Intuitively, the marginal governance cost (MGC) is positive with respect to both stock and harvest levels because there will be more to protect with higher stock levels and more to distribute and monitor with higher harvest levels. *G* is assumed to be a stable function of conservation, i.e. even though the marginal benefits of conservation change over time, the governance cost function does not, for a given institution.

The form of these governance costs is here assumed to be increasing in the resource stock. This fits with the existing literature; it also highlights the limited dimensionality of the existing literature. As Allen (2002) and others have tried to explore these almost amorphous governance costs within the Coase-Demsetz framework, they have focused on one portion or another of a broad definition of transactions costs to fit a particular case. This broad definition can be divided into two camps, the "neoclassical" camp, where transaction costs are costs of exchange, and the "property rights" camp, where transactions costs are all costs of establishing and enforcing property rights (Allen, 1998).

Now recognizing that enforcement is costly, we can see that second-best optimal enforcement is generally less than that which generates the stock and harvest levels in the first-

[11] For the special case where the organization is a firm, governance costs are agency costs (Jensen and Meckling, 1976; Roumasset, 1995).

best solution. There remains ambiguity in these administrative costs. For now, one can think of the Marginal Governance Costs (MGC) as being either "short run," i.e. within a specific institutional framework, or "long run," i.e. the optimized governance structures including institutional change.

In the first-best solution, where enforcement costs are considered zero, $S^*(t) = x_{OA}(t) - x^*(t)$ for all t, so that optimal conservation occurs in all periods. In the second-best solutions, $S^*(i,t) = x_{oa}(t) - x^*(i,t)$, where $x^*(i,t) = x^*(t)$ only when governance is costless, e.g. under open access. In general, if governance costs are positive, then $x^*(i,t) > x^*(t)$ and conservation is lower than optimal. Thus $S^*(t) - S^*(i,t)$ is the net loss of conservation from optimal governance expenditures under institution *i*. Note that it is theoretically possible that an institutional structure could impose over-conservation.

We turn now to formalizing the model to include governance cost, so that institutions might be compared accordingly. The resource optimization problem within an institutional framework i, recognizing governance costs, can be written as:

$$\max_{x(i,t)} V = \int_{t=0}^{\infty} e^{-rt} \left[\int_0^{x(i,t)} P(z)dz - c(s(i,t))x(i,t) - G\Big(x_{OA}\big(P(x(i,t)), c(s(i,t))\big) - x(i,t)\Big) \right] dt$$

$$s.t.\ \dot{s} = F(s(t)) - x(t)$$

where we henceforth generally suppress the institutional subscript *i* for simplicity.

The corresponding current-value Hamiltonian is:

$$H = \int_0^{x(t)} P(z)dz - c(s(t))x(t) - Gx_{OA}\Big(\big(P(x(t), c(s(t))\big) - x(t)\Big) + \lambda(t)[F(s(t)) - x(t)] \tag{1.2}$$

Where $\lambda(t)$ is the shadow price of the resource (the marginal user cost). The first-order conditions are:

$$\frac{\partial H}{\partial x(t)} = P(x(t)) - c(s(t)) - \underbrace{\frac{\partial G}{\partial x_{OA}} \frac{\partial x_{OA}}{\partial P} \frac{\partial P}{\partial x(t)} + \frac{\partial G}{\partial x(t)}}_{MGC_x} - \lambda(t) = 0 \qquad \text{for all } t$$

$$\frac{\partial H}{\partial s(t)} = -c'(s(t))x(t) - \underbrace{\frac{\partial G}{\partial x_{OA}} \frac{\partial x_{OA}}{\partial c} \frac{\partial c}{\partial s(t)}}_{MGC_s} + \lambda(t)F'(s(t)) = r\lambda(t) - \dot{\lambda} \qquad \text{for all } t$$

where we simplify the notation by setting the marginal governance costs (MGC) with respect to harvest (*x(t)*) and stock (*s(t)*) equal to MGC_x and MGC_s respectively, as shown above.

Rearranging the first-order conditions, we obtain an expression for resource royalty, net of governance costs:

$$P(x(t)) - c(s(t)) - MGC_x(t) = \lambda(t) \tag{1.3}$$

Taking the time derivative of Eqn. (1.3) and solving the first-order conditions together:

$$F'(s(t)) = r - \frac{\dot{P} - c'(s(t))F(s(t)) - M\dot{G}C_x - MGC_s(t)}{P(x(t)) - c(s(t)) - MGC_x(t)} \tag{1.4}$$

where the change in the net natural growth rate of the resource stock, $F'(s(t))$, again equals the discount rate minus the percentage change in the resource value, i.e. a net growth rate of the value of the asset, including discounting. Now, however, the resource value includes the costs of governance.

Note that, as with the first-best case, if the Hamiltonian expression (equation (1.2)) is linear in the control variable, *x(i,t)*, as it is here, then the optimal solution will follow a most rapid approach path, where:

$$x(i,t) = \begin{cases} \underline{x} & \text{if } s(i,t) < s^*(i,t) \\ x^*(i,t) = F(s^*(i,t)) - \dot{s}^*(i,t)) & \text{if } s(i,t) = s^*(i,t) \\ \overline{x} & \text{if } s(i,t) > s^*(i,t). \end{cases}$$

Using Equations (1.1) and (1.4) together, assuming a constant discount rate across institutions, with 1 and 2 indexing first and second best respectively, so that the stock level in the first-best optimal case is s_1 and the stock level in the second-best case is s_2, then we can identify the relationship between the first-best optimal and the second-best optimal for any given institution at any given time as satisfying:

$$F'(s_1) - F'(s_2) = \frac{\dot{P}_2 - c'(s_2)F(s_2) - M\dot{G}C_x - MGC_s}{P_2 - c(s_2) - MGC_x} - \frac{\dot{P}_1 - c'(s_1)F(s_1)}{P_1 - c(s_1)} \tag{1.5}$$

In other words, the difference in the net natural growth rates from the first-best to the second-best should equal the difference in the percentage changes in the resource values from the second-best (including governance costs) to the first-best resource use levels.

