Spontaneous Property Rights in Open Access Resources

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This paper examines the emergence of spontaneous, informal first-possession property rights under open-access settings for five resources in U.S economic history. Although early models of open-access predicted full rent dissipation as infinite numbers of homogeneous agents entered to exploit the resource, later theory and empirical observations indicated persistence of inframarginal rents. If agents are heterogeneous in search and production cost and the resource is large and heterogeneous in quality, then not all rents are dissipated. Low-cost parties search for the most productive regions and apply their superior skills and develop human and physical capital to earn inframarginal rents. The existence of inframarginal rents under open access has been recognized in the literature. The incentive of agents to invest in *de facto* informal property rights to protect rental streams from competitors has not been explored. Moreover, there has been no recognition of how these informal arrangements might contribute to observed resistance by inframarginal-rent earners to external rationalization schemes designed to reduce the aggregate rent dissipation from open access. Proponents are high-cost agents, who earn low or zero rents. Under open access there may be aggregate net benefits from the more formal assignment of property rights, referred to as rationalization. To gain consensus on rationalization in the presence of aggregate net benefits, high-cost agents ought to be able to compensate low-cost agents for a shift to a new property rights regime. But empirically, this appears not to happen. We develop a simple framework to show differential rents and informal claiming by heterogeneous parties and to outline why willingness-to-pay and willingness-to-accept may not overlap in the presence of asymmetric information. When these values do not converge, rationalization is not Pareto improving and agreement to formally end open access does not occur, even with general agreement on the overall problem of rent dissipation. We apply the framework to historical experiences in gold, oil and gas, rangeland, and western U.S. water to show the development of informal property rights and why gaining a consensus on valuing these is difficult.

Introduction

The losses of competitive entry and production in open-access resources have long been recognized. Gordon (1954) outlined the situation in fisheries, which are iconic open-access resources and Hardin (1968) described the general problem across natural resources as the "Tragedy of the Commons." The notion is that in the absence of formal property rights there are no restrictions on entry and agents do not bear the full costs of their production decisions. Classic externalities arise with the use of excessive capital, other inputs, short-time horizons, races to produce, congestion, reduced investment in the resource stock, and lower output value. To mitigate these losses, various regulatory and (more recently) rights-based instruments are implemented by governments to constrain entry, to limit output, and to internalize external costs.

These institutions are referred to as rationalization.[1] The potential for open access exists or has existed for many natural resources associated with the historical U.S. frontier, whereby hundreds of thousands of individuals arrived in North America to claim the continent's natural resources. We examine the economic history of five natural resources formally under open-access conditions to identify the formation of informal, prior-possession property rights to protect inframarginal rents: hard-rock minerals (gold and silver), western Great Plains rangeland, oil and gas deposits, fisheries, and western U.S. surface water.

The view that inframarginal rents—positive economic profits earned by low-cost producers in competitive settings—exist in open-access settings has long been recognized, particularly in the fishery-economics literature (Clark, 1980; Johnson and Libecap, 1982; Johnson, 1995; Heaps, 2003). Johnson and Libecap (1982) show how differential production costs generate inframarginal rents captured by highly-skilled agents that are vulnerable to redistribution or loss if uniform quotas or shares in a total allowable output are installed. Johnson (1995) and Anderson et al. (2011) argue that Pigouvian taxes or the auctioning of production shares transfer rents from low-cost agents. Despite the recognition that inframarginal rents exist in an otherwise open-access resource, the economics literature has not explored the connection between sustained open-access and the existence of these rents nor developed the implications for the establishment of endogenous, first-possession property rights (Lueck, 1995). Inframarginal marginal rents mold long-term expectations regarding the profits to be earned from resource exploitation under open-access. Those with low expected rents who view the resource stock at risk and/or who see the claims and returns of previous claimants as inequitable lobby for a reallocation of access and use rights.

The purpose of this paper is to describe how informal, spontaneous rights emerged in these resources, the nature of the claimants, the inframarginal rents earned by them even under general open access, and identify why these rights were incorporated formally into U.S. law in some cases but not others and how information problems limited consensus on valuing them in certain cases. This exercise is a first step in understanding why open-access problems persist, inflicting aggregate losses, but disagreement on the distribution of the net benefits blocks collective action. Some parties that have adapted well to open access and invested in informal rights or other skills to capture and protect inframarginal rents may be made worse off by rationalization schemes even when there are aggregate net returns. Our framework allows inframarginal rents to develop endogenously, in contrast to most resource models which impose rent-generating heterogeneity exogenously.

The existence of aggregate gains that appear to substantially exceed foregone rents for those users who are made worse off creates a puzzle for economists because the existence of net surplus suggest that side payments are possible and should be observed. That is, beneficiaries of

[1] Pigouvian taxes are presented as another means for integrating social costs into private decision making, but are rarely adopted, likely for the same information reasons we explore in this paper.

rationalizations ought to be willing and able to pay opposing parties to consent to the rationalization scheme in any setting where rationalizing creates a surplus. In such settings willingness to pay for transfers exceeds willingness to accept transfers and institutional responses to address open access dissipation should be observed. Empirically the process is far more complex, with certain parties systematically holding out.

We shed light on this disconnect between apparent Pareto-improving rationalizations and empirically observed opposition. We present a framework of search and exploitation and formation of informal claims to a stochastic and heterogeneous resource by users who are heterogeneous in productivity and cost. The existence of heterogeneity both in users' costs and in the resource itself has important implications for the emergence of informal, *de facto* property rights in the absence of formal legal rights. These rights emerge due to low-cost users' ability to discover and invest in more productive spatial claims. In settings where individuals interact with the resource in particular locations with differential information about the overall stock and invest in protecting their rent-generating spatial claims, aggregate policy tools may strand individuals' investments in the resource, their informal claims to it, and any associated human capital--resulting in the expropriation of *de facto* property rights.

II. Framework

1. Sources of inframarginal rents in open access

Understanding how users earn non-zero rents in open access settings is critical to understanding how informal and later formal property rights can emerge. The most common explanation of inframarginal rents assumes heterogeneity of extraction costs. Some users have lower costs than do others and those users with lower costs are able to earn positive rents even when individuals on the margin earn zero profit. This way of thinking about heterogeneity is the most analytically tractable and so has received the most attention in the economics literature. This is problematic because the only way rent-generating cost advantages can persist is through differences in knowledge either about the resource or about production techniques. Because open-access settings are characterized by a lack of formal rules or restrictions, all users are free to adopt similar technologies and methods for harvesting the resource if they are aware of them. If this knowledge were common or costless to obtain, costs would converge and we would not observe the sustained existence of inframarginal rent-earners. This implies that differences in knowledge must drive users' ability to sustain inframarginal rents over time.

Differences in knowledge about the resource will arise in settings where the spatial distribution of the resource is heterogeneous; it is large; and users extract it from particular locations. If search is costly and users are heterogeneous, those with lower search costs will find more productive locations from which to earn inframarginal rents. If these users also invest in specialized knowledge about how to produce from the resource from particular locations and related specialized physical capital, their production costs are lower. The ability to invest in this

site-specific physical and human capital increases the expected gains from searching. Rents derive from asymmetric information—over the resource and over techniques—so settings where information is less stratified, ironically, will be more subject to rent dissipation.

Where the resource is small and homogeneous in quality and users are also similar in search and production costs, then the full-dissipation competitive setting described by Gordon (1954) exists because no agents are able to earn or protect inframarginal rents. This also, paradoxically, is the setting outlined by Ostrom (1990, 90) for successful collective action for communal management of a local common-pool resource (CPR), motivated by the potential for rent dissipation. Ostrom (1990, 90) predicts successful informal communal management to block rent dissipation when the resource is small and homogeneous and users themselves are homogeneous, but Gordon (1954)'s model of an open access resource with full dissipation assumes similar conditions, although with large numbers of agents made possible by homogeneity. We seek a more general characterization of open access that allows for the possibility of inframarginal rents and informal property rights in the presence of possibly heterogeneous users with limited information about a heterogeneous resource. Table 1 shows how our setting compares to those considered by Gordon (1954) and Ostrom (1990, 90).

Table 1: Existing Literature

	Resource Characteristics	
User Characteristics	Small, Homogeneous	Large, Heterogeneous
Homogeneous	Ostrom (1990)/Gordon (1954)	
Heterogeneous		*Our Framework*

2. Threats to inframarginal rents in open access

With no restrictions on entry or harvest in open-access resources, users with specialized, rent-generating knowledge and capital face a variety of threats to long-term gains. New entrants or higher-cost users may attempt to extract resources from the same locations as inframarginal rent-earners in settings where the primary source of inframarginal rent is knowledge of productive locations. If rents are primarily generated by specialized techniques, high-cost users will attempt to copy low-cost users and increase their output per unit of effort. Many spatially heterogeneous resources are also spatially interconnected, so that the value of a productive area can be at least partially reduced by excessive access in other locations.

In general we conceive of a gradient of inframarginal rent-earners based on differences in search costs, production costs, and endogenous knowledge and capital. Those users who earn smaller inframarginal rents will tend to be on less-productive spatial areas of the stock than are high rent-earners and invest less in specialized techniques and capital. These marginal users will be most threatened by new entries or dissipation due to existing users. If there are positive but diminishing returns to search, knowledge, and capital investments, high-cost users will tend to

"catch up" to low-cost users over time unless low-cost users develop a way to exclude others from their sources of rent. Accordingly, inframarginal rent-earners have a strong incentive to invest in strategies that block others from capturing their rent-generating locations and knowledge.

