THE CLASSICAL LIBERAL INSTITUTE
NEW YORK UNIVERSITY SCHOOL OF LAW

WORKING PAPERS SERIES

VIRTUAL PARCELING

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Working Paper No. 1

December 13, 2016

An index to the working papers in the Classical Liberal Institute Working Paper Series is located at http://www.classicalliberalinstitute.org/ideas-opinions/working-paper-series/

VIRTUAL PARCELING

Karen Bradshaw & Bryan Leonard***

INTRODUCTION

In 2015, the U.S. Senate passed a budgetary amendment to privatize federal public land. If the House of Representatives follows suit, large swaths of public land may be broken into small and parcels sold to states and private parties. Received scholarly wisdom suggests that such privatization effectively mitigates the tragedy of the commons, resource exhaustion caused by users failing to internalize the costs of their uses (Gordon, 1954; Hardin, 1968). Yet, other scholars have suggested that privatization sometimes fragments property interests into too-small pieces, producing underuse of resources (Heller, 1998; Buchanan and Yoon, 2000). To date, however, there is limited recognition that privatization *creates* over-fragmentation of severable property rights to resources which can only be efficiently managed at the landscape level, such as oil and gas or minerals (Bradshaw Schulz and Lueck, 2016; Leonard and Parker, 2016). As a result, existing scholarship underestimates the second-order transaction costs associated with privatization, understates the importance of initial entitlements, and fails to account for the subsidizing effects of public land.

We fill the theoretical gap between privatization and fragmentation by providing a model demonstrating that dividing land according to an efficient scale of management for one resource produces inefficient scales of management for other resources. To maximize secondary resources, resource users must assemble severable resource rights into efficiently-sized ownership bundles with boundaries differing from land parcels—a process we term "virtual parceling." Thus, each geographic land unit contains multiple systems of parcels – recorded land parcels and overlapping virtual parcels for resources ranging from oil and gas development to wildlife habitat.

In this article, we set forth a general theory suggesting that virtual parceling allows the management of dynamic natural resources while maintaining fixed entitlements to the land that contains these resources. This theory synthesizes a growing body of recent empirical work of resource developers and conservationists re-bundling fragmented resources—such as oil and gas reserves and wildlife habitat—that can only be managed at the landscape level. It also draws upon the well-established literature on land assembly (Epstein, 1985, 2014a; Heller, 1998; Brooks & Lutz, 2016; Isaac et al., 2016) to suggest that a parallel process of re-bundling occurs with commercially viable resources that begin as severable interests in land.

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To demonstrate the theory of virtual parceling, we model the effects of privatization on a landscape containing two resources. The primary resource is subject to a tragedy of the commons under an open-access regime, and thus is managed more efficiently under a privatization regime; the second resource is a landscape-level public good with an efficient scale of management larger than individual parcel sizes. Privatization of land to solve the tragedy of the commons for one resource creates a coordination failure for the other. We discuss how failure to coordinate in the provision of landscape-scale public goods can become more economically important as underlying resource conditions change. We further consider how second-order policy tools can coordinate users of private parcels to assemble property rights in resources so they can be managed at a landscape level. Statutory requirements, coordination among resource developers, and public ownership of land all serve to increase provision of landscape scale resources while leaving parcel ownership intact.

In sum, we theorize that plural systems of virtual parcels of resources run parallel with recorded land parcels. Land is dynamic, and so are the natural resources upon it.[1] The laws that govern real property must then also be dynamic, and they are.[2] Existing theory does not, however, fully capture the role of custom, law, and markets in embedding flexibility amidst a system of fixed entitlements and fluctuating resources. Virtual parceling of resources allow the maintenance of private property while permitting loose regional or national work-around of antitrust policies for resources that run with land. A mix of legal and private interventions emerge to allow dynamic resource management amidst a world of fixed private parcels. Custom, contract, and statute allow efficient unbundling and re-parceling of various resources into appropriately-sized parcels for management. Virtual re-parceling allows dynamic resource management, shifting the scale of management in response to changed ecological, social, or market conditions. Thus, it is an essential, but currently unrecognized, mechanism without which private property could not efficiently exist.

I. SCALING LAND AND RESOURCES

Property theory has long overlooked both the process and effects of converting open-access land into private property.[3] Carol Rose suggests that this "gap in the classical theory" began when Locke and Blackstone alike jumped from a system of unclaimed land to a private property regime (Rose, 1990). Coase's (1960) theory begins in a state of preexisting property rights to land and other assets (Fennell, 2013). Although Demsetz (1967) describes the conditions under which private property rights emerge, he did not describe the process through which those rights are allocated.

[1] The artifice of this division is evidenced by law school curriculum, in which property law, environmental law, land use, and natural resources are taught as separate courses. Scholars tend to research in one area, but not others, missing valuable opportunities to understand the intersections between the fields.

[2] Yet, existing property theory operates around anthropocentric definitions of the field as social relationships among people, transacting over time for a fixed set of things. For a summary of property theories, Bell & Parchomovsky, A (2005). See also Coase (1960) and Merrill & Smith (2001).

[3] The most direct consideration of this question is found in Anderson & Hill (1975).

Recently, law and economics scholars have begun describing the process of converting unowned or public lands into privatized holdings.[4] Collectively, these accounts reflect received wisdom that private property necessarily incentivizes efficient control of natural resources because landowners must now internalize the costs of management decisions. This literature does not, however, grapple with a new and growing body of natural resources scholarship that raises a downside of fixed entitlements: that breaking land into parcels of a size appropriate for individual ownership constrains on landowners' ability to manage resources that cannot be efficiently managed at the parcel level.

The well-recognized legal doctrine of severability permits the unbundling of resources from the land on which they exist. For example, a landowner may sell the oil and gas or mineral rights under his land while retaining full title to the land itself. Although the doctrine of severability is well-established, there is limited empirical work exploring what happens to rights once severed—how they are transacted and aggregated and how they evolve over time.

We argue that unbundled resources are reassembled to create an efficient scale for management, which can be at the landscape, regional, national or global level. We term the re-bundling of resources "virtual parceling" – a system in which natural resources are grouped at scales different than land parcels. Mechanisms to facilitate virtual parceling fall into two rough groupings: government (through statute, public land, public interest in resources) and private (through custom, contract).