If we assume for simplicity that marginal costs of extraction are zero ($c(s) = 0$) and that that the system is in a steady state where there are no changes in prices or marginal governance costs, then equation (1.5) simplifies to

$$F'(s_1) - F'(s_2) = \frac{-MGC_s}{P_2 - MGC_x}, \text{ or}$$

$$P_2 = MGC_x + \frac{MGC_s}{F'(s_2) - F'(s_1)} \tag{1.6}$$

Since MGC_x and MGC_s are assumed to be increasing in harvest and stock respectively, so then is P_2. Differences in the relative stock levels will affect the second best price through the growth levels. Since under most functional forms of growth functions, $F'(s_1)>F'(s_2)$ if $s_1>s_2>s_{msy}$, then when $s_1>s_2>s_{msy}$ the effect of higher marginal governance costs for the stock on the second best price will be dampened and vice versa for $s_2>s_1>s_{msy.}$ For the cases where stocks are below maximum sustainable yield, the effect on price will depend on depensation tendencies in the growth function. In the case of no depensation (simple logistic growth), for example, then $s_2<s_1<s_{msy}$ results in a higher price and vice versa for $s_1<s_2<s_{msy.}$

Governance costs of the stock and the harvest will clearly raise the second-best price above marginal user costs when the higher costs of governing the harvest and stock combine with higher growth rates at the second best stock level. If growth rates for the second best stock level are lower than at the first best, then the effect on price is dampened or could potentially lower price below the first best price (i.e. below marginal user cost, in which case open access may be optimal).

Furthermore, using equation (1.4) for two institutions, i and j respectively, equation (1.7), below, shows how two institutions' net resource growth rates and values should vary, given differences in their governance costs:

$$F'(s(i,t)) - F'(s(j,t)) = \frac{\dot{P}(j) - c'(s(j,t))F(s(j,t)) - M\dot{G}C_x(j) - MGC_s(j,t)}{P(x(j,t)) - c(s(j,t)) - MGC_x(j,t)} - \frac{\dot{P}(i) - c'(s(i,t))F(s(i,t)) - M\dot{G}C_x(i) - MGC_s(i,t)}{P(x(i,t)) - c(s(i,t)) - MGC_x(i,t)} \quad (1.7)$$

As above, we simplify for exposition. Under steady state conditions with no changes in prices and governance costs and zero marginal extraction costs, for the two institutional systems to generate identical growth rates (and stock populations), the following will hold:

$$MGC_s(j)/ MGC_s(i) =(P(j)-MGC_x(j)) /(P(i)-MGC_x(i)). \quad (1.8)$$

We see in this simplification that institutions will have equivalent effects on resource growth when the ratio of the marginal governance costs of the stock are equal to the ratio of the difference between the price and the marginal governance costs of the harvests across the institutions. Furthermore, the within-institution ratios *of* $MGC_s(k)/(P(k)-MGC_x(k))$ will be equal across institutions, or in other words the substitutability ratio between marginal governance of the stock and marginal governance of the harvests net of price are equal across the institutions. We label this within-institution ratio the marginal rate of stock to harvest governance substitution. We consider that it reflects the institution's structural 'technology' for achieving lowest-cost second best outcomes in terms of resource populations and growth.

When the growth rate of the resource under institution i is greater than that of *j*, we then note that the marginal rate of stock to harvest governance substitution for institution *j* is lower than that of institution *i*. Thus, when $F'(s(i))>F'(s(j))$, then the marginal rate of stock to harvest governance substitution is lower for institution *j* than for *i*, and vice versa. Thus in cases where $F'(s(i))>F'(s(j)) \Rightarrow (s(i))>(s(j))$, such as when stock levels are greater than S_{msy}, then $s(i)>s(j)$ corresponds to the marginal rate of stock to harvest governance substitution being lower for institution *j* than *i*, and vice versa.

When considering the dynamic path, then, we can see that changes in the relative institutional advantages between governance of the stock and governance of the harvest, as well as changes in relative prices associated with the different harvests, should change the optimal institutional framework.

For clarity and generality, we do not further assign functional forms to specify possible dynamic paths that optimal resource use takes over time here (see e.g. Clark, 1990, for visual representation of various functional forms), nor do we model the human population growth or labor decision as integral to the use of the resource stock; unlike the Brander-Taylor (1998) model we do not automatically assume that the population is dependent on this resource for survival (i.e. $\underline{x}$ may equal zero) and thus we assume a more broadly applicable, exogenous demand curve that easily reflects changes in relative prices for alternative goods. Rather we describe the static first and second-best outcomes at different points in time to emphasize the shift in resources to compensate for the move to the second-best outcome.

4. Application to the Hawaii Case

4.1. Growth and institutional change

We hypothesize that had Hawaii maintained independence as a kingdom longer after western contact rather than becoming part of the United States in the late 1890s, the centralization of authority and decisions would have been unstable and failed to last (Glaeser & Shleifer, 2003). Of the many Pacific Island kingdoms that developed via similar hierarchical processes to Hawaii, only Tonga remains a monarchy today. The Tongan monarchy is increasingly unstable, as population pressures that challenge longstanding mandates of land tenure[12] make it difficult to resist calls for democratic reform and devolution of power; its first democratically elected prime minister took office in 2006.

[12] Each male at age 16 is to receive 8.25 acres [U.S. Department of State Background Note, Tonga, 2003]

According to the theory set forth above, efficient governance becomes more centralized as an economy grows, while efficient decision-making becomes first more centralized then more decentralized. An alternative path, where decision-making also continues to become more centralized, is not expected to be optimal as the constitutional agency costs shift to favor a system that minimizes governance costs at a higher governance level, capable of sustaining higher resource pressures. Furthermore, within every institutional framework, governance efforts increase in response to benefits of greater specialization, intensification and greater resource scarcity. The Hawaiian record is consistent with this perspective.