We conceive of productive locations and specialized extraction techniques as rent-generating factors of production. Low-cost users are able to sustain their rents to the extent that they can maintain exclusive use of these factors of production. Access to either productive locations or better production practices depend on knowledge, which is why asymmetric information is so valuable to inframarginal users. Essentially, rent-earners face a different cost curve than marginal users. High-cost users' actions may dissipate rents even for users with lower costs in two ways. First, if high-cost users attempt to directly access the specialized factors of production by imitating low-cost users (either following them to productive locations or adopting what they are able to observe about extraction techniques).[2] Second, entry by high cost users—though it generates little to no rents—may deplete the aggregate stock in a way that reduces rents for inframarginal users.[3]

3. Strategies to defend inframarginal rents—the spontaneous emergence of *de facto* property rights

Inframarginal rent-earners stand to lose if other users are able to dissipate their rents through crowding, copying, or entry. Demsetz (1967) established that in general individuals will invest in defining property rights so long as the benefit of doing so exceeds the cost. The benefits of establishing informal claims under open access are the streams of inframarginal rents that users seek to protect. There are a variety of ways in which rent earners might defend their rental streams, and the method ultimately chosen will depend on the characteristics of the resource and its users, informal norms, and broad underlying political institutions. Under conditions where users can profitably invest to defend their inframarginal rents, informal property rights will spontaneously emerge. The emergence of these informal rights may cause formal open access to persist longer than would otherwise be expected if the spontaneously-emerged rights are not converted to *de jure* property rights. Hence, the type of informal property rights that emerge has important implications for whether users will be willing to transition to a formal rights regime or a joint-management regime which may be formal or informal.

Depending on the sources of their inframarginal rent and the attempts by other users to compete those rents away, rent earners may pursue a variety of strategies to defend their claims. One option for blocking competition is to invest in *de facto* spatial exclusion. Options for doing

[2] We assume here that it is less costly for high-cost users to imitate low-cost users than for low-cost users to discover the rent-generating factors of production in the first place.

[3] See Levhari and Mirman (1980, 324) for an example of a resource harvesting problem that as a stable Nash Equilibrium in harvest strategies that may correspond to a declining resource stock.

so include threatened or actual force, fencing, and continued occupation or beneficial use. We provide specific examples of this type of behavior in our case studies. The returns to spatially excluding other users are greater when rents derive primarily from knowledge of productive locations and when the spatial distribution of the resource is not subject to high variation over time. For example, informal spatial claims within a fishery focused on a relatively stationary species like lobster have much higher expected returns than spatial claims in fishery for tuna, which migrate globally. We expect to see the emergence of *de facto* spatial claims in settings where there is greater variation in the quality of the resource across space but the spatial distribution is relatively stable over time.

Users may also be able to employ the existing legal framework for other resources to exert spatial claims. Many spatially heterogeneous resources are relatively fixed and so correspond closely in their location with the location of land. Grazing lands, river water flows, stationary marine species such as lobster, and, (to some extent) oil reservoirs are a few examples. In these settings staking *de jure* claims to land coinciding with productive resource locations allows *de facto* exclusion of outsiders from the resource. Such *de jure* provisions quickly transform truly open-access resources into limited-access resources because users must have a land right prior to occupation and production. Like *de facto* exclusion, this approach is much less effective if the spatial distribution of the resource is highly variable. For example, Lueck (1989) documents the challenges associated with managing highly-migratory wild game through private property rights to land alone. Users of a resource will prefer *de jure* to *de facto* spatial claims in settings where there is a low-cost and low-risk existing legal framework for asserting title to land. In this case, users rely on the state to keep outsiders from extracting the resource in their valuable location.

For some resources, the primary source of inframarginal rent may be specialized knowledge about production itself. In these settings spatial exclusion is less efficient for protecting inframarginal rents and users will invest to prevent others from learning about their advantage. Users may attempt to conceal knowledge that they have already accumulated by limiting observability. In some resources it may be possible to simply not share information. *De facto* or *de jure* spatial claims and privacy are likely complements—it is easier for users to keep their production processes (oil well depth, fishing location, water ditch dimensions) hidden when others are unable to observe. Users may reduce effort and output if doing so prevents others from learning by example. Alternatively, they may over exploit the resource so as to reduce incentives to search, enter, and copy and to minimize potential competitive losses. If spatial exclusion and private information are costly or not effective or if competitive entry continues inframarginal users capture more of the resource rents short-term to prevent long-term losses. In general, we expect inframarginal rent-earners to invest in natural capital—to save some of the resource stock for later—if they have successfully established a *de facto* or spontaneous right. In either case,

foregone rents from behaving less efficiently constitute an investment in the *de facto* sole right to produce in a particular way.

Faced with the prospect of dissipation through knowledge dissemination, users invest in knowledge and processes that are inherently difficult to communicate or copy. This up-front investment in highly-specialized, private, and tacit knowledge reduces the costs of maintaining privacy later. As with search, users with lower costs of investment in knowledge and greater capacity to pay up-front costs will earn differential rents from their investments. The choice of whether to invest in "cheap" or "costly" knowledge as such has important implications for users' ability to agree on compensation when faced with the prospect of joint management or rationalization by the state. If users possess differential costs of learning about production and about the resource, it will necessarily be the case that low-cost users have information and knowledge that high-cost users lack. The upshot is that asymmetric information is endogenous in spatial heterogeneous resources with heterogeneous users.

Spontaneous property rights to open access resources will tend to emerge in settings where users and the resource are both highly heterogeneous (large potential gains) and the spatial distribution of the resource is relatively stable over time, production is not fully transparent, and there is potential for learning by experience (lowering costs of developing rights). Spatial claims are more likely when inframarginal rents are primarily generated through search to find highly valuable resource deposits, such as gold or other minerals. Even in the presence of spatial rights, users may be able to compete away inframarginal rents by adopting similar production techniques and copying skills. Hence, low-cost users will invest in forms of knowledge that are inherently difficult to communicate in order to prevent these losses. The greater the gains from private information over the stock or over production technique, the more users will invest in keeping their advantages private. As in any competitive setting, rents accrue from the exclusive use of a factor of production. In our case, that factor can be an especially productive location or a production technique. Either way, keeping knowledge of the factor private is the only way to prevent rents from being dissipated. For those users who earn positive rents, information is valuable precisely because it is asymmetric.

4. Challenges in transitioning to *de jure* property rights

The extent and character of spontaneously-evolved, informal property rights in open-access resources determine whether collective action to create formal property rights will confront bargaining problems over rent distribution. Informal property rights emerge as the result of costly investments in search, knowledge, capital, and exclusion. The creation of formal property rights may strand some of these investments—users' ability to earn rents may be transferred from *de facto* advantages. A user's willingness to accept rationalization will depend on their expected stream of rents under open access and under the new regime. If the investments

made to secure rents under open access are not as productive after rationalization, inframarginal rent earners will demand compensation. These investments, however, are likely to be difficult to value because of endogenous information asymmetries.

While recognition of informal rights is important in any transition from informal to formal property rights, rationalization of open-access resources presents unique challenges. Users' ability to earn inframarginal rents in open access derives from their ability to translate some particular realization of the stochastic resource stock into output more effectively than others, due to specialized knowledge, capital, and locations. Shares are, by definition, a direct translation of the aggregate resource stock into individual output that works in the same way for every user. Hence, rationalization tends to put all users on equal footing with respect to the variability of the aggregate level of the resource in a given period, be it stream flow, fish stock, or rangeland. Rationalization harms inframarginal users of the resource by reducing their competitive advantage. Whereas before they could assert an informal right to more of the stock, once rationalization occurs their ability to extract more of the stock depends—in a uniform way—on the structure of the formal property rights.

Users whose spatial claims are more productive may be constrained by their initial share allocation if their *ex ante* level of extraction in their claimed location exceeds the size of their share allocation. These users must now buy the rights to additional units of output, whereas they previously could chose extraction levels freely. This reduces the value of the information that generated rents under open access. Users can no longer profit directly from their specialized knowledge and capital and cannot easily convey this knowledge to others because they invested in knowledge that would be difficult to convey. The corollary to this loss is that users with higher search costs that face low probabilities of discovering productive spatial claims and lack capital investments stand to gain from being granted the right to a given amount of output. These users are granted a right to the return on natural capital investments that have been made by inframarginal users, forcing inframarginal users to buy back their own returns as shares. This implies that rationalization in certain settings may represent the *de facto* expropriation of informal property rights and redistribution of the rents from natural and human capital investment. This outcome creates the need for side payments if *de facto* property rights holders are to agree to rationalization.

Other types of rationalization redistribute assess to the stock. This has been the case for rangeland and likely would have been the case for hard rock minerals. It both settings, because of the spatial size of the resource, uncertainty as to location of prime deposits, and an ability to mark fixed boundaries, uniform access or shares of the stock, rather than caps on annual production characterize rationalization. The motivation for rationalization in this case is less to avoid open-access losses because of the ability to mark and enforce resource boundaries and more on the differential rents obtained by low-cost parties that may be inconsistent with broad

wealth distribution objectives. Even so, reallocation undermines the gains from search, learning, and investment in specialized knowledge and capital associated with production from particular sites. *De facto* claimants who benefit from search, investment, and production are made worse off unless compensation is provided. Compensation however may be impossible by construction. Iif the goal is to redistribute rents from some users to other, side payments to compensate transferred rents defeat the purpose of the program.

The aggregate gains from rationalizing open-access resources may be quite large, even in settings where inframarginal users are made worse off. Costs associated with declining stocks of renewable resources and externalities from overproduction in both renewable and nonrenewable resources can be substantial from competition on the margin. Averting open-access losses and instituting a sustainable management regime has both immediate and long-run benefits. These benefits accrue especially to high-cost, marginal users of the resource because they are most affected by variation in the stock and have the least specialized knowledge and capital. These users ought to be willing to pay low-cost inframarginal users to agree to rationalize. This willingness to pay for transfers should exceed the low-cost users' minimum willingness to accept in any setting where aggregate net gains exist, if users agree about the net gains from rationalization. Agreement will fail in the presence of what appear to be large aggregate gains if users' knowledge about the resource and the source of differential returns from exploitation systematically differs.

Individuals who stand to gain from rationalization may form their beliefs about the aggregate resource stock based on biased draws from the overall spatial distribution of the resource. If the most productive claims are defended by low-cost users, then the claims available for extraction by high-cost users will be systematically less productive and lead to a more pessimistic view of the resource. Holders of *de facto* property rights learn more about the location-specific dynamics of the resource in their location than do other users, giving them a different estimate of the stream of rents associated with holding that *de facto* right under open access. Low-cost users learn about the value of their site-specific human and physical capital over time and adjust investments in it, while high-cost users learn about the spatial distribution of the least productive spatial units. These different draws, investment, and production responses to them result in a divergence of views about the gains and losses associated with rationalizing the resource. Each type of user is learning about the resource and responding to that knowledge in a fundamentally different way.