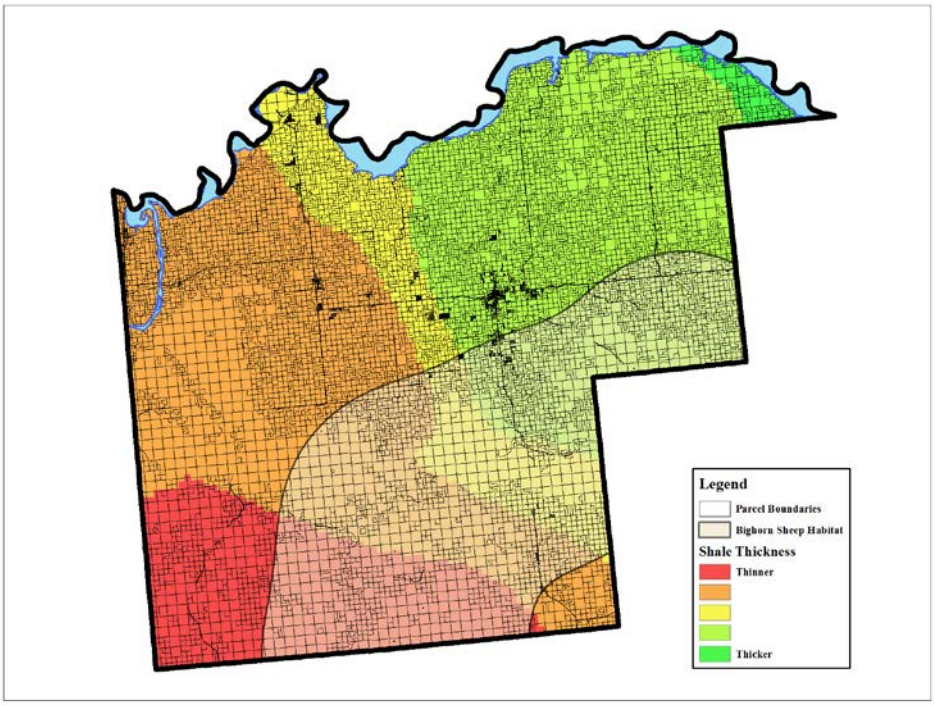
To illustrate virtual parceling, consider the example of McKenzie County, North Dakota depicted in Figures 1 and 2.[5] Figure 1 shows parcels of land in McKenzie County and how they overlay other natural resources that run with the land. The green to red shading indicates the thickness of the shale underneath the landscape—a measure of the endowment of valuable natural gas. Thicker shale, depicted in green, contains more natural gas than thinner shale, depicted in red. Much of McKenzie County overlays valuable shale deposits, but the subdivision of property into parcels requires coordination across many parcels for the development of even one horizontal drilling project (Leonard and Parker, 2016).

A portion of McKenzie County is also critical habitat for bighorn sheep, indicated with the outlined tan shading in Figure 1. Actions of landowners anywhere in the shaded area have the potential to affect the overall population of bighorn on the landscape by either damaging or protecting portions of its habitat. Individual landowners can have an especially dramatic effect on wildlife populations when connectivity is an important part of habitat preservation because damages on just a few parcels can impact the conservation value of the landscape as a whole if wildlife corridors are severed.

[4] Recent law and economics literature describes the land titling process in Brazilian frontiers, American Plains, and through a natural law account (Alston & Libecap., 1996; Anderson & Hill, 1975; Libecap and Lueck, 2011; Epstein, 2014b). Leonard & Libecap (2016) study the emergence of quantified property rights to water.

[5] Parcel map obtained from McKenzie County Assessor's Office at http://county.mckenziecounty.net/DepartmentsDisplay.aspx?ID=GIS. Shale thickness and oil field data obtained from North Dakota Industrial Commission Oil and Gas GIS Hub as https://www.dmr.nd.gov/OaGIMS/viewer.htm. Bighorn sheep habitat, National Parks, and National Grasslands obtained from State of North Dakota GIS HUB at https://www.nd.gov/itd/statewide-alliances/gis.

Figure 1. Land Parcels and Natural Resources



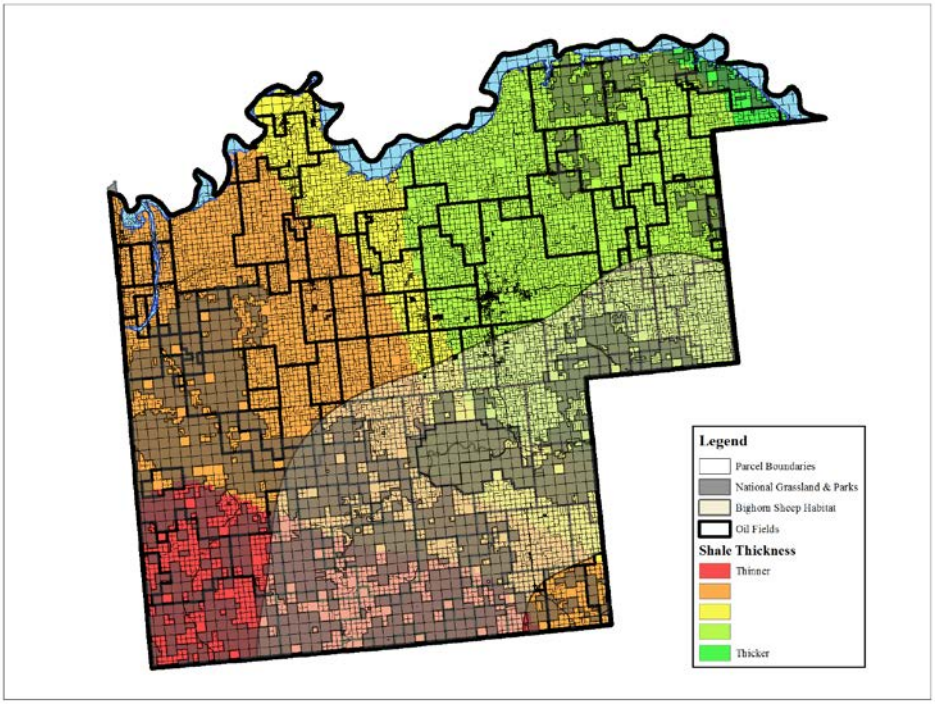
The size of the bighorn sheep habitat and the shale endowment reflect the fact that some resources operate as very large, landscape-level resources spanning tens of thousands of individual parcels. Any single land parcel is subject to multiple sets of virtual parcels that govern the actual management of these large-scale resources. To extract shale, oil developers assemble mineral rights into larger tracts and get "spacing units" approved for individual drilling projects which are then aggregated to a larger administrative rule-making unit referred to as an oil field. These oil fields, depicted in Figure 2, are the virtual parcels that govern the ownership and management of shale resources that were initially subdivided into smaller parcels— a single oil field contains between dozens and hundreds of parcels.