Extensive growth, characterized by consistently replicated patterns of use, results in constant returns to inputs of labor and capital as long as the underlying resource base is constant. Extensive growth requires little governance or enforcement. As such, decision structures may be fairly flat and authority rather decentralized. In Hawaii, this is clearly the case in the colonization and development eras; as *ohana* networks provide both the decision-making and the authority at the level of the extended family, or tribe.

Once the best land is brought under cultivation, production expands according to the increasingly intensive Ricardian gradient. As returns diminish, specialization and intensification may evolve to increase yields from an existing resource base through land-saving technical change. The use of labor-saving tools begins along with modest capital accumulation. Intensive growth is further promoted by specialization, as witnessed by standardization of production tools and techniques. Increasingly centralized decision-making facilitates horizontal specialization by task. Vertical specialization increases. The chiefs and *ali'is* are not replaced; they are merely consolidated by adding vertical layers. Governance expenditures increase accordingly as warranted by the gains from *horizontal specialization.* In the case of Hawaii, as population grew and spread from the coast inland, intensification generated stronger links between *'ohana* and the hierarchical authority and decision-making increased together, taking advantage of increasing specialization in agricultural and fisheries inputs and outputs.

Evidence from joint archaeological and soil scientist work (Vitousek et al, 2004; Kirch et al, 2004) on the intensification of dryland agriculture on Maui and Hawaii versus the less labor-intensive, higher-surplus irrigated wetland agriculture on Kauai and Oahu may explain why the more aggressive and expansive chiefdoms grew from Maui and Hawaii, and that final unification came under a chief from Hawaii, rather than the older islands of the archipelago. These chiefs were motivated to increase their authority and expand their territory because the rents they could extract from the marginal lands they controlled were lower than those extracted by the chiefs irrigated wetlands.

As demand increases, whether due to increased population pressure or increased opportunities for rent-seeking, resource productivity may be enhanced through capitalization that captures economies of scale. Infrastructure and other capital-deepening enterprises may increase the productivity of existing resources (e.g. the effect of irrigation on land and water productivity) and/or increase resource flows from existing stocks. Increasingly centralized authority and decision-making will together increase the ability to capture economies of scale. As the hierarchical authority in Hawaii strengthened, large capital projects, particularly fishpond construction to enhance fish stocks and irrigation projects to increase taro production, were undertaken, with rents accumulating mainly to the high chiefs.[13]

Though the big picture of institutional change in Hawaii is one of increasing resource pressure accompanied by increasing governance and decentralization of authority, governance may also vary over space and time according to the present value of the remaining resource stock. For example, when costs of maintaining property rights increased for the *konohiki* fisheries at the end of the 19th century, responses varied according to economic benefits of the resource, with higher-valued fisheries commanding greater effort in the establishment of rights. Furthermore, as time decreased the value of all coastal fisheries due to native population reduction, increasing international trade and the greater availability of preferred substitutes, governance over all coastal fisheries decreased.[14]

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[13] From records of oral genealogical history, we know that populations must have been driven to create ponds as soon as there was sufficient labor available to do so, if appropriate environmental conditions existed. There are at least 6 fishponds constructed on Oahu and Kauai before the 13th Century (Kikuchi, 1973). Also at this time communities begin to develop in the drier, leeward valleys, suggesting population expansion and resource pressures. The primary growth in fishponds is attributed to the 16th Century (Kikuchi, 1973), as is the growth in population. By the 18th Century, repairs to existing ponds may have been as important as new construction. The last ponds were constructed at the beginning of the 19th Century, as Western contact and the resulting population decreases changed the social structure and manpower of the islands. There were also more profitable opportunities for the *ali´i* developing in trade for other resources, particularly sandalwood.

[14] See Appendix 4 for supporting discussion

Throughout the process of consolidation, the responsibilities of the commoners changed little; each was expected to perform his farming or fishing duties under the authority of the *ahupua'a konohiki*. Two important trends evolved, however. First, the commoners developed specialized skills (e.g. in taro and dryland farming and various fishing techniques), enhancing resource productivity while tying them more closely to the *ahupua'a* (Handy and Handy, 1991, p. 310ff). Second, the *konohiki's* role of manager evolved with increased responsibilities and specialized knowledge (e.g. organizing *hukilau*, irrigation and other communal activities). When the position of *konohiki* first emerged (during the expansion period), he was primarily a tax collector providing service for a superior *ali'i* in return for status and a portion of the harvests. By the time of the Great *Mahele*, his role had been gradually transformed into a position that claimed ownership of the resources, and the associated ability to make decisions. This presented the attractive option to separate authority and decision-making in the move to private property by leaving the management of low-value coastal resources to the *konohiki*, lowering governance costs of the new system.

5. Conclusions

We provide a dynamic theory of property rights focused on the co-evolution of governance, specialization, intensification, and economic growth. In particular, we elucidate the dynamic foundations needed for a complete theory of second-best resource management and introduce the concept of marginal rates of stock to harvest governance substitution within an institution to distinguish governance tradeoffs amongst institutional options. We have also sketched a categorical theory explaining why, as the benefits of resource management increase with population pressure or other causes of specialization, governance costs increase both within and across institutions. A methodological point of possible interest is that second-best analysis cannot proceed without first-best analysis. Indeed this is implicit in Coasean analysis. It is precisely the proposition that, absent transaction costs, different institutions are capable of the same first-best solution, which allows us to use the first-best solution as a benchmark against which the transaction costs of alternative institutions can be compared.[15]

[15] For this to be generally true, we must use transaction costs in its broadest sense, i.e. that transaction costs are the costs of running the economic system and are the equivalent of friction in physical systems (Williamson, 1985).