The key insight of our framework is that inframarginal rents in open-access resources ultimately derive from differences in highly-specific knowledge. Those users who develop spontaneous claims to the resource develop knowledge of the stock in their private location—this knowledge generates inframarginal rents, shapes expectations of future rents, and molds investment and production choices. High-cost users learn about the resource in a different way because they observe less-productive and more vulnerable parts of the stock. Low-cost users

invest to protect their rents by keeping their differential knowledge private. Through this process informal, *de facto* property rights emerge spontaneously with no central organization or demarcation. Accordingly, these informal rights are inherently difficult to value because their basis is in asymmetric information and private, tacit knowledge and related production and investment decisions. Users seeking to negotiate over rationalization will find it difficult to credibly communicate their profitability under either regime because their differences in knowledge are the source of their differences in profitability.

Some of the *de facto* rights we have outlined are more amenable to formalization and rationalization than others. Understanding when these rights are likely to exist clarifies why rationalization proves elusive in certain settings. *De facto* spatial rights may be converted to *de jure* rights at relatively low cost if it users have clear claims to particular stationary locations. Rights to the resource itself rely on knowledge of the productivity of particular locations. Property rights in resources exhibiting heterogeneous but stable spatial distributions have evolved from informal spatial claims to formal rights when there is political support for the associated distribution of wealth—hard rock minerals, and generally to surface water as compared to rangeland below. On the other hand, where the resource is mobile so that stationary claims are not effective, such as with fisheries and generally with oil and gas deposits, *de facto* spatial rights are converted to *de jure* rights at much higher cost.

Table 2 lists some hypotheses that structure our examination of the natural resource cases.

Table 2: Hypotheses

De facto or spontaneous property rights emerge on spatially heterogeneous resources.
Differences in knowledge of specialized sites and/or production processes drive sustained inframarginal rents.
Inframarginal rent earners are motivated to invest in strategies that generate private knowledge of the resource and/or techniques and block others from copying.
Informal rights spontaneously emerge as spatial exclusion when the spatial distribution of the resource is not subject to high variation over time, generating durable productive locations.
Informal rights spontaneously emerge as spatial exclusion to adjacent land when bounding costs are lower than for the resource itself.
Spontaneous spatial property rights emerge where users and the resource are highly heterogeneous but the spatial distribution of the resource over time is stable; production is not transparent; and there is learning by experience.
Informal rights spontaneously emerge as evasive actions or secrecy when the source of inframarginal rents is specialized production knowledge.
Informal spatial rights may complement valuable specialized knowledge when the spatial claim limits observation.
Informal spatial claims may be marked and defended by foregone inframarginal through under or overexploitation.
Inframarginal rent earners have an incentive to support rationalization if it recognizes their informal claims.
Investments in secrecy or highly-specialized knowledge regarding location and/or production processes to define informal claims and earn inframarginal rents makes asymmetric information endogenous and hinders agreement on shares in subsequent rationalization.
Shares via rationalization may not be Pareto improving even when there are aggregate benefits. Distributional disputes result in delayed or blocked rationalization.

III. The Framework Applied

Table 3: Resource and Exploiter Characteristics, Spontaneous Property Rights

Natural Resource	Hard-Rock Minerals	Rangeland	Oil and Gas Reservoirs	Fisheries	Surface Water
Large, Heterogeneous Resource in Quality (Production Potential)	Yes	Yes	Yes	Yes	Yes
Open-Access Potential	Yes	Yes	Yes	Yes	Yes
Large Numbers of Claimants, Heterogeneous in Search and Production Costs	Yes/No	Yes	Yes	Yes	Yes
Spontaneous/First-Possession/Informal Property Rights to Stock	Yes	Yes	Yes	Yes	Yes
Formally Recognized	Yes	No	Yes/No	No	Yes
"Rationalization"	No	Yes	Yes/No	Yes/No	No (Yes Proposed)
Compensation such that WTP = WTA?	NA	No	Varies	Depends on Timing	Not proposed
Rule of Capture	Yes	Yes	Yes	Yes	Yes
Beneficial Use/Occupancy	Yes	Yes	Yes	Yes	Yes
Investment in Human/Physical Capital to Define Property Rights	No	Yes	Yes	Yes	Yes
Shares in Total Annual Production, Stock	Shares of Total Stock	Shares of Total Stock	Shares of Total Annual Production	Shares of Total Annual Production/Stock	Shares of Total Stock
Evidence of Differential/Inframarginal Rents	Yes	Yes	Yes	Yes	Yes
Evidence of Total Long Term Rents	Yes	No	Yes	Yes	Yes
Differential Stock Assessments/Rents	NA	NA	Yes	Yes	Yes

A. Gold and Silver Exploitation and Production

1. Nature of the resource

The resource is large, spatially heterogeneous, but the spatial distribution is stable over time. Gold deposits in the western Sierra foothills of California were found in a generally large area of approximately 200 miles by 50 miles (Charles Drayton Gibbes, A New Map of the Gold Region in California, 1851, Harvard Map Collection). Actual deposits of sufficient size and quality, however, were very sporadically located, mostly in stream beds and adjacent hillsides across the region, and locating ore involved important uncertainty. Accordingly, while the region was larger than the local common pool resources (CPRs) examined by Ostrom (1990) in

discussing local management to mitigate open-access losses, the smaller sites where production concentrated more closely approximated the conditions she outlines for successful mitigation (Ostrom 1990, 90).

2. Potential for Open Access

Initially, there were no restrictions on entry. Discovery of gold ore at Sutter's Mill in California in 1848 set off a stampede of migration to the region. Within weeks, thousands of prospectors poured into the Sierra foothills, raising the population of California from approximately 50,000 in 1848 to 89,000 in 1849, and to 100,000 or more in 1852, mostly concentrated in the gold region of the Sierras (Clay and Wright 2005, 158; Libecap 2007, 267; Clay and Jones 2008, 999). Individual regions or mining districts could have 1,500 to 14,000 miners (Stewart 2009, 219). Prospectors had no official sanction to occupy or search for gold on federal lands. The land laws focused on agricultural use and not on mining (Libecap 2007, 267).

3. Characteristic of Claimants

Claimants initially were homogeneous in search and production costs. With little experience in hard-rocking mining in the U.S., which until 1848 had not had important ore deposits, most migrating to the region likely had similar search and production skills. Early on, no prospectors had information advantages regarding the location of ore. Clay and Jones (2008, 1016) are explicit in modeling prospectors as initially having similar chances at success. There were, however, returns to search and speed. Search was critical, and this is why early miners are termed "prospectors" and not miners. California ore in particular was in shallow deposits, whereas silver ore, found subsequently in western Nevada's Comstock Lode was primarily in deep-vein deposits. In the case of California, those who found ore could mine it with comparatively less capital investment than was the case on the Comstock where those who discovered the ore generally had to sell to those who had access to capital (Libecap 1978, 1979).

4. Nature of Individual Returns/Inframarginal Rents

Some claimants earned large rents; others did not. In the presence of uncertainty, prospectors searched a region, occupying a site briefly and if it did not pay off, moving on. Once ore was discovered in a place, miners tended to congregate near any discovery because the exact location and extent of any deposit would not be known until further production ensued. Eventually, the most productive land was claimed and newcomers had to work less favorable areas. Clay and Jones (2008) examine the 1850 and 1852 Censuses of Population in California to determine the characteristics of migrants and economic outcomes. They find that on average individuals who migrated to the California gold fields may have done no better than what day laborers earned elsewhere in the U.S. (Clay and Jones 2008, 1022). This finding would be

consistent with zero rents for marginal entrants into an open-access resource, as characterized mining regions in the early gold-rush period. A few miners, perhaps lucky ones, found and claimed very productive areas and earned rents either though production or sale to those with more access to capital. Their returns represented a share of the total annual production of the mining region. These implicit shares were not uniform. They were based on discovery and many prospectors earned no production rents (Clay and Jones 2008, 1022). Once production began in 1848, the region continued to produce ore through the 19th and 20th centuries (Clay and Wright 2005, 159 for 19th century patterns).

5. Nature of Spontaneous Property Rights

Claimants formed spatial land claims to mineral land and maintained them through continued occupancy or beneficial use. Although Clay and Wright (2005, 175) view migration and subsequent gold production in early California as consistent with open-access with rapid early production, the history of the mining region suggests that local, spontaneous, first-possession rights emerged quickly. Rights to the ore itself were based on the rule of capture, but rights to potentially-productive land areas were based on bargaining within local mining camps and maintained through occupancy.

To accommodate search and avoid conflict that would divert productive inputs, once enough prospectors located in an area, informal and (later) formal mining camp rules were agreed upon. Over 600 mining camp rules were established across the U.S. West and they describe very similar, spontaneous first-possession mineral lands claims (Libecap 2007, 267; Clay and Wright 2005, 163). In the presence of uncertainty of the location of ore, prospectors expected to locate and move numerous times before finding a paying deposit. The rules recognized claims to the first prospector to arrive at a location thought to have deposits of valuable ore. Hence, the rules rewarded socially-valuable search. Indeed, those that discovered a new larger district (larger area of shallow ore or outcroppings of multiple subsurface deposits) were granted two mineral claims, whereas all others were allowed a single claim. Ownership was recognized so long as the claim was marked and worked—a beneficial use requirement. For example, one mining district in 1852 required miners to work their claims at least one day out of three during the mining season and another in 1853 specified that a miner was to dig a ditch on his claim “one foot wide and one foot deep” within three days of locating a claim (Libecap 2007, 268). If not worked, the claim was viewed as abandoned and opened for entry and occupancy by others. Worked or occupied claims, however, were viewed as held by the miner and others were prohibited from entry on to it.