Similarly, Figure 2 also depicts National Grassland and National Parks, shaded in grey. This public land is managed by agencies of the federal government to achieve a variety of goals, including maintenance of critical habitat for the bighorn sheep. Note that much of the bighorn's critical habitat overlays public land. This arrangement allows protection of a species with broad conservation value while reducing the burden borne private landowners. The mix of private and public parcels in the landscape provides second-order flexibility in meeting conservation goals while honoring the fixed entitlements associated with private land ownership.

As depicted through the diagrams, each land parcel contains multiple severable resources (indeed, this county contains a plethora of resources we do not depict). Resource managers—including oil and gas developers, conservationists, and fracking companies—assemble valuable resource rights into parcels of efficient scale of management. The bundled resources are a parallel system of parceling to land parceling: they are equally alienable and subject to

regulation as is the land which they overlay. Virtual parceling differs from land parceling in that it generally lacks a centralized, easily accessible system of recordation across resources, and the market for resources may be less transparent than the ubiquitous and easily-accessible market for land. Such parcel and resource mismatch is ubiquitous.[6] Collectively, law, market, and custom serve to adjust property allocations that do not map neatly onto underlying natural resource distributions. Seemingly every parcel of land is subject to multiple back-end controls ensuring resource flexibility over time.

Figure 2. Virtual Parcels and Public Land



Thus, although privatization encourages efficiency with respect to certain resources, it necessarily and simultaneously impairs the efficient management for other resources, which are best managed at a landscape-level. Linking property and natural resources scholarship suggests that privatization comes with a downside: it creates overly fragmented property rights in resources, necessitating transaction costs to reassemble resources to an efficient scale of management.

At the moment of privatization, land is removed from open access or public trust regime in relatively smaller pieces than afforded to individuals as parcels. Privatization necessarily requires

[6] This is function of initial entitlements, the time that has passed since the time the entitlement was granted, natural and human-caused changes in the natural resources it the area, and the mix of value-generating resources on the land.

a fixed parcel; the size of that parcel varies depending upon a plethora of factors (Ellickson, 1993).[7]

What if the initial allocation of property gets the parcel size wrong—if it is too large for the landowner to manage, or too small for them to survive? What if a once-sensible allocation becomes insensible at another point in time?[8] What if parcel sizes sensible for one resource are inefficient for a different resource, which becomes more important over time?[9]

Over time—in response to changed social, market, and ecological conditions—initial entitlements will inevitably be reshaped to efficient size with respect to various marketable resources. Law, custom, and market transactions serve to re-bundle overly fragmented resources. Analytically, this functions similarly to the familiar topic of land assembly (Epstein 1985, 2014a; Heller & Hills, 2008). The tools of adjusting de facto parcel size include customary agreements to pool parcels, transactions to grow or shrink parcel holdings managed by a single owner, easements, and statutory interventions to increase or diminish rights of landowners (Bradshaw and Lueck, 2015). These tools provide back-end flexibility that mitigates the limitations of static nature of property rights for addressing changes in resource abundance or value. First-period initial allocations therefore drive the level and content of second-order interventions (Ellickson, 1993).

Consider a few examples. Robust statutory regimes governing clean air, clean water, and the protection of wildlife can be understood as legal tools operating to re-bundle too-small units of landscape-level resources into workable size. Custom and contract operate similarly to group road sharing, wildfire prevention, predatory species abatement, and oil and gas reserves. Market transactions, conservation easements, and compensated takings have, over time, consolidated too-small parcels into sweeping landscapes for wildlife corridors, migratory bird flyways, and recreational uses.

The relative merits of each second-order solution depend upon the nature of the landscape good and the distribution of property rights to land. This suggests that initial entitlements matter more than generally recognized. If land is distributed such that individuals can remain profitable and pubic goods remain at socially acceptable levels, the balance of resources to resource users will remain relatively undisturbed.[10] Insensible allocations, or once-sensible allocations that no

[7] Spanish colonists granted parcels of hundreds of thousands, sometimes millions, of acres to incentivize settlement and encourage investment and defense. In the pre-industrial era, parcel sizes reflected an appropriate scale for individual agriculture. Land disposition policies in the homesteading era allotted each landowner a 160 acre plot.

[8] Understanding the relationship between parcel size and resource management is particularly critical when property rights bundle land with landscape-scale resources with public characteristics, such as, air quality, open space, natural disaster risk, migratory species, and wildlife habitat. Many such resources evolve dynamically over time in response to a variety of shocks, ranging from climate change and technological discoveries to invasive species or human population growth—a factor which further complicates the management of resources at all scales. The scale of private property rights determines the extent to which individual landowners will be able to coordinate as they adapt to changing resource conditions.

[9] These questions are not hypothetical: Coordinated management of large scale natural resources such as oil, natural gas, and wind, public goods like clean air, open space, and pristine views, and large scale conservation efforts are all stymied by the subdivision of a landscape into parcels sized for efficient agricultural development.

[10] Among animals, population pressures or resource shortages produce eventual exclusion of non-rights holders, which forces migration and extinction. Among humans, markets, custom and law shape prosocial behavior in the

longer accord to changed resource distributions, are subject to subsequent intervention. The initial allocation of property and subsequent strength of property rights drives reliance on tools for governing those distributions over time.

II. A MODEL OF OVERLAPPING RESOURCES

1. The Traditional Privatization Account

We draw upon McCarthy et al.'s (2001) characterization of a rangeland commons to show how privatizing land can solve a tragedy of the commons for a particular resource. Consider N users of a landscape of size L, each choosing how many cattle x_i to graze. The cattle weight production function reflects a basic tragedy of the commons whereby ranchers cannot exclude one another from grazing their cattle. Individual i maximizes her profit by choosing how many cattle to graze, taking the actions of other ranchers as given. Individual i solves:

$$\max_{x_i} \ \pi(x_i) = p x_i \left(a - \frac{b(x_i + x_{-i})}{L}\right) - c x_i \tag{1}$$

where $x_{-i} = \sum_{j \neq i} x_j$ is stocking by other ranchers, p is the price of output, c is the cost of stocking an additional animal on the range, and a and b are parameters of the cattle weight production function, adapted from Hart (1989) by McCarthy et al. (2001).