More specifically, with respect to alternative solutions to the open access problem, we have shown the following. First, it is not necessarily a problem; open access can be the first-best solution. This is the case in early Hawaiian history, when resource pressures were low, and though the *kapu* institution was available as it was brought with the first settlers, its use was expectedly minimal. Second, even if open access is first-best inefficient, it is not necessarily the case that open access is inferior to at least one of the three proposed alternatives; it can be second-best efficient. Indeed, we have suggested that there is a second-best transition, as the optimal degree of specialization increases, from open access to common property management to private property, which helps to explain the *governmental Kuznets curve*.

The second-best theory of induced institutional change predicts an increase in conservation effort as population pressure and modernization deplete natural resources. Unlike previous theoretical frameworks, the suggested theory allows for changing resource extraction (or changing investment) over time. We witness this increase in conservation effort in Hawaii along with institutional development that benefits from the ability of hierarchy to capture economies of scale in land and resource management, and then seeks to benefit from the change in relative benefits by decentralizing decision-making into the hands of the *konohiki* rather than the king. The increase in governance and the institutional change from open access to the intermediate *ahupua΄a* system and later to a centralized system accord with second-best theory. Religion and brutal hierarchical control were used effectively to enforce limited access at relatively low cost.

While the co-evolution of intensification, specialization, and consolidation are consistent with second-best theory, subsequent developments require third-best analysis. For example, while centralized governance was initially effective at resource conservation (under King Kamehameha I), the inherent opportunities for rent-seeking were exploited by King Kamehameha II (Liholiho) and subsequent rulers. The intervention of Western culture and politics created an additional third-best force at odds with efficient institutional change. Western influence stressed the hierarchical system in at least two ways. First, it provided opportunities for specialization and trade beyond *ahupua'a* boundaries that were not readily captured under *ahupua'a* governance. Second, Western contact increased the benefits of extracting labor taxes from the commoners in order to import status goods.

From Hawaiian history, we garner three potential trends in institutional evolution. First, each institutional framework has some flexibility in accommodating increased governance. Governance within an institutional system can respond to changes in resource pressures, albeit large changes in relative prices may occasion a transition to new institutions. Subsequently, we see continued evidence of the ways in which resource use intensifies and develops, creating economic growth, even with population decline rather than growth. Finally, institutions do not simply switch instantaneously from one form to another, even when they are seemingly imposed. The example of the *konohiki's* slow transition from a minion of the *ali'i*, to an incentive-driven resource owner, shows the shift from manager to owner that accompanies a shift from a common property regime to a private property one.

As Hawaii's population increased, production systems were intensified. Social organization became increasingly complex, accommodating increasing division of labor. The increased vertical and horizontal specialization was facilitated by new incentive and governance structures summarized by the *governmental Kuznets curve*. Specifically, we witness a natural progression from a small, ohana network of reciprocal exchange, managed by a clan chief, to an increasingly stratified hierarchy and resulting in a monarchy in 1805. With Western contact, relative resource values diverge greatly from the past, and a new path toward decentralization of decision-making begins while centralization of authority is transferred from one institutional framework to another but continues to intensify, despite the decline of population. With respect to marine property, this increasingly centralized authority is evidenced in the increasing adoption of open-access fishing restrictions. At the same time the government foregoes its previous rights to shares of the catch, which are dwindling in economic importance.

We see increased governance and development of hierarchy as populations grow. In addition, it follows that the value of marginal land, as the land is being cleared with population growth and added to the resource base, satisfies the condition that the cost of clearing equals the present value of implicit rents that it earns in the future. In this case, the marginal user cost of land as capital is constant until the land frontier is reached and intensification begins. With even greater population pressure, intensification and resource depletion, however, potential gains from trade across districts increase (LaCroix and Roumasset, 1984) and the dictatorial hierarchies controlling each ahupua´a economy were not well suited to exploit those opportunities. If such potential gains are large enough to warrant the increased governance costs of further centralization of authority (albeit not necessarily of decision-making), the second-best theory predicts that such institutional change will take place. At the time of Western contact, Hawaii was headed for just this sort of unification of authority.

Inasmuch as Western institutions were exogenously imposed, we cannot be sure that hierarchical authority would have eventually withered away and been replaced by market institutions. Considerable specialization and exchange was possible within the hierarchical system. The development of the position of *konohiki* as a specialized land manager and then its transformation into resource owner exemplifies the interdependence of specialized skills and productivity, which intensifies along with institutional change.

To the extent that inter-district trade is facilitated by centralized authority and decentralized decisions, two questions arise that may be suitable for further research. First, can the decentralization of decision-making evolve from the top-down system of medieval Europe or pre-contact Hawaii without violence or external force? Second, where decision-making is centralized as well as authority, e.g. as in socialism, is it prudent to transition directly to decentralized exchange at the national level or is devolving central authority to a sub-national level a useful intermediate step?

We hope that the theory provided here is found to be applicable elsewhere. While we have emphasized the role of efficiency in determining the coevolution of production and governance, extended models will have a less deterministic flavor. In particular, the balance of rent-seeking and efficiency will vary according to specific circumstances. While replacement of the Hawaiian monarchy by private property was accelerated by coincidence, other economies may exhibit more institutional inertia. Shocks to population (e.g. from disease), changing international demands and the transaction costs of trade, and shocks to the resource base itself, e.g. via invasive species, are natural candidates to explore in numerical analysis.