McDowell (2002, 6-11), Clay and Wright (2005, 162) and Libecap (1979, 368) argue that in the early period, miners preferred to have claims left relatively vague so that boundaries could be moved to cover ore deposits and that the mining camp rules be flexible enough to facilitate

multiple claim locations and abandonments. More formal recording and definition followed as ore discoveries were made and uncertainty reduced regarding the location of the most productive regions (Libecap 1978, 343; 1979, 368-9; McDowell 2002, 12). Mining camp rules limited claim size according to potential payoff. Smaller claims were allowed in likely richer stream beds where gold was thought to congregate and water for extraction nearby, whereas larger claims were allowed on drier hill sides that offered lower prospects (Libecap 2007, 268). Enforcement costs were apt to be higher for the former than the latter so that smaller claims were more defendable. Initial, placer ore was from the surface, but as it played out, the focus shifted to deeper ore or quartz veins, where different and more capital intensive production methods were required. Whereas placer claims were bounded in terms of surface area, quartz claims were assigned to the ore vein and were separate from surface ownership. Extra lateral rights were granted whereby the vein owner was granted the ability to follow the deposit wherever it traveled beneath the surface.

While spatial land claims may not have emerged strictly as precisely as described by Umbeck (1977), they gradually emerged generally through local mining camp negotiations and subsequent rules in a manner more like that outlined by Ostrom (1990, 90) with limited violence (Libecap 1978, 342).

6. Nature of Formal Property Rights Defined by the State

As shown by Libecap (1978) informal spatial mining claims gradually became formalized, recognized by territorial and state governments as property, and traded routinely on the San Francisco Stock Exchange and elsewhere. Claims were consolidated to allow for economies of scale in production. The federal government recognized mining camp rules and the spontaneous property rights associated with them in the Mining Law of 1872 that provided for fee simple title. There was no "rationalization" to redistribute mineral rights. There was no serious rent dissipation once the costly search process was complete to generate collective action privately or in the political arena for top-down mitigation via imposition of an exogenous rights structure or regulation. There was no interdependence among miners at different locations on the aggregate resource stock. Further, there were no politically-important competing constituents for mineral land, and political representatives from western states, especially Nevada, played a critical role in gaining federal recognition of the endogenous mineral rights structure in the West (Libecap 1978, 361). Accordingly, claims to a large, valuable, but heterogeneous resource were recognized as property and the property rights structure became the basis for the subsequent development of the hard-rocking mining industry in the U.S. West (Libecap 2007, 270). The industry grew and became a central contributor to the broader development of the country and U.S. industry became more mineral intensive in production than the country's physical resource endowments would have otherwise suggested.

B. Rangeland

1. Nature of the Resource

The resource was large, spatially heterogeneous in quality with limited spatial variation across time. The Great Plains of North America are massive, running from western Texas/eastern New Mexico north through western Oklahoma, Kansas, Nebraska, South and North Dakota and to eastern Colorado, Wyoming and Montana. They cover some 321,237,120 acres. In his report to the House of Representatives on the Range and Ranch Cattle Business Joseph Nimmo, Chief of the Bureau of Statistics, U.S. Treasury (1885, reprinted 1972, 5) stated that 130,000,000 acres of the western Great Plains were the primary resource. Most of the Great Plains, especially the western short-grass prairies received far too little rain to be attractive for initial agricultural settlement and were crossed as part of the "North American Desert" by eastern settlers following the agricultural frontier to Oregon and parts of California. The traditional dividing line is the 98th or 100th meridian between humid and semi-arid parts of the Great Plains (Hansen and Libecap 2004a, 107; Libecap and Hansen 2002, 90) Libecap and Hansen (2002, 90-2) for example provide data on annual precipitation for areas east of the 100th meridian and those to the west from 1895-1947. Mean precipitation values in the former are over 33 inches annually with a low coefficient of variation, whereas those to the west have mean values of 14-25 inches annually with coefficients of variation double or more.

Beginning in the 1870s and 1880s, however, high cattle prices, heavily-stocked ranges in eastern and central Texas, availability of Scottish and English investment funds, and the gradual removal of hostile native tribes opened the western Great Plains to rangeland settlement by ranchers (Nimmo 1885/1972, 5, 13-19, 75, 192-4 with cattle export values from 1790-1884; Osgood, 1954, 85, 92-95). With a massive, unoccupied, and highly-variable resource in terms of topography, access to water, and grass stand quality, ranchers could achieve economies of scale when rangeland carrying capacities for cattle might require 25 acres or more per animal at 10,000 acres or more (Libecap 2007, 271).

2. Potential for Open Access

There were no initial restrictions on entry. With the removal of native tribes, untapped and unoccupied grazing lands, and rising livestock prices after 1880, the western and northern Great Plains had potential for open entry. Nimmo (1885, 13-9) and Osgood (1954) describe the range resource and the rapid movement of livestock raisers into the region. Dennen (1976) presents evidence that livestock associations were able to successfully block entry and raise returns to members. Later, however, the federal government rejected the land claims of ranchers; removed their fences; and opened the region to unrestrained settlement by homesteaders with 160-acre farmland claims. Rents were dissipated with excessive labor and capital with migration

entry by homesteaders into the western Great Plains (Libecap and Hansen 2002 and Hansen and Libecap 2004a).

When *de facto* ranch claims were removed by the state, open entry appeared. The outcome of open-access on the western range is described by Libecap (1981, 24-8) who examines stocking and grazing practices once fencing and other actions taken by livestock associations to limit entry were blocked by the General Land Office, beginning in the late 1880s. Over time, grazing intensity increased, grass stands were depleted, and livestock mortality rose by the 1920s relative to areas under private property rights. In 1936, the U.S. Department of Agriculture reported that "There is perhaps no darker chapter nor greater tragedy in the history of land occupancy and use in the United States than the story of the western range…the major finding of this report…at once the most obvious and obscure is range depletion so nearly universal…"(U.S.D.A. 1936, 3, quoted in Libecap 1981, 13).

3. Characteristic of Claimants

Claimants appear to have been heterogeneous in their knowledge of production processes and subsequently, of the range. There is little systematic documented evidence of differential skills among herders, but local knowledge was required of when to place livestock on the range and when to remove them in order to sustain the range resource and livestock health. Nimmo's report (1885, 146) includes an article from the *Rocky Mountain Husbandman* April 2, 1885 about the importance of learning about placement of livestock on the range and herding on grazing intensity in particular locations. Placing livestock on the range in the spring and removing them in the fall too soon or too late posed risks for livestock and for maintenance of grass stands over time. Too early grazing could trample plants and limit growth of over the growing season and similarly too late removal through roundups could over deplete forage stock as well as run livestock with heavy winter coats that could result in overheating and mortality. There also was related information required about interpreting livestock prices and when to sell herds. Hence, there were returns to learning and investment in human capital. Not all herders were successful. But others did very well, earning land rents (Nimmo 1885, 20). Placing cattle on the new ranges was risky especially because of a lack of experience with the weather (Libecap and Hansen 2002; Osgood 1954, 134). Osgood (1954, 88) comments: "The Wyoming stock grower had developed the range system of cattle growing because the country in which he operated was not adapted to any other method. The Texas men, the acknowledged experts, with whom he had early come into contact, had taught him the fundamentals." But adjustments were required for the northern plains where weather could be very severe.

4. Nature of Individual Returns/Inframarginal Rents

There appear to have been inframarginal rents earned by some parties. There also is limited information on individual ranching returns. Dennen (1976) describes how members of livestock associations could sell membership, implying positive returns to membership, and how those members better survived the historic blizzard of 1886-87 (Libecap 1981, 19). Many ranchers endured in the semi-arid region, and as Nimmo's report (1885, 20) suggests, some earned high profits whereas others did not. Homesteaders who subsequently invaded the region under the federal land laws, however, more generally failed. Hansen and Libecap (2004a, 111-3) argue that homesteading brought farming units that were too small for the crop and livestock diversification required to withstand the periodic droughts of the western Great Plains.

5. Nature of Spontaneous Property Rights

Spatial rangeland claims were linked to land adjacent to water and enforced by fencing and livestock associations. Spontaneous, first-possession property rights emerged to avoid competitive open access losses with the size of the claim effectively determined by the market (competitive search and claiming and production requirements). Livestock owners secured shares of the total available rangeland in the Great Plains. As with mineral lands, there was no provision in the federal land laws for large ranching claims. Land policy was driven by agriculture and focused on 160-acre allotments, far too small for ranching operations. Ranchers searched and claimed land near water sources to control surrounding areas and maintained the claim through continued occupancy, much like continued occupancy requirements in mineral lands. Dennen (1976, 424) discusses how entrepreneurial skills led to first-possession claims to the range. Actual informal ownership of the range was secured through occupancy--grazing or the rule of capture. Livestock were owned, whereas the range was occupied informally. Osgood (1954, 115) describes the returns to search: "His idea was to find a large isolated area with as few neighbors as possible." Claims were maintained occupancy or beneficial use. Should a rancher not fully stock an area during the spring-to-fall grazing season, good lands would be occupied by others: "A custom has grown up and become thoroughly established among people of this community that once a stock man has developed water on and taken possession of the range by fully stocking the same that he will not be molested by other stockmen in his passion and enjoyment of such range (statement by William Jones, rancher, Eddy County, New Mexico, 10 April 1917, quoted in Libecap 2007, 271).

Individual claims were recognized by local livestock associations in an outcome similar to that outlined by Ostrom (1990, 90). The numbers of ranchers in any particular livestock association were smaller than the total number of livestock owners in a region. They communicated regularly; engaged in repeat exchange in enforcing livestock brands and coordinating spring and fall livestock roundups and in enforcing claims to rangeland; they apparently had trust; and were homogenous in their norms and expectations regarding range land use. The livestock association rules reduced the requirement for continued occupancy or beneficial use, allowing for livestock to be withdrawn seasonally and to allow grass stands to

rejuvenate. As described below, this benefit was lost once livestock associations and the other actions of ranchers to partition the western range were rejected by the federal government. Livestock associations constrained entry on the range; the placement and movement of livestock on it; registering and policing of livestock brands; coordination of roundups and marketing; and of restricting entry by nonmembers to avoid open access. Osgood (1954, 185-6) quotes the following from Wyoming in the 19th century: "We, the undersigned stock growers of the above described range, hereby give notice that we positively decline allowing any outside party's herds upon the range…." The Wyoming legislature helped to enforce these informal claims in the same way that the Nevada legislature supported mining camp rules. There were no restrictions on transfer. Patented ranch properties could be bought and sold and these included membership in livestock associations that helped to police the broader informal claims to rangeland made by the rancher. With the introduction of barbed wire in the latter 19th century, ranchers also fenced between 9 and 11 million acres of the western range (Libecap 1981, 20). The fences dramatically reduced the costs of geographic control of cattle in a region where there were few trees and little wood available for traditional fencing.