Profitability for each rancher depends on the total number of cattle on the range, but ranchers only internalize the effect of additional stocking density in their own profit, resulting in a tragedy of the commons. In a symmetric Cournot-Nash equilibrium, in which each rancher takes as given the actions of all other ranchers and chooses the best response, individual cattle choices and the associated profits in the commons are given by:

$$x_i^c = \left(a - \frac{c}{p}\right)\frac{L}{(N+1)b} \qquad \pi_i^c(a, b, c, L, N) = p\left(a - \frac{c}{p}\right)^2 \frac{L}{(N+1)^2 b} \tag{2}$$

For comparison, we note that the sole owner of a landscape of size L would choose:

$$x^* = \left(a - \frac{c}{p}\right)\frac{L}{2b} \qquad \pi(a, b, c, L) = p\left(a - \frac{c}{p}\right)^2 \frac{L}{4b} \tag{3}$$

Multiplying the per capita stock and associated profit in the commons from equation (2) by N and comparing aggregate outcomes to the equations in (3), it is evident that common ownership of the range results in overuse of the landscape by ranchers, lowering profits for all.

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form of circumscribed property rights that are constantly, forever subject to latent intrusion on behalf of the common good. The Constitution reflects this need for some degree of collectively governed land in the Property Clause:

> The Congress shall have power to dispose of and make all needful Rules and Regulations respecting the Territory or other Property belonging to the United States; and nothing in this Constitution shall be so construed as to Prejudice any Claims of the United States, or of any particular State.

U.S. CONST., art. IV, § 3, cl. 2. Federal public land currently comprises approximately thirty percent of the United States. See infra Part II.A.3.

One method for mitigating this tragedy of the commons is to privatize the range by subdividing it into N parcels, and granting each individual exclusive use of one parcel. Denote an individual parcel size as L_i, then each rancher maximizes her profit by choosing how many cattle to graze on her own parcel, no longer subject to an externality from other ranchers' cattle:

$$\max_{x_i} \ \pi(x_i) = px_i\left(a - \frac{bx_i}{L_i}\right) - cx_i \tag{4}$$

This results in an optimal stocking density and associated profit on each parcel:

$$x_i^p = (a - \frac{c}{p})\frac{L_i}{2b} \qquad \pi_i^p(a, b, c, L_i) = p\left(a - \frac{c}{p}\right)^2 \frac{L_i}{4b} \tag{5}$$

If the range is equally divided among the N ranchers and each has a parcel of size $L_i = \frac{L}{N}$, then privatization implements the sole owner's solution at the landscape level. For simplicity, we maintain the implicit assumption that parcels are not subdivided beyond the minimum efficient parcel size for ranching. We also note the landowner's value function—her profit from optimally stocking her private range—is linear in acreage L_i, which is relevant to the consideration of optimal parcel size below. Below, we suspend the artificial assumption of a single resource on a landscape and consider the effects of parcelizaiton on landscapes with multiple resources.

While sole ownership of the landscape and subdivision the landscape into private parcels both result in efficient resource use, subdivision is by far the more empirically prevalent outcome in settings where there are multiple users across the landscape at a given point in time. Leonard and Parker (2016) note this empirical regularity and theorize that it can be explained by the political and economic disadvantages of landscape-level sole ownership stemming from monopolization of land and from principle-agent problems associated with farm tenancy.

2. Multiple resources

In practice—although generally not in existing models—each land parcel contains multiple natural resources. The mix of available resources on a particular parcel varies according to geography and historic management. Landowners generally manage land to maximize the extraction of any profitable resources such as agriculture, hunting rights, and oil and gas reserves. Landowners must also manage uses consistent with statutory obligations to preserve the quality of resources such as air, water, and wildlife. For the sake of illustration, we simplify the multiplicity of resources to two in the discussion below.

Specifically, define air quality as Z. Rangeland is generally parceled in units of hundreds of acres, whereas effectively managing air sheds requires coordination of hundreds of thousands of acres. This typifies a landscape level resource, which necessitates landowner coordination at a scale above the individual parcel. Suppose that individual landowner i's share of aggregate air quality depends on the size of her land endowment relative to the landscape:

$$Z_i = Z \times \frac{L_i}{L} \tag{6}$$

As discussed above, rangeland and air resources have vastly different efficient scales of management (Bradshaw and Lueck, 2015). Scaling L_i to the efficient scale of management for grazing unwittingly creates inefficient scales for the coordinated management for air quality, wildlife habitat, and other large-scale resources.

We assume the landscape level-resource is the result of the sum of individual effort, denoted e_i, to provide a public good. Suppose the cost of supplying this effort is quadratic with scale parameter k and that costs rise on a per-acre basis. There is some threshold level of the public good denoted $\bar{Z}$ that is required for individuals to not suffer damages. Broadly, this could be a minimum standard for air quality, an open space requirement, or a socially desirable amount of habitat for wildlife such as the grey wolf. The parameter r is the per-acre benefit associated with the public good. Finally, the effectiveness of individual effort is given by β. Then the individual chooses their contribution to the landscape resource to maximize the per-acre profit from their share of the resource minus the cost of contributing:

$$\max_{e_i} \; r(\beta \sum e_i - \bar{Z}) \frac{L_i}{L} - L_i k \frac{e_i^2}{2} \tag{7}$$

Individual contributions to the public good and the resulting profit in a symmetric Cournot-Nash equilibrium are given by:

$$e_i^* = \frac{r\beta}{kL} \qquad \pi_i(r, \bar{Z}, k, L, L_i) = r\left(\beta N \frac{r\beta}{kL} - \bar{Z}\right)\frac{L_i}{L} - L_i k \left(\frac{r\beta}{kL}\right)^2 = \frac{rL_i}{L}\left[\frac{\beta^2}{KL}\left(N - \frac{r}{k}\right) - \bar{Z}\right] \tag{8}$$

Note the benefit of the landscape resource depends directly on $\bar{Z}$, which reflects the latent availability of the resource and depends upon surrounding lands, including public lands. An increase in the threshold level $\bar{Z}$ could be offset by increased contributions from users, including government landholdings managed for multiple uses instead of commercial maximization of a single resource. We will return to this observation when we consider second order solutions for management of the landscape resource.