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Appendix 1: First Best Resource Extraction

To understand the first best solution, suppose that a resource stock at time *t* is *s(t)* is extracted at rate *x(t)* at a cost of *c(s(t))* per unit to obtain benefits (consumer surplus). Assume that *P(z)* is the inverse demand function or price of the resource. The cost of extraction is assumed to be a decreasing function of its own stock, *c'(s)≤0*. The stock increases with natural growth, *F(s(t))*, and decreases with harvest, *x(t)*. The natural growth function, *F(s),* is assumed to have the traditional properties; strictly concave and attains a maximum at a finite value of *s*. Over time, the rate of change in stock is then $\dot{s}(t) = F(s(t)) - x(t)$. Given discount rate *r*, a hypothetical social planner chooses the resource extraction path, *x(t)*, to maximize the present value of net social welfare, which includes the consumer surplus from resource consumption minus the cost of extraction, i.e.,

$$\max_{x(t)} V = \int_{t=0}^{\infty} e^{-rt} \left[\int_{0}^{x(t)} P(z)dz - c(s(t))x(t) \right] dt$$

$$s.t.\ \ \dot{s}(t) = F(s(t)) - x(t), \quad \underline{x} \le x(t) \le \overline{x}, \quad x(0) \text{ given},$$

Where $\underline{x} \ge 0$ is the level of subsistence dependence on the resource, which may equal zero if the resource has substitutes, and $\overline{x}$ is the maximum harvest allowed using the existing technology. The corresponding current-value Hamiltonian is:

$$H = \int_{0}^{x(t)} P(z)dz - c(s(t))x(t) + \lambda(t)[F(s(t)) - x(t)] \qquad (1.8$$

where λ_t is the shadow price of the resource (which is equal to the marginal user cost). The first-order conditions are:

$$\frac{\partial H}{\partial x(t)} = P(x(t)) - c(s(t)) - \lambda(t) = 0 \qquad \text{for all } t$$

$$\frac{\partial H}{\partial s(t)} = -c'(s(t))x(t) + \lambda(t)F'(s(t)) = r\lambda(t) - \dot{\lambda} \qquad \text{for all } t$$

Rearranging the first-order conditions, we obtain an expression for resource royalty:

$$P(x(t)) - c(s(t)) = \lambda(t)$$

Solving the first-order conditions together:

$$P(t) = c(t) + \frac{\dot{P} - c'(s(t))F(s(t))}{r - F'(s(t))} \tag{1.9}$$

where P is the resource price, and the RHS represents the marginal opportunity cost (MOC), composed of c, its marginal extraction cost (MXC), and the marginal user cost evaluated at the end of the period (MUC).[18]

This can also be written as:

$$F'(s(t)) = r - \frac{\dot{P} - c'(s(t))F(s(t))}{P(x(t)) - c(s(t))} \tag{1.10}$$

Since the right-hand side of (1.9) is the marginal opportunity cost, (1.9) states that optimal resource extraction is achieved when the marginal benefit (price) of resource use equals the marginal opportunity cost.[19] Equation (1.10) restates this condition so that the change in the net natural growth rate of the resource stock equals the discount rate minus the percentage change in the resource value, i.e. a net growth rate of the value of the asset, including discounting. Equation (1.9) or (1.10) implicitly defines both the optimal stock (s*) and the optimal extraction (x*), at any point in time.

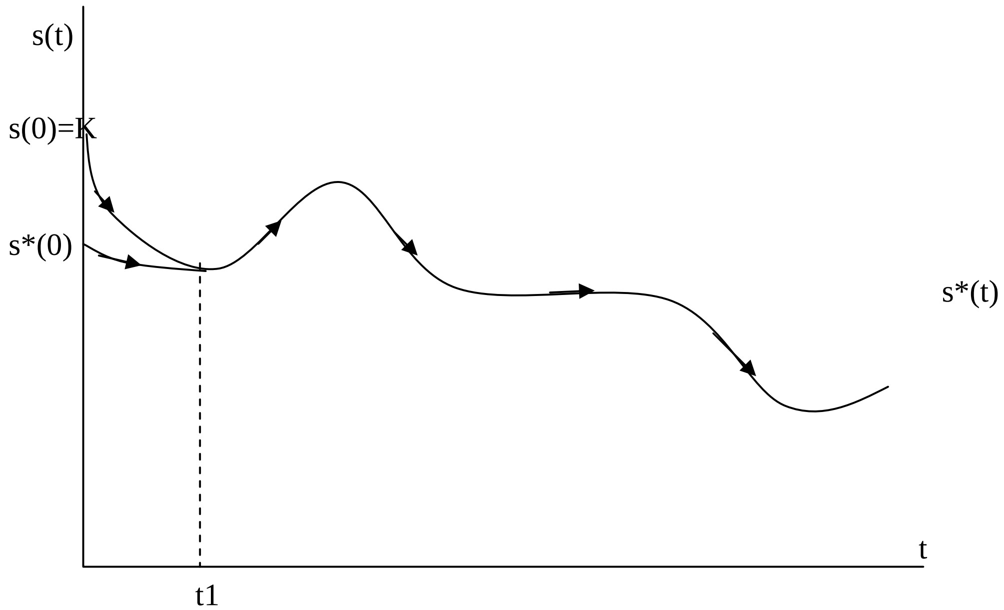
[18] Strictly speaking, marginal user cost is defined as the reduction in the present value of the stock from extracting an additional unit (Dorfman, 1969). By convention, however, MUC in resource economics is typically evaluated at the end of one period so that it is commensurate with royalty. That is, the second term on the RHS of 1.1 is the Dorfman marginal-user-cost times one plus the real rate of interest.
[19] See e.g. Pearce and Turner (1990).

Note that if the Hamiltonian expression (Eqn.(1.8)) is linear in the control variable, *x(t)*, as it is here, then the optimal solution will follow a most rapid approach path, where:

$$x(t) = \begin{cases} \underline{x} & \text{if } s(t) < s^*(t) \\ x^*(t) = F(s^*(t)) - \dot{s}^*(t)) & \text{if } s(t) = s^*(t) \\ \overline{x} & \text{if } s(t) > s^*(t). \end{cases}$$

Figure A1 illustrates a potential phase plane diagram for the optimal resource stock over time.

Figure A1: First Best Solution: Phase plane diagram for resource stock with optimal extraction over time. Here, a newly discovered resource moves to optimal levels along the most rapid approach path and is thereafter used optimally.