6. Nature of Formal Rights as Defined by the State

De jure rights did not recognize *de facto* rangeland claims. Redistribution, not rent dissipation was the objective of rationalization. There were no open-access losses from excessive entry by livestock owners and associated resource stock depletions and rent dissipation to stimulate mitigation via government intervention through rationalization. Rather, the redistribution via a removal of spontaneous informal property rights and a reassignment of rangeland came from political pressure for access to land. By the late 1880s most of the available arable land for homesteaders under the federal land laws was taken. In 1890 the Federal Census declared the frontier closed. This meant that options were narrowing and homesteaders turned to the range resource held informally in large blocks by ranchers. Nimmo's 1885 report to Congress noted growing tension between livestock operations, federal land laws, and homesteaders (Nimmo 1885, 39, 43, 47, Appendix 3, letter from Silas Bent of the Las Animas County Cattle Growers Association, 99).

Various efforts to reform the land laws in 1878 and later (Hansen and Libecap 2004a, 106-10) failed in Congress. The limitations of semi-arid farming were not understood and John Wesley Powell's call for 2,560-acre homesteads (still too small), for example, were 16 times greater than the 160 acres allowed under the Homestead Act. If adopted it would have potentially reduced the number of new occupants and populations of aspiring states and territories (Colorado, Wyoming, Montana). Instead, the General Land Office and the Interior Department as well as the U.S.D.A, supported removal of ranchers' fences; the breakup of the ranches; and adoption of new farming techniques (Libecap 1981; Libecap and Hansen 2002; Hansen and Libecap 2004a). There was no compensation to ranchers because their spontaneous holdings were considered to be illegal. Valuating their claims may also have been contentious, given

asymmetric information about the value of their individual holdings and private investment in local knowledge and capital.

One can think of this new allotment policy as dividing the range into 160-acre "shares" of the total resource. This differs from the rationalization schemes in fisheries, for example, that divide up a total allowable catch or production into shares, with the reallocation of output instead of input. Enforcement of federal land laws was not termed "rationalization" because it was not aimed at correcting over exploitation. Rather it was aimed at redistribution (Hansen and Libecap 2004a, 105-13; Libecap 2007, 273). Ranchers naturally resisted the reallocation of their lands and the removal of their fences that were termed "unlawful enclosures of the federal domain" (Libecap 1981, 33, quoting from President's Cleveland's executive order).

C. Oil and Gas

1. Nature of the Resource

The resource may be large or small, but is always spatially heterogeneous and there is potential for variation in its spatial distribution over time due to the actions of certain producers. The size of oil and gas reservoirs generally is given in production potential (see for example list of world's largest oil fields in http://en.wikipedia.org/wiki/List_of_oil_fields). In the U.S. access to subterranean deposits, however, is granted by surface land owners so that surface acreage is a more useful measure. Field size ranges from 213,543 acres for Prudhoe Bay in Alaska (http://en.wikipedia.org/wiki/Prudhoe_Bay_Oil_Field) to 140,000 acres for East Texas (http://www.texasarchive.org/library/index.php?title=East_Texas_Oil_Fields) to 26,400 acres for Yates in west Texas (http://en.wikipedia.org/wiki/Yates_Oil_Field) to 13,770 acres for the Oklahoma City field (http://en.wikipedia.org/wiki/Oklahoma_City_Oil_Field), and of course, there are also smaller ones. But larger fields, with more fragmented surface ownership raise the potential for open access.

Hydrocarbon reservoirs are heterogeneous in terms of the production potential, amounts of oil versus natural gas, subsurface flows, porosity, and rock formations. Accordingly, there are more productive areas in the reservoir, often above the deepest portion and others less productive, often on the periphery of the deposit. Moreover, natural gas tends to congregate in certain areas termed the gas cap whereas oil settles in areas termed the oil rim (Wiggins and Libecap 1985; Libecap and Smith 2001, 2002). This heterogeneity affects the value and productivity of those firms that hold productive leases to the reservoir.

2. Potential for Open Access

There are limits to entry based on the number of leases from surface land owners, but the resource itself migrates, setting up the potential for competitive well drilling and draining of the hydrocarbon reservoir. Of the resources examined here, subterranean oil and natural gas deposits and mobile fish stocks are the most truly iconic open-access resources (Smith 1987). In the case of hydrocarbons, oil and natural gas deposits are lodged in subsurface reservoirs under great pressure. When any part of the surrounding geologic formation is punctured by a well bore, a low-pressure area is created and natural gas and oil migrate toward the opening. Movement depends upon subsurface pressures, oil viscosity, amount of natural gas, and the porosity of the surrounding rock. In the U.S. mineral rights are granted generally to surface land owners, who in turn grant search and production leases to specialized firms. Both surface property owners and lease holders have an incentive to produce rapidly and most leases contain production time lines. Oil and natural gas cannot safely be left in the ground. Secure property rights to oil or gas are secured only via the rule of capture.

In this regard, oil and gas is similar to the other natural resources potential exploited under open-access conditions with occupancy and use requirements. The location of the best deposits is very uncertain, particularly until wells are drilled providing core samples of the surrounding medium and production has taken place revealing output patterns and subsurface flows. Surface land owners hold mineral rights and lease search and production rights to producing firms. Depending on the potential for drainage, land owners and firms are motivated to competitively drill and drain. Where surface rights are very splintered, such as with town-lot drilling in Oklahoma City, Oklahoma, Long Beach, California, and Beaumont Texas, hundreds to thousands of adjacent wells were drilled; whereas in smaller fields with large surface land owners covering all or much of the field, capitalization and production patterns are reduced.

With fragmented surface ownership, multiple firms extract from the same reservoir, and they are motivated to competitively drill and drain to increase their shares of oil field rents, even though these individual actions lead to aggregate open-access losses. Rents dissipate as capital costs are driven up with the drilling of excessive wells (more than geologic conditions or price and interest rate projections warrant); with the construction of surface storage, where oil is safe from drainage from other firms; from fire and other losses from surface storage; from the too-rapid venting of natural gas, which is lighter than oil but is necessary to push it across subsurface formations to the surface, necessitating early use of costly injection wells as well as the reduction in total recovery because heavy oil becomes trapped in formations as gas passes by; and from competitive production patterns that deviate from those that would maximize the value of output over time.

The problem of open-access losses in oil and gas production has been recognized since first discovery in the U.S. in 1859 (Libecap and Smith 2002, 591-2). By the early 20th century oil was valuable enough to raise concerns about the losses and engineering information had

developed sufficiently to understand potential remedies, chiefly buy out of competing leases or combining them via unitization, whereby one firm would be chosen to develop the reservoir and all other firms would receive shares in the net returns (Libecap and Wiggins 1984; Wiggins and Libecap 1985; Libecap 2008, 393).

3. Characteristic of Claimants

Claimants invest in specialized search and production methods and once on a productive lease have an incentive to draining neighboring properties secretly. Although surface land rights are secure, with migratory hydrocarbons that can be extracted from many parts of the field and uncertainty as to location and size of deposits, there is an important benefit from search. Certain small firms specialize in search and risk taking and they are termed "wildcatters," while larger firms, with multiple leases across many fields are termed "majors" and they may also have integrated refining and retail operations along the supply chain. The latter are more likely to agree to constraints on production to reduce open-access losses because they capture more of the in situ rents, whereas smaller lease owners depend more on drainage or hold rights to particularly valuable locations less vulnerable to overall field conditions and hence, are more likely to resist those controls. For example, unconstrained output from the East Texas field in the early 1930s led the Governor of Texas to place the field under martial law, enforced by the National Guard. The main problem was rampant violation of state efforts for production constraints by small firms (Wiggins and Libecap 1987, 3-4).

4. Nature of Individual Returns/Inframarginal Rents

Some leases are far more productive than are others and holders of leases to small, very valuable portions of a reservoir are often favorably positioned to capture subterranean hydrocarbon flows and earn rents, even in the presence of competitive open access drilling and production. These lease holders are shown to be the ones that resist unitization or buy out as solutions.

5. Nature of Spontaneous Property Rights

Informal claims to hydrocarbons are linked to formal or *de jure* property rights to surface land. Under competitive oil and gas production firms secure rights to search and produce via leases from land owners and property rights to oil via the rule of capture. As described, this creates incentives for competitive waste. Local common-pool management as outlined by Ostrom (1990, 90) can occur via unitization or by lease consolidation through buyout. With either the rule of capture is replaced by single firm extraction or ownership of the subsurface hydrocarbon stock. But leases are not uniform in production potential or value and this heterogeneity blocks agreement on those options. When competitive extraction is eliminated a

time pattern of output that more closely approximates the return-maximizing pattern can be implemented; capital investment in wells and storage occurs only if it is profit enhancing; and overall recovery increased.

Unfortunately, neither of these options was widespread through the 20th century. Even where the numbers of lease owners are relatively small, an Ostrom (1990, 90) solution for the management of a local common-pool resource through local agreement does not occur. As late as 1975 neither Oklahoma nor Texas, two leading producing states, had as much as 40 percent of production from fully-unitized fields, and even the huge Prudhoe Bay field, discovered in 1968, suffered from competitive production until buyout was completed in 1999 (Libecap 2008, 396). Wiggins and Libecap (1985) and Libecap and Smith (2001) show that opposition has not merely been holdup by lease owners to extract more of field rents, with lease owners defecting sequentially as purchase agreements are completed or as unit agreements are finalized. Rather, certain lease owners systematically resist because they believe their leases are more valuable than do those seeking to purchase or unitize with them.