To see the coordination failure for provision of the landscape-level public good, consider the welfare-maximizing effort contributions. Welfare maximization requires:

$$\max_{\bar{e_i}} \quad \sum_{i=1}^{N} \left[r(\beta \sum e_i - \bar{Z}) \frac{L_i}{L} - L_i k \frac{e_i^2}{2} \right] \tag{9}$$

Which would entail additional contribution to the public good from each individual, relative to their uncoordinated contribution level:

$$e_i^O = r\beta \frac{\sum L_i}{L \square kL} = \frac{r\beta}{kL} + \frac{r\beta \sum_{j \neq i} L_i}{kL} = e_i^* + \frac{r\beta \sum_{j \neq i} L_j}{kL} \tag{10}$$

Under the uncoordinated regime the aggregate landscape level good is:

$$Z^{UC} = \beta N \frac{r\beta}{kL} - \bar{Z} \tag{11}$$

Under the optimal regime the landscape level good is equal to:

$$Z^{C} = \sum_{i=1}^{N} r\beta \frac{\sum L_i}{L_i kL} - \bar{Z} = \beta \frac{r\beta}{kL} [N + (N-1) \sum_{i=1}^{N} L_i \,] - \bar{Z} \tag{12}$$

The difference between optimal and uncoordinated provision of the public good is

$$Z^{C} - Z^{UC} = \beta \frac{r\beta}{kL} (N-1) \sum_{i=1}^{N} L_i$$

$$Z^{C} - Z^{UC} = \frac{\sum_{i=1}^{N} L_i}{L} \times \frac{r\beta^2 (N-1)}{k} \tag{13}$$

Visual inspection of equation (13) provides some intuition about the factors that lead to under-provision of the public good. The difference between the welfare-maximizing provision versus uncoordinated provision of the public good is increasing in the share of land that has been privatized, $\frac{\sum_{i=1}^{N} L_i}{L}$, while it is decreasing in total landscape size L, holding the size of private holdings fixed. Intuitively, landscapes that have a greater share of land pass into private hands are more subject to coordination failures because under-provision of the public good occurs across a broader share of the landscape.

Under-provision of the public good also grows with N because the external effects of private action are magnified for each additional user that is added to the landscape. Hence, the more users on the landscape and the greater the share of the landscape that has been privatized, the greater the difference between the welfare-maximizing and the actual amount of the landscape-level public good—the tradeoffs of privatization for landscape-level use depend critically on the initial determination of parcel size. More land is likely to be privatized when either i) initial parcels L_i are relatively large or ii) N is large so that aggregate demands for private land consume much of the landscape. Below, we discuss how the existence of public land on the landscape provides an additional benefit for landowners by subsidizing their under-provision of Z.

3. Choosing Parcel Size

Recall that both grazing and the public good Z_i confer some constant per-acre damage or benefit to each landowner. Specifically, $G = \left(a - \frac{c}{p}\right)^2 \frac{p}{4b}$ is the per-acre profit from optimally choosing herd size on the parcel and $R = \frac{r}{L}\left[\frac{\beta^2}{KL}\left(N - \frac{r}{k}\right) - \bar{Z}\right]$ is the constant per-acre benefit associated with the uncoordinated provision of the landscape-level public good. Hence, the benefits

associated with land ownership for both ranching and the public good are linear in private acreage L_i.

We assume that the costs of establishing property rights to a given parcel are quadratic in acreage.[11] Specifically, we assume the costs of claiming an area of size L_i are given by $F\frac{L_i^2}{2}$. This is akin to saying that the costs of physically enclosing the parcel, with say a fence, are linear in linear miles of fence.

Assuming i) that cattle are stocked optimally and ii) the public good contribution equilibrium exists once a parcel is established, the decision of how large of a parcel to claim can be expressed as:

$$\max_{L_i} \quad \Pi_i(L_i) = GL_i + RL_i - F\frac{L_i^2}{2} \tag{14}$$

This results in an optimal parcel size for a given individual of:

$$L_i^* = \frac{G+R}{F} \tag{15}$$

Optimal parcel size is increasing in the per-acre benefits of privatized ranching, G, and the per-acre benefits of consumption of some share of the landscape resource, R. Parcel size is decreasing in the marginal cost of claiming an additional acre, F. In many settings, the landscape-level public good is not valued, or even known, during the initial period of privatization, so that parcels are chosen assuming $R = 0$, resulting in a parcel size that is too small. We are particularly concerned with situations where the public good is not valued initially when land is privatized but later comes to be an important resource.

An example examined in detail by Leonard and Parker (2016) is the subdivision of oil and gas resources that are trapped in tight shale formations. At the time that most of the Western Frontier was privatized into 160 acre allotments under the Homestead Act, there was no known ability to recover minerals from tight shale and so the resource was not valued—corresponding to $R = 0$. The advent of horizontal drilling and hydraulic fracturing made these deposits quite valuable, but successful development of shale deposits now requires coordination of landowners because the efficient scale for a single well is roughly 1,280 acres, comprising 8 homestead claims (Leonard and Parker, 2016).

Essentially, privatizing land to solve a tragedy of the commons inadvertently produces an inefficient scale of management for landscape goods like Z. Further, the coordination failure associated with provision of Z reduces the per-acre benefit of the public good relative to optimal provision, so that individuals would choose larger parcels ex ante if the coordination problem could be solved ex post. To the extent that users anticipate some future coordination failure like air quality, it makes initial land claims small relative to an efficient scale that would optimally balance private and public interests on the landscape.

[11] Any measure of area such as acreage is the square of some linear unit, so it is intuitive that expanding area claimed would cause claiming costs to rise in a quadratic manner.

Across many areas of the U.S. West, human impacts on air quality were initially quite small, so that zero provision by all landowners still result in clean enough air that there were no negative effects on health or views— $\bar{Z}$ was initially very low and so zero contributions were needed. Over time, changes in technology have led to situations where positive mitigation effort is required in order for landowners to not suffer some damage from poor air quality, implying a higher $\bar{Z}$ than when land was initially privatized. This, in turn, requires virtual parcels to change in response to changed resource conditions.

Parcel sizes are determined at a particular point in time, without insight into future ecological, social or market conditions of resources. Sometimes, the size of initial entitlements is completely divorced from localized resource conditions. Spanish government officials granting land to private individuals in what became the American West had never touched foot on the soil which they were giving away. In the absence of information of local resource conditions, grants ranged between thousands and millions of acres in size depending upon the social and military status of the grant recipient.

Similarly, later United States land disposition policies overlaid a surveying grid system with 160 acre parcels across the Western landscape. Parcels suitable for mining, farming, or ranching, particularly those near water, were the first claimed. Eventually, millions of unclaimed acres of resource-poor parcels reverted to the federal government. Through historical accident and low population density, public lands have subsidized nearby private landholders for generations, through provision of below-market-value resource extraction (minerals, grazing, timber) and contributions to public goods which would otherwise be borne by private landowners (carbon sequestration, air, water, habitat, and recreational uses).

As illustrated by historical examples of land distribution, initial entitlements will inevitably not match future land uses. Thus, for a system of privatization to work, there must be subsequent flexibility. In the following section we suggest that law, markets, and custom provide a vital role in re-bundling inefficiently partitioned natural resources into efficient scales of management. Continuing the example of grazing and air quality, the most desirable parcels in the American Southwest were privatized by Spanish and Mexican land grants in the 1700's (Bradfute, 1975). The privatization occurred approximately two hundred years prior to the coordination failure surrounding efforts to provide or maintain clean air sheds. Eventually, Congress imposed a duty on private individuals to manage for air quality through enactment of the Clean Air Act.