Appendix 2: Centralized Authority and Decision-Making: The *ahupuaʹa* system

The top-down management of the *ahupua′a* can be classified as common-property management, albeit more sophisticated than commonly described.[20] The *ahupua′a* provided everything "from *uka*, mountain, whence came wood, *kappa* for clothing, *olona*, for fish-line, ti-leaf for wrapping paper, *ie* for rattan lashing, wild birds for food, to the *kai*, sea, whence came *i′a*, fish, and all connected therewith" (Davis, 1974, p. 124). Both internal economies, e.g. in fishpond construction, and external economies were exploited. The strong hierarchical authority also allowed enforcement of conservation measures that reduced the depletion of natural resources.

Under the *ahupua`a* system, governance took the specific form of the *kapu* system. A kapu, or taboo, functioned in part by enlisting the gods' support in watching over resource exploitation. The fear of a god witnessing the breaking of a *kapu* and inflicting punishment certainly reduced enforcement costs, but did not eliminate them[21].

The chiefs limited access during certain seasons by placing a *kapu* (taboo) on fishing.[22,23] The *kapu* were clearly conservation oriented; one of the most important *kapu* created alternating closed seasons for two species of primary import.[24] Other *kapu* closed fisheries during spawning seasons in particular.

The community worked under a gift-exchange system known as *ko kula ʻuka, ko kula kai*, where those upland traded with those on the sea. This allowed considerable expertise and specialization to develop as evidenced by the highly developed knowledge and skill amongst both fishermen and planters, and kept most economic transactions within the *ahupua′a*. The *ali′i* placed taxes on the *maka′ainana* (commoners) by requiring them to deliver commodities such as

[20] See e.g. the cases decribed in Ostrom, 1990.

[21] In 1824, C.S. Stewart noted in his published journal that he had seen a brackish fishpond "literally alive with the finest of mullet; the surface of the water is almost in a constant ripple from their motions; and hundreds can be taken at any time by a single cast of a small net." He attributes this to the success of the *kapu* and the fact that no one of rank had lived there lately (Dieudonne, 2002, p. 105). Alternatively, a 19th century Hawaiian historian wrote that pond caretakers could eat some fish species openly, "but others they would eat secretly" (Summers, 1964).

[22] Fishponds may have been a response to this resource pressure not only as a source of increased production, but also as a social mechanism by which the *ali′i* could continue to consume fish during the *kapu* periods without "offending the gods." Indeed, two main benefits arose from the ponds: (1) fish could be held and cultivated for easy access by the chiefs when desired, and (2) fish would be available to the chiefs during times of *kapu*, because the enclosure removed the area from the sea, which had the *kapu*, and placed it on land, from which the chiefs could still eat.

[23] These *kapu* are generally associated with particular gods and variants of the system are known throughout Polynesia.

[24] *ʻopelu* (Mackerel scad) and *aku* (skipjack tuna).

taro and to contribute labor, e.g. to the building of fishponds. Enforcement of the hierarchy rested in part on brutality and fear of the wrath not only of the chiefs but also of the gods. Both conditions enhance the benefits of common property rights as 2nd-best (Deininger, 2003, p. 31).

Top-down management also allows the exploitation of benefits across ecosystem boundaries, not just within them. Some of these benefits fit the standard theory, such as increased risk reduction. However the *ahupua´a* system also provided the external economies of specialization and trade, e.g. between taro cultivators living on the plains and fishermen living on the coast. (Only external economies within the scope of the *ahupua'a* government could be readily exploited, however.)

The hierarchical system allowed exploitation of the external economies from specialization, given the existing avenues for trade, as well as internal economies in the production of particular goods. Furthermore, the centralized authority at the *ahupua´a* level satisfied the four requirements for viable common property rights discussed in the introduction. "Unambiguous property lines" prevailed in Hawaii as *ahupua´a* generally (though not always) followed watershed lines. "Economies of scale and ecosystem enhancement improved directly the lives of the people," as shown by investment in irrigation and fishpond infrastructure, increasing taro and fishery production capability, and the simultaneous existence of leisure-time; community property "alleviated risks of enemy incursion and reduced idiosyncratic risks" as a portion of the production of the *ahupua`a* was collected returned to the individuals through festivals, and planters and fishermen "retained portions of their effort, reaping individual benefits from their productivity."

The case of the *ahupua´a* system affords a further generalization to the condition that benefits should be rather equally divided across group members, i.e. proportional taxation can also be efficient and readily administered where wealth is unequally distributed, provided that separate rules are specified for each stratum and the members of each stratum have roughly equal entitlements.

First, the top-down management of the meant that work and reward were not distributed equally across society, only within each stratum. This facilitates a more general statement about the condition for successful common property management, namely that the allocation of costs conforms to the principle of benefit taxation, albeit within the prevailing system of vertical equity.

Appendix 3: Summary of the Hawaiian Record in Economic Context

Table 1: Evolution of Specialization and Production through Unification

Time Period	P: Population
	SMS: Social/Management Structure
	PS: Production and Specialization; Technological Change
	IP: Intensification of Production
	T: Trade
Extensive Growth (300-1100 AD)	P: Grows from less than 100 to around 20,000
	SMS: Ohana network; ancestral; little social stratification
	PS: Wide variety of fishing implements and adzes; little specialization, evolves to incipient form of Hawaiian 2-piece fishhook,
	IP: Introduction of new plants, pigs, dogs, rats; transformation of landscape to support Polynesian culture
	T: Little; trade within ohana network develops
Extensive and Intensive Growth (1100-1650 AD)	P: Grows from c. 20,000 to several hundred thousand (estimates vary widely, from 110,000 to 1 m).
	SMS: Ohana network; stratification increasingly evident (status goods growing)
	PS: Coastal intensification; new 1-piece fishhook introduced and becomes dominant; Inland extensive growth: Adzes fully standardized
	IP: Extensive growth dominant; Beginnings of irrigation and development of fishponds; increasing productivity yields in wet windward valley