Information on lease production potential is released regarding productivity from individual wells, but it is descriptive only of the immediate vicinity (Libecap and Wiggins 1985, 696). Through drilling their individual leases, firms gain knowledge of their portion of the reservoir, and the full extent of the deposit and the productive potential of other areas is revealed only through drilling activities of other firms. The production potential and commercial value of a lease are a function of objective variables such as the number of wells, current and past production, and lease acreage as well as subjective geological variables, including the amount of oil below lease lines, net oil migration, oil viscosity, permeability of the surrounding medium, bottom hole pressure, net-acre feet of pay (nonporous and non-oil-bearing rock are subtracted for estimates of gross acre feet of pay, which is the estimated size of the producing formation), and assessments of remaining reserves below lease lines and location of the lease above subsurface flows (some leases are well situated to capture hydrocarbon movement across the formation). Interpretation of data gathered from well bores on these latter parameters is drawn from samples of the thickness of the formation, oil and gas migration, and surrounding mediums along with estimates of how production techniques might fracture the formation and release more hydrocarbons. These interpretations are translated into long-term production projections costs through subjective assessments by company engineers (Wiggins and Libecap 1985, 370-1). These assessments may differ importantly among engineers from different firms, but they are the basis for private value estimates by lease owners. The more complex and depth of the formation and the more natural gas and oil are lodged in different parts of it, the more likely there will be different views of the value of particular leases.

For instance, Wiggins and Libecap (1985, 370) report that in cases where share disputes temporarily halted agreement, there were often very large reassessments of lease values once

negotiations are re-opened. In one Texas field, a seven year delay--accompanied by the generation of additional information from production--resulted in a 50 percent increase in remaining reserve estimates for some leases, a key parameter for lease value determination. The reason for observed disputes lies in differential private and public information that cannot be aligned and related for certain lease value estimates.

Wiggins and Libecap (1985, 372-6) identify small lease holders above the deepest and potentially longest-lived portion of the reservoir as the firms that are most likely to resist buyout or unitization . Estimating long-term production patterns in these areas involves more subjective private information and more uncertainty than is for leases located in shallower areas on the field periphery where value assessments based on private and public information often converge. Firms with large leases covering more of the reservoir or with many leases on the field also are more likely to have value assessments that are agreed upon by others because they bear more of the field-wide rent losses and differing value assessments across leases offset. Libecap and Smith (2001) also emphasize the bargaining problems raised when lease owners are specialized in oil or natural gas due to the difficulty in valuing the two different hydrocarbons and in developing an agreeable conversion factor to translate natural gas into oil or vice versa. Sixty three percent of the largest U.S. oil fields have contained significant volumes of natural gas along with oil; oil lease owners prefer to re-inject gas into the formation to expel the oil, whereas gas lease owners prefer to sell the gas. Another, related asymmetric information problem that is not stressed by either Wiggins and Libecap (1985) or Libecap and Smith (2001) is valuing locational advantages as well as human and physical capital investments that provide value under open access, but not under rationalization. Unitization changes field and production dynamics so that lease locations above past reservoir flows and related investments to understand and capture them may no longer have value. This is, in effect, stranded capital that affected firm owners would seek compensation for in voluntary transactions as part of their willingness-to-accept calculations. At the same time, other parties may not agree on the value claims made by those lease owners or not even agree that rationalization is warranted. Hence, their willingness-to-pay calculations may be too low to support side payments.

In a detailed analysis of unitization efforts for seven reservoirs in Texas and New Mexico, Wiggins and Libecap (1985, 103) found that negotiations took from four to nine years to complete. Negotiations over one of the fields, Empire Abo in New Mexico, took six years and required 58 different votes on the distribution of shares (Wiggins and Libecap 1985, 378, 384). The division of net revenues via shares is specified at unit agreement, and these are permanent: updates are not possible because once the unit is formed, production dynamics change and the lease loses its production role. Some wells are plugged and others are converted to natural gas injection to maintain subsurface pressure, causing subterranean hydrocarbon flows to change. The absence of contingent updates places particular pressure on long-lived lease holders who have the most asymmetric information and uncertainty associated with calculation of lease

values. Moreover, in five of the seven cases, the acreage in the final unit was far less than that involved in the early negotiations because not all parties would agree (Wiggins and Libecap 1985, 384). Subunits, however, are less complete solutions because they involve only part of the formation and because they require the drilling of costly boundary wells to block the migration of hydrocarbons to non-cooperating leases. Libecap and Smith (1999) examine 60 unit agreements and they find (Libecap and Smith 2001) that those with distinct oil and gas deposits are most apt to be incomplete. They detail the case of Prudhoe Bay where 31 years from discovery passed with competitive subunits until there was agreement between lease owners on the gas area (gas cap) and the oil area (oil rim) to consolidate. In the meantime there was much waste in lost oil production and excessive, competitive capital.

6. Nature of Formal Property Rights Defined by the State

Formal rights via rationalization that do not reflect the productive advantages of certain productive areas and processes can result in stranded capital and knowledge. Large firms, often majors, with multiple leases across many non-unitized oil fields bear disproportionate costs from the failure to cooperate to control rent dissipation. They lobby state legislatures to impose field wide unitization. This, however, has met with intense opposition from the same small lease owners that resist voluntary private agreements (Libecap and Wiggins 1985, 706-12). Lease owners have not believed they would receive sufficient returns under the new arrangement, even with open access and with forced unitization they are not offered compensation to align willingness to accept with willingness to pay. Similarly, the state of Alaska was unable to force complete unitization of Prudhoe Bay and in other states forced unitization statutes have been implemented to assign net production shares and to complete units once a designated percent of the field acreage agreed to unitize. In Oklahoma compulsory unitization legislation was adopted in 1945, requiring unitization once 85 percent of the leased acreage supported unitization. This percentage was gradually reduced to 63 percent by 1951 as production declined and information asymmetries dissipated. In Texas, however, opposition by small lease owners has continued so that the state has not adopted a compulsory unitization law that would force lease owners to accept a share that they believed undervalued their leases. In the latter case, the move would not be Pareto improving.

D. Fisheries.

1. Nature of the Resource

The resource can be large and spatially heterogeneous with the spatial distribution varying over time. Depending on the species, fish stocks may be large and variable as to location in the sea and migration patterns. Shell fish, such as oysters, lobsters, mussels, crabs, and clams, tend to be located in specific sites with little movement, whereas demersal fish move more

broadly near sea bottoms. Pelagic fish may migrate across large areas of the sea so that their distribution is often imperfectly known and uncertainty increases with range of movement and variation in currents and sea floor terrain. As a result distinct areas of the sea offer greater returns than do others. The sea is heterogeneous in the probability of harvest and this condition creates returns to search and a race to locate the richest fishing areas. The potential areas involved are very large, even within U.S. waters. The length of coasts is 12,383 miles with tidal shorelines comprising 88,633 miles (http://www.infoplease.com/ipa/A0001801.html). The exclusive economic zones (EEZs) of the U.S. in turn, extend out 200 miles into the open sea, constrained by the international boundaries of adjacent coastal states.

2. Potential for Open Access

There are few restrictions on entry either because of the large nature of the migratory resource or to legal requirements for open access by the general population. Wild ocean fisheries are classic open-access resources. They are the focus of the most complete discussion of the theory and empirical evidence of the losses of open access (Gordon 1954; Scott 1955; Smith 1969; Grafton, Squires and Fox 2000; Myers and Worm 2003, Devine, Baker, and Haedrich, 2006). With relative ease of entry from long coastlines, migratory stocks that can be intercepted by fishers from many different ports, and growing harvest pressures that raise values, fish stocks are depleted, catch-per-unit-of effort and incomes decline, over capitalization and excessive labor inputs are added, and the value of the product is reduced by the rush to harvest whereby output is comprised of small or juvenile fish or frozen fish products instead of more valuable larger and fresh products.

3. Characteristics of Claimants

Fishers invest in specialized search and production skills and capital and in concealment through limited information sharing. Hence, they are heterogeneous in their search and production skills, and differential harvests and incomes persist. In fishing communities it is well known that there is a hierarchy of fishers exploiting the resource and more skilled fishers--termed highliners--do better consistently (Johnson and Libecap 1982, 1010-11). Scott notes (1979, 733): “Fisheries experts repeatedly speak of durable groupings of skippers, vessels, and crews according to the size of their catch or earnings, year in and year out.” These returns are primarily attributed to knowledge of how to set nets and regulate their spread, where to set lines and their depth, correct trawling speed, and identifying where to find fish (Hilborn 1985; Kirkley et al 1998). These skills develop over time and are not easily duplicated. They cannot be readily conveyed from fisher to fisher or from skipper to skipper. As with oil and gas lease valuation, public information on differential success includes past and current harvests, vessel size, equipment, crew size and departure and arrival times at port. Private information includes the

subjective interpretation of tides, water temperatures, ocean currents, floor terrain, historical migratory patterns of the stock, as well as the art of fishing itself.

There may be 2,000,000 commercial ocean fishers in the U.S. (http://en.wikipedia.org/wiki/Commercial_fishing) and they tend to specialize in particular regions, although there can be migration, in fish types (demersal/pelagic/shell fish), in particular equipment (long-line, purse seine, gill net, pole and line, trawl), in vessel size, and in ports or communities. Accordingly, the relevant numbers of fishers in any particular fishery location is far less than the U.S. total.

4. Nature of Individual Returns/Inframarginal Rents

Long-lasting, higher-than-average catches translate into inframarginal rents that exist even when average fishers may earn no rents. Johnson and Libecap (1982, 1010-11) provide evidence of persistent differential harvest returns among fishers using data from the Fall 1978 bay shrimp season on the Texas Gulf Coast. Those fishers with catches one standard deviation above the sample mean were termed, good; those at the mean, average, and those one standard deviation below the mean, poor. These differences across fishers persist through the fishing season.