III. SECOND-ORDER FLEXIBILITY

Severability—the ability to separate resource rights from a parcel—reflects the truism that land uses must be flexible because populations and natural resources shift over time.[12] Fixed entitlements alone cannot accommodate natural resource fluctuation for resources with management scales exceeding a single parcel. Landowners only internalize part of the costs and benefits of their actions and do not consider their effect on the broader landscape (Hansen and Libecap, 2004). Moreover, the effect of coordination failure in provision of the public good can be exacerbated by shocks to the latent quantity of landscape resources, reflected in the threshold $\bar{Z}$. If clean air or water is initially maintained by natural processes that degrade over time

[12] The animating concern underlying Hardin's (1968) canonical "Tragedy of the Commons" was concern over growing human populations.

(perhaps due to humans or climate change), the contributions of individual landowners become essential in landscape-level resource management.

When the resource distribution changes across a fixed set of entitlements, several tools emerge as second-order, back-end mechanisms to ensure the appropriate balance of resource uses over time.[13] Second-order tools include custom, law, and markets. These tools re-scale resource uses to resource distribution when the unit of ownership is not properly scaled to the efficient unit of management for the resource.

1. Government Interventions: Statute, Regulations, and Public Lands

Anglo-Saxon legal tradition permits each landowner to determine both the level of resource use and acceptable resource users for his land. Initial entitlements are not inviolable rights granted at a particular point in time, and then forever surrendered to operate henceforth at the whim of the owner. Instead, there forever remains a latent possibility that the rights granted may be increased, diminished, or revoked altogether by government in any subsequent period after the initial distribution. In this way, government operates as a dynamic system—responding to changes in population, land use, and natural resources as well as shifting social attitudes on each of these points.

If landowners' use of natural resources diminishes public goods beyond a socially acceptable level $\bar{Z}$, the citizenry will demand restoration of the public good.[14] Social reform limits landowner gains, although social movements and the passage of new laws generally lag resource depletion. Government enacts back-end controls weakening property rights or removing land from individual ownership and returning it to a system of communal governance.[15] Absent reform, social movements form. In the extreme case, revolution and war may re-set landholdings (Ellickson, 1993). In this manner, strong property rights coupled with inadequate landowner resource management may produce subsequent statutory, judicial, and administrative interventions to ensure adequate production (and protection) of public goods.

When the entirety of a landscape L is initially privatized, takings for the purpose of establishing vast swaths of public land may not be politically or fiscally feasible. Statutes and regulation allow uncompensated requirements that individual landowners privately provide a public good.

[13] We define appropriate level of resource use as below the level which would cause such resource diminishment that social response would be necessary, an admittedly circular response.

[14] A formula expressing the point of public good loss at which a society will demand change—whether through social movement culminating in legislation or literal revolution—could likely be expressed by a formula developed from historical data with regard to public good loss, such as the poor water and air quality that spurred the Environmental Movement in the United States.

[15] This dynamic underlies Congress' creation of public forest lands managed by the United States Forest Service, which was created to prevent the continuation of widespread clear-cutting followed by land abandonment (Bradshaw Schulz, 2013). This example highlights that subsequent efforts to correct for overly-generous initial entitlements or too-strong property rights can long-term create government expansion. If the strength of property rights versus the size of government is indeed a tradeoff—which I suspect, but do not empirically prove, is the case in a democracy—then the disappointed proponents of small-government, strong-property-rights would have to choose which of two objectives are stronger.

In the terms of the model, statutes and regulations aim at individual effort contributions consistent with overall welfare maximization:

$$e_i = \frac{r\beta}{kL} + \frac{r\beta \sum_{j \neq i} L_i}{kL} \qquad \forall i \tag{16}$$

Statutory solutions, if perfectly enforced, theoretically produce the efficient outcome in terms of the desired level of public goods. Importantly, statutes that require efficient provision of the public good result in a socially efficient use of the landscape without voiding individual rights to land.

There is, however, ample reason for pessimism for statutory and regulatory fixes. If there is a heterogeneous initial distribution of land L_i statutory solutions create winners and losers who are clearly identifiable ex ante. For example, landowners may be disproportionately disadvantaged based upon the features of their property. Public choice literature studying environmental legislation suggests that interest group pressure and capture may produce suboptimal provision of public goods (Ando, 1999). This is especially true because landowners subject to pending legislation tend to be a wealthy group upon whom a concentrated harm the generates dispersed benefits is about to be visited. Accordingly, they can put up quite a fight (Weingast et al., 1981).

Moreover, some camps argue against statutory restrictions on property uses without takings compensation. Such arguments have historically proved unsuccessful, but the threat of judicial challenges to regulation have caused agencies to negotiate with landowners about regulation.

2. *Private Ordering: Custom and Contract*

Landowners may also cooperate to maximize their individual profits, as with ranchers contributing to prey abatement or foresters enforcing norms surrounding fire protection. The potential for Coasian transfers incentivizes efficient bundling of resources by creating a profit-motive for private parties to contract or cooperate to bundle valuable or harmful resources.

Historically, timber landowners cooperated to reduce fire risk and lobby government efforts to achieve the same. Similarly, ranchers pooled resources to exterminate predator species. Prior to eradication efforts of wildfire and prey species, neither commercial timber production nor ranching was financial feasible. Virtually re-parceling the resources to a communal governance regime enabled landowners to achieve profitability. Subgroups of resource users may privately order through custom and contract to select and maintain levels of the public good within units that span individual parcels. Examples of custom and cooperation range widely in sophistication, ranging from informal neighborly agreements to complex certification regimes.

Contract and custom allows landowners to pool and manage land and resources collectively (Bradshaw and Lueck, 2015). Adjacent landowners with pre-existing social networks can define use rules dynamically, in response to on-the-ground natural conditions and responsively adjust

resource-use decisions in real time to changed circumstances at low cost (Ellickson, 1991).[16] Ongoing cooperation establishes a platform of relationships as already established for quick and friendly negotiation for unpredictable resource fluctuations or threats.

Suppose for instance that J individuals form a unit that internally coordinates on provision of the public good to increase the benefits for landholders within the unit. The unit members solve:

$$\max_{e_j \in J} \quad \sum_{j=1}^{J} \left[r\left(\beta \sum e_j - \bar{Z}\right) \frac{L_j}{L} - L_i k \frac{e_j^2}{2} \right] \tag{17}$$

and share the associated profit. Subgroups may spontaneously organize, organize at the behest of an interested third party, or organize around one good and use the existing structure and relationship to manage others. Subgroups can, and often do, involve a mix of public and private actors.