	T: Specialized producers of adzes (Mauna Kea) , trade apparent Fishing gear increasingly standardized
Intensive growth and Capitalization (1650-1778)	P: Population growth slows, pop'n may even decline with increased warfare, labor taxes through hierarchy
	SMS: Transition to territorial hierarchy (*ahupua'a* system) complete (*konohiki* class evident, alii genealogy distinct from commoners now tied to land not family)
	PS: Craft specialists develop in producing status goods (feathers, carvings) for increasingly stratified *ali'I* class
	IP: Intensive dryland farming techniques developed; irrigation and fishpond development continues in established areas
	T: Increasing in the limited status goods (e.g. feathers from upland)

Trade: Economic growth under hierarchy (1778-1800)	P: Rapid decline in native population begins
	SMS: *Ali'i* and *kahuna* (priest) classes increasingly stratified, increasing intensity of *kapu*; *konohiki* managers and specialized commoners for land and sea; *ali'i* increasingly favor rent-seeking Increasing unification of authority
	PS: Introduction of western goods and technology increases efforts at crafts, shipbuilding, sandalwood harvest under *konohiki* management
	IP: Harvesting of resources for trade intensifies
	T: Western contact; trade for status goods and weapons

Table 2: Evolution of Production and Specialization, Post-Unification

Economic growth (trade) under Monarchy (1800-1840s)	P: c. 200,000, decreasing with disease, labor taxes, commoners leaving to work on ships
	SMS: Monarchy under Kamehameha I and family. Highly stratified, pressures on *kapu* increase with evidence from Western contact, rent-seeking; acquisition of status goods continues.
	PS: Development of use of Western goods (e.g. metal) and technology, mainly for extraction of rents

	IP: Increasing fishpond investment; intensive harvesting of sandalwood resource
	T: Continued accumulation of western goods among *ali'i*
Economic growth under Constitutional Monarchy (1840s-1900)	P: c. 90,000 (Population dwindles with western diseases, labor taxes)
	SMS: Constitutional monarchy; Private property initiated under Great Mahele; government and *konohiki* control marine property; public goods provision by state (e.g. education)
	PS: *Konohiki* managers become *konohiki* owners; Western interests accumulate land, introduction and growth of plantation sugar industry
	IP: Sandalwood depleted; fisheries suffering; fishpond development ends (1839 last pond)
	T: Heavy influence of small number of Westerners; sugar industry develops
Economic Growth as US Territory (c. 1900)	P: 154,000 (Foreign migration)
	SMS: Private ownership of land; increasing regulation of marine commons with size, gear restrictions; nearshore resources controlled by *konohiki*
	PS: Coastal fishing dwindles and offshore fishing increases in importance
	IP: Privately funded irrigation projects for sugar *Konohiki* owners balance enforcement benefits and costs as registration required to continue marine rights
	T: Islands become more dependent on imported goods as relative prices favor imported food, etc.
Economic Growth under Statehood (c. 2000)	P: 1.2 million
	SMS: Federal, State, and Local Controls Land: Privately owned with restrictions on use Fisheries: Regulated open access with subsidized fish populations

	PS: Diversified agriculture (plantation sugar industry unsustainable with removal of subsidies) Tourism (7 million visitors per year)
	IP: Public and private investment in cage farming technology Leasing of marine rights for cage farming -- intensification of fish production
	T: Islands dependent on trade

Appendix 4: Fisheries and governance under fluctuating institutional arrangements

The *ahupua΄a* extended into the sea, and property rights were also redefined and extended in coastal fisheries. Fishing rights remained tied to the management of the land, and remained in the hands of the *konohiki, ali΄i* and the king, with intent of balancing stewardship for the people with private goals. While the fisheries were still common property, enforcement costs and benefits in coastal fisheries controlled directly by *konohiki* differed from those of the government controlled, open water fisheries, and the coastal, *konohiki*-managed fisheries. While government lands and their appurtenant fisheries quickly were opened to the public, the *konohiki* retained their rights to private use throughout the 19th century.

The *konohiki* (acting for the *ali΄i*) could regulate fishing by monopoly reservation of a particular species and by seasonal restrictions. He could collect in rents 1/3 of the harvests of open access fishes, for the benefit of the *ahupua΄a* (Khil, 1978, p 10). The rights belonged to the job of *konohiki*, not the man, and were not transferable, with the intent of maintaining incentives for stewardship. The king also had the ability to set restrictions on non-transient shoal fishes and transient shoal fishes in the Main Hawaiian Islands. He was entitled to 2/3 of all harvests, for the benefit of the government (Khil, 1978, p. 11).

Throughout the 1840s, the Great Mahele and the changing constitutional rights slowly made more explicit the powers of the *konohiki* and the king and their portions of the take changed. In 1841, the king’s take was reduced to 50%, and in 1845, the *konohiki* was given rights over the sea extending one mile from the beach at low water. The catch was to be shared evenly with the tenants. In 1848, Hawaiian property rights received their greatest institutional change under the Great Mahele. Under increasing pressure from the growing Caucasian population, the land was permanently divided amongst the king (state), the *ali´i* and *konohiki* (*ahupua´a*) and the commoners, paving the way for transferable rights to land and sea. It is at this time that the role of the *konohiki* seems to have changed from steward to owner[25].

The monarch's fisheries moved towards open access[26] while many of the *konohiki*, where governance provided valuable returns, adopted stricter enforcement policies. In 1858, tenants regained some legal ground in piscary rights with a court ruling that stated the *konohiki* rights were subject to the tenant's rights, where tenants included all residents of the land (Khil, 1978).