5. Nature of Spontaneous Property Rights

For highly migratory species enforcing claims to fish stocks via land claims is not feasible. Control instead arises from investment in specialized search and production skills and keeping that information private or asymmetric. Because there is very little way in which fishers for migratory fin fish can establish spontaneous, informal first-possession claims, they rely upon secrecy and limited sharing of information about productive fishing locations and useful fishing techniques among vessels from their own community or fleet. There are complex quid-pro-quo information sharing practices that favor long-term, local knowledge of the stock and of fishers. Other, less-skilled, higher search and production-cost fishers have incentives to free ride as much as possible, so highliners limit information sharing (Wilson 1990, Abbott and Wilen 2011). As with oil and gas and rangeland, secure property rights to open-access fish stocks are granted only by the rule of capture. Hence, first arrival at a spot and limited information sharing as well as superior skills and lower costs form a type of spontaneous property right when more formal ownership rights, such as those called for by Scott (1955) are not feasible. Differential shares of harvests are maintained by these informal/private actions. Fishers are motivated to invest in knowledge and other human capital as well a physical capital and crews to maintain these information-based property rights and the inframarginal rents they provide.

Because shell fish are relatively less mobile across the ocean floor, it would be feasible to establish private property rights to habited areas. Generally, however, formal ownership is illegal in the U.S. (Johnson and Libecap 1982, 1006), but informal property rights exist. Acheson (1975, 2003) has described territorial rights to lobster grounds off the coasts of Maine with those near islands most secure and termed perimeter defended, whereas those near harbors where entry is of lower cost, less secure and termed nucleated. Differential harvests persist based on experience as to where and how to set traps and success in protecting harvest rents. These spontaneous claims emerged in the 19th century and have persisted over time. Acheson (2003) describes conservation efforts by those lobster fishers with perimeter defended rights though trap limits, season closures, and size limits, as well as use of harvest techniques that release juveniles and molting lobsters. Perimeter defended rights are secured through land ownership on islands and as such have not required continued occupancy and use, whereas nucleated rights require occupancy. The most secure rights are obtained via the rule of capture. Even so, these informal territorial use rights are generally respected by local lobster fishers, who interact with one another frequently and who may be members of the same fishing organizations. These ties promote the development of local fishing norms to protect the stock because they are consistent with the conditions for successful collective action described by Ostrom (1990, 90).

6. Nature of Formal Property Rights Defined by the State

With informal claims based on secrecy and asymmetric information, conveying the sources of differential rents is difficult for securing agreement on rationalization. Certain low parties are motivated to maintain open access which recognizes their differential skills and rents. Widespread open-access losses since the 1960s have prompted state and federal governments in the U.S. to implement a variety of regulations to constrain entry and harvest. These include limited entry, limited fishing seasons, vessel and equipment controls. Fishers have adapted around these regulations and stock and rent depletion have continued. Grafton, Squires, and Fox (2000) for example detail increases in the number of vessels and other capital in the Pacific Northwest halibut fishery as seasons were tightened to protect the stock. Between 1980 and 1989 the number of vessels rose by 31 percent and as stock levels fell, regulators progressively reduced the fishing season from 65 days to 6 days a year by 1990. The shortened season led to further investment by fishers in larger and more powerful vessels and to a competitive fishing derby to harvest as many fish as possible in the limited time available. (Grafton, Squires, and Fox 2000, 684). Ultimately a share-based system was implemented to more effectively enlist the incentives of fishers to conserve the stock. Deacon, Parker, and Costello (2013, 84) discuss how imposed total allowable catch limits and assignment of shares in the annual total, such as individual tradable quotas (ITQs), can conserve the stock and raise total rents.

Johnson and Libecap (1982, 1012-17), however, show how the spontaneous property rights and inframarginal rents based on them earned by highliners are at risk from rationalization

that imposes uniform quotas or in other ways undermine their skill and knowledge advantages and investments. These advantages and related human and physical capital investments allow highliners to out-compete others under regulated open access. Unless they are compensated, rationalization is not Pareto improving for them, even though the overall fishery stock is better conserved and total rents increase. Similarly, Abbot and Wilen (2011) discuss how catch limits to reduce bycatch result in races to harvest commercially-valuable stocks before the total allowable bycatch is reached. These regulatory-imposed races change optimal fishing strategies, potentially reducing returns and inframarginal rents.

There are few documented cases of the opposition of highliners to rationalization. Deacon, Parker, and Costello (2013, 88-112) provide such as study of the short-lived Chignik Salmon Fishery Cooperative in Alaska. Although the creation of the cooperative increased rents in the fishery, it was resisted by highliners. In 2002 the Alaska Board of Fisheries approved a request from a group of fishers to create a voluntary cooperative to coordinate harvests and to limit effort and the number of vessels. 18 highliners, whose catch histories exceeded those of members, chose not to join. The share of the total annual allowable catch assigned to the cooperative was increased by the Alaska Board of Fisheries as the number of cooperative members grew from 77 to 87. The cooperative retired by 31 percent the proportion of permits and vessels that otherwise would have been used by its higher-cost members, reducing capital and labor costs per unit of harvest. It also increased the fishing time or season for its members by about 48 percent through reducing the race to intercept fish in the open ocean. Rather, cooperative members waited to cooperatively harvest, using shared capital, as fish concentrated in the Chignik Lagoon (Deacon, Parker, and Costello 2013, 103-8).

There was general agreement by highliners and members that the cooperative improved overall rents by around 33 percent, but there was disagreement as to the division of the rents (Deacon, Parker, and Costello 2013, 110, 112). The cooperative was granted a growing share of the total annual allowable catch (TAC) as its membership expanded (Deacon, Parker, and Costello 2013, 88). Hence, allowable harvests were not distributed according to historical catch shares. Rather the share granted by the regulators to independents declined in 2004 by 40 percent. The declining share of the total allowable catch available to independents threatened their inframarginal advantages which were most valuable under competitive conditions and entry controls. Independents took advantage of their interception skills and fished more outside of the Chignik Lagoon than did coop members who did not have such advantages and who relied upon cooperative fishing efforts. In the face of this, two highliners with among the highest historical catches successfully sued to block the Alaska Board of Fisheries allocations to the cooperative in 2005, and the cooperative was dismantled by court order.

One might ask why historical harvest was not used in the allocation. The cooperative, as with oil field unitization, however, changed fishing practices and location so that past practices

that reflected fish interception in the open ocean and uncoordinated harvest were no longer relevant. Highliners who had invested in those techniques would have demanded compensation or allocations based on them. Cooperative members, however, were earning rents based on new coordinated fishing practices, not historical ones, and apparently, did not have willingness to pay (or allocations) commensurate with the willingness-to-accept demands of highliners. Although there is no information as to the source of any bargaining breakdown, it is consistent with difficulties in valuing stranded capital and skills appropriate for open-access and a race to capture portions of the stock under the rule of capture, but not relevant or valuable under rationalization. This bargaining breakdown in the presence of aggregate benefits is similar to outcomes observed in oil field unitization efforts, and likely undermines other efforts to rationalize.

There are also other potential information asymmetries not included in the Chignik case. High-cost fishers likely have more negative assessments of stock conditions because of their lower catch per unit of effort. Low-cost fishers with great catch per unit of effort may have a more positive assessment. While high-cost fishers would be apt to lobby for top down intervention and rationalization, they would be concerned about granting shares to low-cost fishers that lock in their advantages. Hence, there is a documented reluctance to grant shares based on historical catch. Indeed, rationalization schemes in the U.S., such as adoption of catch shares, have been plagued by distributional conflicts even though conditions have deteriorated as fish stocks have declined. For instance, concerns over the allocation of rents resulted in a moratorium on the assignment of catch shares, such as individual transferable quotas (ITQs) in the U.S. from 1996-2004 (McKay 2004). Moreover, in the U.S. catch shares are use rights only, and explicitly not a property right, which adds uncertainty to the share and potentially undermines the advantages of highliners if the share is revoked or changed arbitrarily. Grainger and Costello (2014, 229-31, 233-36) contrast share arrangements in the U.S. and Canada to New Zealand where rights are secure. They compare dividend price ratios (lease price/sales price) and find that the ratios are significantly higher in the U.S. where granted shares are less secure because of revocation risk, deterring sales. The U.S. federal government retains the right to revoke shares, emphasizing the public, rather than private nature of the resource. Further, in the design of catch shares in the U.S. there has been an effort to preserve the relative position of regions, communities and their fleets limiting the trading of shares that could facilitate consolidation, possibly by low-cost fishers. Some U.S. shares (ITQs) are reserved community development and are not granted to individuals. There also are formal limits on the size of individual share holdings and their transferability. In the Alaska halibut fishery, for example, only transfers from larger to smaller vessel classes are permitted, and no individual is allowed to own more than 0.5 percent of the total quota. Other controls over share concentration limit holdings and maintain a targeted number of vessels in the halibut fleet (Singh, Weninger and Doyle 2006).

E. Western Water.

1. Nature of the Resource

The resource potentially is large and spatially heterogeneous, but the spatial distribution is generally stable over time. River stocks are variable in magnitude and location. In the semi-arid West, rivers are far more limited in total and in distribution across the land scape than in the East, where precipitation levels are higher and where topography is generally flatter. Western river basins vary in size depending on the stream. Very large rivers that dump into the sea, such as the Colorado and Columbia drain some 246,000 square miles and 258,000 square miles respectively (http://water.usgs.gov/watercensus/colorado.html; http://en.wikipedia.org/wiki/Columbia_Basin). Tributaries, such as the Snake (Columbia) or Platte (Missouri), necessarily drain smaller areas at 108,000 square miles and 84,910 square miles respectively (http://en.wikipedia.org/wiki/Snake_River; http://en.wikipedia.org/wiki/Platte_River). Tributaries to these rivers are smaller still. Further, the nature of the surface freshwater stock varies along any particular stream, with smaller flows near headwaters and greater ones near the mouth or convergence with larger streams.

2. Potential for Open Access

As noted above, west of the 100th meridian, annual precipitation as far less than to the east. Aridity is a defining characteristic of the West. Hence, access to water was critical for early economic development in agriculture and mining (Libecap 2011). Because mining sites and arable lands were often far from river flows, diversion dams had to be constructed to capture water, to store it, and to direct it into canals and ditches that transported water to desired locations. The Los Angeles Aqueduct for example, was 240 miles long, transporting water from Owens Valley to the Los Angeles basin (Libecap 2007, 41). Each diversion dam and related canal infrastructure, however, was at risk from the construction of upstream dams that could intercept water and leave downstream investments high and dry. Absent any property rights regime, such competition and the uncertainty it raised would have dissipated rents from mining and agriculture made possible from water capture and transport.