Subgroup coordination results in a level of overall provision that is greater than the uncoordinated outcome, but less than the optimal outcome. Unit members partially internalize the externality associated with provision of the landscape-level good by considering the effect of their provision on other members, but they do not consider the effect on users outside the unit. The total size and number of units will determine how far short of optimal the unitized solution falls.

The costs of unitizing or contracting rise with the number of included parties, so that units are likely to remain small relative to the total number of users (Libecap and Wiggins, 1984; Wiggins and Libecap, 1985). So long as multiple distinct units exist, there is under-provision of the public good, even if all users are members of *some* unit, because each unit only partially internalizes the externality. The transaction costs associating with Coasian bargains prevent optimal management of the landscape good, even when contracting does occur. Interestingly, however, it appears that groups that have organized around a particular historical goal (i.e., wildfire management) use existing network relationships and organizational structures to manage resource challenges unanticipated at the point of original organization.

Conservation easements are yet another private mechanism for virtual parceling which mimic the statutory solution by imposing constraints on landowner behavior. Landowners who sign conservation easements enter into a contract in which they promise not to engage in certain practices, with the goal of preserving open space, habitat, and critical wildlife corridors (Parker, 2004; Parker and Thurman, 2017). Land trusts engage in similar contracts but also buy land outright to set it aside for conservation.

With respect to property, the second-order controls seem substitutable (Bradshaw Schulz, 2013).[17] Markets allow strangers to directly and simply split and aggregate land in response to

[16] Ellickson (1991) showed that Shasta County cattle ranchers found law a clunky and needlessly expensive system compared to neighborly good will. *See also* McKean (2000) describing collaborative governance for Japanese forests as allowing dynamic interactions between social needs and resource conditions.

[17] Bradshaw Schulz (2013) notes that the Forest Service announced in 1941 two alternatives for managing forests: either public ownership of timberland or national regulation of forestry practices.

resource distribution. Law forces individual land uses to align with broader social objectives, such as preservation of public good.

Landowners fearing regulation may limit the loss of public goods to a socially-acceptable level to avoid legal intervention.[18] If the threat of involuntary external action is high, the likelihood of an internal voluntary response increases. Voluntary action to constrain resource use may presumptively or responsively lessen the threat of reform, and also preserve the long-term control over the entitlement.[19]

In a regime in which landowners have strong rights to exclude, extinguishable only through takings, we theorize that one can expect to see a mix of offsetting statutory land controls, public land, or landowners voluntarily submitting to weakened rights. Given the implicit right of government to limit resource uses on land in subsequent periods, strong property rights in one period that result in diminishment of public goods will almost certainly produce customary rules emerging among resource users or intervention by government in subsequent periods.

IV. IMPLICATIONS

1. The Importance of Entitlements

Initial entitlements are a frequently mentioned, seldom discussed aspect of property. Coase's work is often misunderstood as arguing that initial entitlements did not matter because subsequent transactions would fix any mistaken allocations. In fact, his work suggests that initial entitlements matter a great deal because transaction costs exist in the real world (Coase, 1960; Kelman, 1979). If the initial allocation of land does not accord with the resources on it, I argue, back-end correction through law, markets, or custom will emerge. Moreover, these tools provide those excluded from initial entitlements to exercise some degree of control over land and resource use.

One consequence of fixed entitlements is that the very incentives to exclude on the front end embed inevitable disputes in future periods.[20] With fixed entitlements, a finite amount of property is allocated among individuals. Each individual is incentivized to collude with other, similar individuals to limit the class of people eligible to own property to a class of people large enough to exclude but small enough to maximize the property of each member of the group.

[18] Bradshaw Schulz (2013) describes the forestry industry developing the American Tree Farm certification, an industry-developed corporate social responsibility mechanism, to stave off threats to regulate forestry practices, or make all domestic timberlands public as a conservation tool to offset industrial practices of clear-cutting timberland). Bradshaw Schulz (2015) suggests that some corporate social responsibility programs are designed to divert public attention, rather than achieve genuine public goods improvements.

[19] In response to threatened regulation of timber harvest practices, the forestry industry voluntarily created a certification program of private regulation, the American Tree Farm System (Bradshaw Schulz, 2013). More generally, landowners voluntarily restrict their own property rights through sustainability certifications governing land management, conservation easements, production agreements with buyers, insurance contracts. Incentivizes include price premiums, tax benefits, and reducing public scrutiny and regulation.

[20] The necessarily exclusionary nature of initial entitlements embeds future conflict, which necessitates second-order controls to mediate disputes in future periods. Of course, conflict exists in an open-access regime as well; indeed, a foundational reason for transition from open access to private ownership among both humans and other animals is likely to promote survival of the species by reducing conflict over the same resources.

Such exclusion functions to allow in-group members to increase their share of the property at the expense of non-group members.

There is a temporal aspect to the exclusion as well. Initial entitlements fix property rights in a particular point in time, excluding past and future users who might otherwise access a resource. Property law mitigates the exclusionary effects by recognizing the rights of previous users through customary law. Future users are granted access to under-utilized resources through adverse possession and the rules surrounding lost property (Strahilevitz, 2010). In some regimes, property rights are re-set every few years.[21] Markets also function to permit future access by excluded users, but necessarily require money, which is generated partially through property.

What the entitlements are do not matter. Who the entitlements are given to, matters a great deal. Law provides a nonviolent mechanism to maintain balance between property holders and those excluded from initial entitlements.

2. The Subsidizing Effects of Public Lands

A key, under-theorized consideration is the percentage of land allocated to private landholders relative to the portion retained for communal purposes.[22] Privatization is seldom an all-or-nothing proposition. First-order decisions on the amount of land to retain as public likely have sizable effects on which second-order tools for resource-scaling are necessary. Communal governance preserves flexibility lost through fixed entitlements. If more land is communal, then one would expect fewer second-order adjustments. The offsetting considerations, however, are the cost of administering communal lands and statutory controls necessary to avoid capture.