The opening of state fisheries to the general public was explicitly an act to reduce enforcement costs on a low productivity resource. The new law, enacted in 1850, read in part:

> Whereas the fish belonging to the government are productive of little revenue; and whereas the piscary rights of the government managed by the fishing agents are a source of trouble and oppression to the people … all fish belonging to or especially set apart for the government shall belong to and be the common property of all the people equally … All fishing grounds pertaining to any government land, or otherwise belonging to the government, excepting only ponds, shall be, and are hereby, forever granted to the people for the free and equal use of all persons… (in Khil, p. 13)

This law increased pressure on the fisheries and resulted in the slow subsequent introduction of increased governance in the forms of gear restrictions, size restrictions, and seasonal restrictions. In 1850, use of fish poisons was made a misdemeanor offense. In 1872, use of explosives was restricted. This was presumably as much for the safety of the users as the preservation of the reef or fish, though in 1888 the possession of fish killed by dynamite was rendered enough evidence for prosecution. In 1888 size restrictions were introduced for mullet,

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[25] Though the Great Mahele ostensibly divided land in equal shares between the royalty, the chiefs and the commoners through the agency of the *konohiki*, the actual process of attaining title to fee simple property was complex, and in particular, required a commutation fee that resulted in a large portion of the chiefs' lands being returned to the state in payment. The commoners' inability as a group to acquire much fee simple property stemmed from hurdles that included paying for land surveys and unfamiliarity with the system. Fewer than 8421 parcels, averaging 3 acres in size, were in the end awarded to commoners, accounting for 28,658 acres of land, or less than 1% of Hawaii's land area (Kame´eleihiwa, 1992, p. 294). The main beneficiaries of the Great Mahele appear to have been Westerners who could now obtain fee simple land.

[26] This is not to say that informal, non-governmental limitations of fishing rights did not exist.

except for live use in stocking fishponds. These restrictions were codified into the code of the Republic of Hawaii in 1893, while the *konohiki* retained their rights. (Khil, 1978).

After annexation in 1898, and shortly thereafter the passage of the federal Organic Act in 1900, the *konohiki* fisheries came into conflict with federal law. The Organic act repealed all exclusive rights, but left a two-year window during which holders of exclusive rights could register and adjudicate their private claim. Any successful private claims could be condemned for public use, however, with allegedly proper compensation. Of the more than 400 private fisheries at annexation, only 107 registered claims were made within the mandated window. More than half were on Oahu, with its greater population, closer proximity to the courts, and growing reliance on markets, factors which lowered the transactions costs associated with enforcement and increased the net benefits of conservation activities.

The registered fisheries also held greater assessed market value on average. At least two attempts were made to value the *konohiki* fisheries, in part for use in condemnations[27]. The first, in 1939, described 349 *konohiki* fisheries, 101 of which were registered. Table 3 summarizes their findings by island. Kauai, Oahu and Molokai all generated greater than average value from the registered fisheries, while Maui actually received less. In this assessment, no account was made for the role of biological growth in the capital stock of the fisheries.

Table 3: Relative value of registered fishery *konohiki* monopolies

Island	***Number of fisheries***	***Estimated value ($)***	***Percent of fisheries registered***	***Percent of estimated value from registered fisheries***
Oahu	64	20,750	82.8	94.7
Hawaii	148	14,800	5.4	5.4
Maui	81	7,350	33.3	27.2
Molokai	28	3,100	10.7	19.4
Lanai	4	400	50.0	50.0
Kauai	24	9,900	33.3	83.8
Totals	**349**	**56,300**	**28.9**	**56.0**

Data from C.C. Crozier, Deputy Tax Commissioner (Mar 14, 1939)

[27] The limited treasury of the new Territory was responsible for financing compensation for condemned fisheries, which limited their interest in doing so. The development of Pearl Harbor led to the first real cases for condemnation.

In 1947, another assessment occurred in which an attempt was made to include biological growth and catch effort (Khil, 1978). These results tended to produce even lower valuations than the 1939 survey. Many of the fisheries were seen as lacking commercial uses and their appraised values reflected this. The most highly valued fishery, the 270-acre Kahana fishery on Maui, generated per-acre values of $37.04. This fishery was operated collectively on a profit sharing basis, where all catches were divided 50/50 between owners and fishermen. The lowest values were for less than twenty-five cents per acre.

Table 4: Percent of catch by habitat type

Year	***Coastal (% of total)***	***Neritic-pelagic (% of total)***	***Slope and Seamount (% of total)***	***Pelagic (% of total)***	***Total Catch (Thousands of Pounds)***
1900	59.1	16.2	3.4	21.2	6157.8
1950 &1953 avg	4.8	3.4	4.0	87.8	17426.7
1985-6 avg	6.1	5.4	16.8	71.8	9868.0
2002-3 avg	1.3	2.5	5.8	90.4	23398.0

Sources: Shomura (1987) and State of Hawaii Department of Land and Natural Resources, Dept of Aquatic Resources (2004).[28]

This institution might have played a greater role in the development of long-term fisheries law if its commercial importance had not dwindled over the century or if enforcement had been simpler. Changing tastes, increased options for foods, and increasingly available open access fisheries all reduced the ability of this institution to function as a mechanism for 2nd best provision. Table 4 shows the relative change in coastal fisheries versus other Hawaiian fisheries over the century.

The simultaneous maintenance of private and open access fisheries in proximate space increased the cost of enforcement for the *konohiki*, and in many cases these higher enforcement costs outweighed the benefits. The commercial value of the in-shore fisheries they held became increasingly limited for much of the 20th Century. Pressures for multiple uses of the areas led to some condemnations, and today, virtually all of the fisheries are operated under complex government restrictions, but open to anyone who conforms to those regulations.

[28] Reporting for the 2002-3 period includes a slightly different composition of species that under-reports coastal fishes compared to earlier years. However the important shift is clear: between 1900 and 1950, coastal fisheries dwindled in comparison to the expanding pelagic fisheries.

The co-incidental use of both “private” *konohiki* fisheries and increasingly regulated, open access fisheries in the 19th and 20th centuries illustrates the role of non-convexities and externalities in the institutional governance of resource use. Indeed, advances in aquaculture technology, such as cages, could have developed quite naturally out of the *konohiki* system described above. They may have been delayed in Hawaii due to required changes in federal law granting leases and uncertainty about the existence of appropriate markets for fingerlings. By abstracting from non-convexities, the standard theory suggests that increased pressure on resources due to economic growth automatically contributes to the evolution from open access towards private or centralized authority.