3. Characteristic of Claimants

Claimants invest in specialized location, extraction, and production technologies. Initial water claimants were miners and farmers that required the transport of water from streams to production sites (Kanazawa 1998; Dunbar 1983). Prospectors for mineral ore or lucrative farming areas engaged in search and initially at least, they may have similar skills and search costs. Once mineral lands or agricultural areas were located and mineral or homestead claims filed, these parties had to locate water sources (Libecap 2011). Only ranchers did not require

diversion capital because livestock could migrate to the water source, but that was not possible in mining or agriculture, where water was a key input for remote production.

4. Nature of Individual Returns/Inframarginal Rents

There is little research on the rents earned by water rights holders. Libecap (2007, 2008) documents the rents earned by Los Angeles property owners as the city secured water through private negotiations with Owens Valley farmers. Today high priority water rights are the most valuable water rights because of their security of access during drought (Libecap 2011, 124-5).

5. Nature of Spontaneous Property Rights

Flowing water is costly to bound so individual claims are linked to stationary land; made through diversion; and enforced by continued or beneficial use. As with private mining and rangeland claims, there was no provision in the Federal Land Laws for the assignment of water rights. In eastern, wetter areas, water rights were based upon riparian land ownership. Riparian rights grants land owners access to water adjacent to or passing through their properties for reasonable use and they can utilize the water so long as doing so does not harm other riparian claims downstream (Getches 1997, 33). These rights are appurtenant to the land are transferrable only with it. The arrangement worked well where precipitation and streams were plentiful and more-or-less uniformly spread. The absence of these conditions in the semi-arid West and the need to move water to remote mining and farming locations required institutional innovation by early claimants.

Spontaneous, first-possession water rights emerged through local arrangements unconstrained by external federal law in a manner similar to development of local mining camp rules and livestock associations (Kanazawa 1998, Libecap 2011, 122). These water claims were recognized in mining camp rules and in irrigation districts and ditch companies, and subsequently by territory and state governments. The most arid western states—Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah and Wyoming constitutionally or statutorily adopted the appropriative water rights system. States with more water maintained a hybrid system of both riparian and appropriate water rights—California, Nebraska, Oklahoma, Oregon, Washington, North and South Dakota and Texas (Getches 1997, 81). For agriculture, the earliest claimants likely sought to divert water from the portions of the stream that were closest to arable, flat lands; that had reliable water flows year-around and across drought periods; and that--all else equa--were closer to the source to avoid the diversion of water from upstream claimants.

Prior appropriation rights grant usufructory or possessory rights to a fixed quantity or flow of water for diversion from a stream, based on the date of the original claim (Libecap 2007,

282). The sizes of their claims were based on the market because there were no outside restrictions on individual withdrawals, except that each party could own only what could be placed into beneficial use. Because beneficial uses were difficult to measure, the basic test of meeting the requirement has been physical diversion. Water could not be hoarded, wasted or abandoned and still be owned. Any of these actions would result in water being assigned to the next priority claimant in a region of general water scarcity. The granting of use rights rather than fee simple title likely reflected the extreme importance of water in a semi-arid region. Wyoming law, for example states: "Because water is so important to the economy of this state, its use is always limited by a concept of public trust; the only uses for which right rights be established are those which receive, 'public recognition' under the law of the state" (quoted in Libecap 2007, 282). So long as individuals complied with the beneficial use requirement and did not abandon the water, they had the right to a priority share to the annual flow of water based on the priority of their claim and the size of their diversion capital. There were no constraints on transfer so long as no harm was inflicted on other diverters, who sequentially used some of the same water. An upstream farmer who diverted water for irrigation consumed only part of it, with the remainder percolating through the ground back to aquifers, streams, or to ditches for repeated access by other downstream parties. Small water exchanges among miners or farmers within a watershed were therefore unlikely to have much impact on others, but larger trades could and hence all states regulate transfers out of basin.

Those with the earliest water claims gained the highest priority and those with subsequent claims lower priority or junior claims. No two parties on a waterway had the same priority so that there was a ladder of water rights, ranging from lowest to highest in ranking. Those with the highest ranking had first access to water, and those with lower ranking access to any remaining water. While high priority rights holders could expect to secure water even during drought or during the driest part of a year, those with lower priorities bore greater risk of receiving no water (Libecap 2011, 125).

In each portion of a river basin, the number of claimants was comparatively small with a primary aim of developing mines or irrigated agriculture. These common semi-arid conditions and development objectives in specific parts of a water shed were replicated across the West, and again, coincide with Ostrom's (1990, 90) lists of factors contributing to collective action to manage a local common-pool resource. Appropriate water rights, in turn, supported the development of mining and agriculture in the semi-arid West. They provided security for investment in mining and agriculture water infrastructure including the elaborate irrigation networks provided by mutual ditch companies, irrigation districts and the federal Reclamation Service that were critical for the region's flourishing agriculture (Libecap 2007, 284). The prior appropriation system also formed the basis for moving water from one location and use to another as was the case with the acquisition of Owens Valley water rights in agriculture by the Los Angeles Department of Water and Power between 1905 and 1935 (Libecap 2007, 2008).

6. Nature of Formal Property Rights Defined by the State

As described above, western states have recognized prior possession water rights in state law. At the same time, water rights are possessory rights only and hence, potentially vulnerable to changes in state law. The public trust doctrine is one potential threat. Joseph Sax argued in 1970 that it could be applied to water law, with the notion that water rights would be conditional upon being consistent with the public trust (Brewer and Libecap 2009). In 1983 the California Supreme Court in *National Audubon vs Superior Court* 685 P.2d 709 appeared to extend the public trust doctrine formally for oversight over prior appropriative water rights. Any adjustments or attenuation of water rights under the public trust doctrine is not compensatory so that any action would make current senior rights holders worse off. Kenney (2005, 167-82) is critical of prior appropriation rights for equity reasons and calls for their redistribution. He argues that they reward those who came early and that they ignore community concerns because private rights holders decide on consumptive use and water rights exchange. Young (2014) argues that a share-based system similar to that used in Australia could be usefully implemented throughout the world to promote trade and flexibility in meeting drought. Unless compensation was provided for high-priority rights holders, none of these actions would be in the interest of those parties. Moreover, it could be very difficult to devise a payment that met the willingness to accept levels of those rights holders.

III. Concluding Remarks

We outline a framework for understanding the emergence of informal property rights in open-access resource settings traditionally characterized as lacking any sort of property right. Our approach elucidates why sustained open-access is observed, even in the presence of apparently large aggregate benefits from transitioning to joint management of the resource. Heterogeneous users of a spatially heterogeneous resource will invest in differential levels of search and human capital development, accumulating knowledge that generates inframarginal rents. In response to threats of continued entry, replication, and other forms of rent dissipation, inframarginal rent-earners invest in strategies to protect their expected streams of positive rent. These strategies create and entrench asymmetric information about the costs and benefits of any particular institutional organization for managing the resource; making bargaining between parties costly, potentially to the exclusion side payments for what otherwise appears to be a Pareto-improving transition to share-based management of the resource.

Though our framework provides a rich characterization of the behavior of heterogeneous users of a resource in settings lacking formal property rights, our predictions are inherently difficult to test. We argue that tacit, private knowledge that is, by design, difficult to communicate is the source of users' ability to earn and protect positive rents. This makes direct

empirical testing difficult. Still, our framework sheds light on why some resources have proven less amenable to rationalization than others. We document the existence of differential skill in locating and extracting gold, productive grazing land, oil and gas, fishery resources, and Western U.S. water. Differential search and learning in each setting resulted in users with differing knowledge about the resource. This differential knowledge stymies rationalization attempts in some cases but does not preclude the development of individualized formal property rights in others.

Rationalization is the chosen policy tool for spatially connected resources because each user's behavior affects all other users by changing the aggregate stock available, even when the resource is spatially heterogeneous. Hydrocarbons and fishery resource both fit this pattern. In both cases, we show that users exhibit differing levels of search and investment and knowledge, resulting in a heterogeneous distribution of rents that is correlated with users' knowledge of the resource itself. Both resources have seen repeated attempts at rationalizing. When unsuccessful, rationalization fails due to users' inability to reconcile their contradictory "local knowledge of time and place" to form an agreement about characteristics of the aggregate resource. The result is sustained open access with competitive losses that are larger for high-cost users who tend to know less about the resource.

Spontaneous informal property may evolve into de jure property in cases where individual claims are less interconnected or where political opposition is absent. Gold claims in particular were able to evolve from informal to formal rights due to the lack spatial connectivity between gold deposits. Rationalization was never proposed for gold because there was no meaningfully connected aggregate stock that required joint management and no competing demands from settlers at that time. Hence, individually-asserted claims to the resource were codified into law without concentrated resistance from other parties. On the other hand, cattle ranchers' informal rights to the open range were expropriated due to concentrated political force from competing users. Rents from cattle ranching were inherently difficult to communicate due to their specialized nature and ranchers were not able to credibly argue for the economic value of their use of the resource given the wealth redistribution objectives of the General Land Laws. Water rights—like gold—evolved from informal to formal property. Attempts at rationalizing water are still largely theoretical, but water users' differential interactions with river resources at locations facing different stream flow and differing agricultural productivity will make valuing their access to water in particular locations difficult.

Formal property rights fail to emerge in natural resources that are characterized by high costs of defining and enforcing rights. We have argued that these costs are primarily information costs. When it is costly to gather information about the resource and about other users, open access persists. Rationalization is proposed when aggregate demands on the resource result in declining stocks and when uncertainty has prevented the development of property rights early on, but may be resisted if informal property rights already exist. Informal property rights are more likely to emerge in settings where the returns to asymmetric information are large and the

characteristics of the resource are such that users are able to invest in private knowledge about the resource—and how to harvest it—that cannot be easily grasped by others. Inframarginal rents arise because some users have more knowledge than others, and informal property rights evolve around the protection of this knowledge. Users resist rationalization and will require compensation when rationalizing expropriates their informal rights. However, the fact that informal property rights emerged in the first place implies that compensation will be difficult to agree upon because different users have acquired different knowledge of the resource and made investments to keep that knowledge private.

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