To see this, denote the land area owed by the government as $L_g = L - \sum L_i$. There will be some amount of public land retained during privatization in the initial period if $NL_i^* < L$, so that not all land is claimed. If the government optimally manages the landscape resource on public land, they will choose contributions to the landscape resource they take into account the effect of their provision on all users of the landscape.:

$$\max_{e_g} \sum_{i=1}^{N} \left\{ r\left(\beta \sum e_i + e_g - \bar{Z}\right) \frac{L_i}{L} \right\} - L_g k \frac{e_g^2}{2} \tag{18}$$

The resulting provision of the landscape good falls in between the pure uncoordinated case and the optimal case:

$$Z^g = \beta \frac{r\beta}{kL} [N + \sum L_i] - \bar{Z} \tag{19}$$

[21] Ellickson (1993) provides the example of Hutterite communities that bifurcate when the group population nears 120 members and Russian *mirs* that reallocated property rights every twenty years.

[22] There appears to be some natural scale of management for an individual, familial group, or communal structure. Expressed preference can provide a guidepost. At some point, the marginal returns of property ownership diminish. While most people would like a second home—say a cabin in the woods, or a condo in the city—who would want fifteen? The same is true with regard to acreage. While a few wealthy individuals can manage vast plots of lands through agents, structures—such as trusts, or timber management operations—typically emerge to spread many owners over many plots of land. At some point, the costs of ownership simply exceed the benefits.

Hence, public ownership of land mitigates the existence of landscape resources with public good characteristics, which may help explain why we see a mix of public and private land. In general, the availability of public land as a management scheme for landscape resources will depend on what share of the landscape was privatized in the initial allocation of land. If the landscape is fully privatized initially, public land can only come through direct takings. In this setting, statutory or customary solutions may be more appealing.

In some settings like the Western United States, much of the land is owned by state and federal government, which allows landscape-level resource management on public lands. Government land management essentially subsidizes the activities of private landowners by mitigating their coordination failure in the provision of public goods associated with the landscape-level resource. For instance, many endangered species require a minimum amount of suitable habitat in order to survive. By its lands to provide habitat for creatures ranging from bighorn sheep to bald eagles, the government increases the amount of habitat in the landscape above the threshold level $\bar{Z}$ needed for species survival, mitigating the need for private efforts to protect habitat.

This realization sheds new light on the conflicts associated with management of public rangelands and timberlands, which in part serve to subsidize private landowners by absorbing provision of habitat for everything from wild horses to wolves. Additionally, the coordination problems among private landowners becomes less severe as the share of the landscape that has been privatized falls. At the same time, the benefits of privatizing land for ranching are strictly increasing in land area, raising important questions about the optimal share of public versus private land in a landscape that we recognize, but do not attempt to resolve, here.

3. Strength of Property Rights

Our model suggests that flexible property rights coupled with more public land minimizes the need for subsequent statutory controls and enforcement. Medium property rights—neither so strong that any regulation must be compensated, nor so weak that takings are ubiquitous—appears to facilitate a dynamic relationship between landowners and government, private and legal interventions.

Surprisingly, slightly weaker property rights in rural landscapes require smaller government. Strong property rights necessitate extensive back-end statutory intervention to mediate the relationships between property owners and others around a central, presently unknown fulcrum of balance between individual consumption and a variety of public goods.

Private order efficiently facilitates virtual reparceling of resources to increase profitability, as evidenced through landowners controlling wildfire and exterminating predators at a landscape-level to extract timber and grazing value from their land.

Absent a profit incentive, landowners lack the incentive to supply public goods without a clearly-expressed market value, such as clean air, clean water, and wildlife. We leave to others the debate about the appropriateness of creating markets for these goods to prompt private responses. At present, the threat of government intervention prompts private actors to privately organize to provide public goods, creating private approaches to public problems. For example, the forest

industry responding to the threat of making timberland public by creating a national set of agreed-upon forestry practices through the American Tree Farm certification system.

4. Some Caveats

We make several simplifying assumptions that could be relaxed in future work to explore additional dimensions of the relationship between parcelization and coordination over landscapes. First, our model assumes that the private use (ranching) does not directly compete with the landscape-level use. We make this assumption to show the tensions for management arising purely from issues of appropriate scale even when different uses are not necessarily at odds with one another. In fact, the private use of parcels is often at odds with the provision of public goods on the landscape. Preservation of endangered species such as wolves is directly at odds with ranchers' objectives, for example.

The second simplification of our model concerns preferences for the landscape public good. We assume that individuals all value the public good in the same way, at least on a per acre basis. In reality it may be the case that different individuals have different preferences over competing uses for the landscape. The grey wolf again provides a salient example—conservation groups value wolves and their habitat, which serve as a nuisance to ranchers.

Although our assumption of homogenous preferences is standard in the analysis of public goods, we note that considering differing preferences for the use of a landscape raises broader questions about political versus nonpolitical mechanisms for social choice. Management decisions for publicly owned landscapes such as National Forests are made through a political process—at least indirectly via appointments that are made by elected representatives. In this setting, heterogeneous preferences are aggregated into a single resource outcome via voting, representation, lobbying, and public comment. In contrast, subdivided ownership of landscapes gives individual landowners power to either develop or block the development of varying resources that run with the land, such as shale oil. On a privatized landscape, market transactions and informal institutions govern the use of the landscape, which may result in outcomes which differ substantially from parcel to parcel.

A broad comparison of market versus political mechanisms for social choice is beyond the scope of this paper, but we note that the coordination problems and holdout can manifest in either context. Owners of individual parcels can hold out against the development of large-scale resources and extract rents from develops from projects that have specific spatial requirements. At the same time, voters, elected officials, and local governments and agencies all have some degree of hold out power in their ability to block projects through the political process. Future work can and should address how coordination problems manifest themselves in each system of translating individual preferences into aggregate natural resource outcomes.

V. CONCLUSION

Fixed entitlements to real property necessitate subsequent interventions to mediate individual consumption against public goods. It is not the mere existence of property that necessitates these

interventions, but rather the fixed nature of entitlements. Law, markets and custom can accommodate fluctuations in natural, social, and economic conditions while preserving the system of private property.

Custom and contract allow landowners within a region to cooperatively govern resources on private lands. Markets facilitate transactions that form a private solution for strangers to aggregate or split land in response to efficient scales of management. Legal interventions—including constitutions, statutes, regulations and judicial rulings—balance resource uses with the concerns of the broader populace. Collectively, these tools maintain perpetual balance between resources and resource users over a landscape. The process occurs through the allocation of property rights and subsequent limitations or expansion of those rights over time.

Cooperative regimes permit more flexible approaches to resource allocation and management. In keeping with the dynamic and ever-shifting nature of real property, cooperative management regimes emerge to balance human claims against natural shifts over time. Law wedded to fixed, inviolable initial entitlements is artificial in the scope of flexible natural systems, and gives rise to the need for even more back-end interventions to mediate ever-changing relationships.

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