Pricing the Opportunity Cost of Conservation

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Abstract

Conservation leasing on public lands has been proposed as a way to allocate land more efficiently by allowing conservation interests to bid against traditional extractive users, but this approach entails opportunity costs from forgone grazing, timber, and oil and gas revenues. We derive the minimum auction bids at which conservation leases maximize the net present value of public revenue, showing that the key tradeoff is between the cost of delaying extraction and the salvage value that conservation preserves. For oil and gas leases, contingent royalty contracts and subsurface uncertainty complicate this comparison, but our empirical analysis of Wyoming state lease auctions shows that energy firms' upfront bonus bids reveal expected production and royalty revenues. This relationship is highly skewed, with production and royalties concentrated in the top decile of bids. Across the bottom half of the bid distribution, fewer than 1 percent of leases produce, upfront bids and rent account for more than 98 percent of expected state revenue from the average lease, and a conservation bid of $10 per acre would increase expected public revenue. Although these low-bid parcels are unlikely to be drilled, firms also bid less for them, so the damage per well required to justify a revenue-neutral conservation bid is comparable to observed conservation easement costs. We show that weakest-link migration corridors and ecological thresholds can generate large losses from a single well, and that both types of habitat in Wyoming are concentrated in the lowest deciles of the oil and gas bid distribution.

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1 Introduction

Most discussions regarding conservation on public lands presume there is a tradeoff between more environmental protection and forgone public revenues from resource development, but this need not be the case. To the extent that conservation groups are willing to pay enough for conservation on specific parcels of public land, conservation leasing provides an opportunity for public agencies to enhance public revenues. However, a conservation lease may preclude leases for alternative uses such as grazing, timber, or oil and gas, and public agencies must also account for these opportunity costs of conservation leasing. Determining when conservation leasing can increase both environmental protection and public revenue requires comparing the revenue a conservation lease generates with its opportunity cost.

Conservation leasing on public land is not just a theoretical approach. At present, there are examples of conservation leasing on traditional grazing lands and to a lesser extent on timber lands, whereby conservation-minded groups have purchased grazing permits or won timber auctions (Leonard et al., 2021). Attempts to apply the approach to oil and gas leases have been prevented by federal and state agencies, however. Recent theoretical work shows that this agency resistance has an economic rationale (Abbott et al., 2025). When conservation buyers are allowed to acquire public resource rights without paying for the ongoing fees and royalties that extractive users would have paid, voluntary buyouts can reduce aggregate social welfare, and the government bears the resulting loss through forgone public revenue. Conversely, pricing conservation leases to hold maintain government revenue eliminates this implicit subsidy and ensures that voluntary conservation trades are welfare-improving.

In this paper, we combine theory and empirics to quantify the opportunity costs of conservation leasing on public lands, test whether private bidding behavior reveals those costs to public agencies, and characterize when conservation groups would be willing to outbid extractive users. We first derive a general theoretical framework that captures the key features of leasing on public lands, with a focus on state trust lands. State trust lands are leased to private interests according to the constitutionally mandated principle of sustainable revenue maximization. Leases are awarded at auction, and this revenue primarily funds schools and other public institutions. Using our framework, we derive a general auction pricing rule for conservation leasing that would maximize revenue for the public agency, and then apply that rule to specific natural resources.

Whether conservation is preferable to other leases hinges on the comparison between the opportunity cost of delaying extraction and the salvage value that conservation leasing preserves (i.e., the trees remain in the forest and the oil remains in the ground). For grazing and timber, where resource stocks are observable on the surface and leases rely primarily on upfront valuation or fixed per-unit fees, that comparison is reasonably straightforward. For oil and gas leases, however, agencies use contingent contracts that combine an upfront bonus bid with a royalty share of future production, and substantial subsurface uncertainty makes comparing a conservation bid with an oil and gas bid much harder. Because a conservation lessee will never drill,

matching an energy firm's upfront bonus bid does not replace the expected royalty stream that an oil and gas lease might generate. This presents an acute challenge for public land agencies, as oil and gas royalties constitute the majority of trust land revenue in many Western states (Culp et al., 2015). Hence, state trust land managers are reluctant to approve alternative uses of land (e.g., conservation) that could jeopardize those royalty revenues from oil and gas leases.

Not all potential oil and gas leases are equally valuable, however. Public agencies routinely offer thousands of tracts spanning proven energy basins and speculative frontier acreage, and in our empirical analysis of Wyoming state trust lands, winning bonus bids from private oil and gas firms vary by four orders of magnitude across leases. In standard auction models, this variation reflects firms' private geological and economic information about the underlying value of each tract (Hendricks and Porter, 1988; Bhattacharya et al., 2022; Covert and Sweeney, 2023). By matching upfront auction bids from 2009 to 2019 with subsequent production and royalty payments through 2025, we test whether private bidding behavior reveals expected royalty revenues to the public agency at the time of auction.

We find that, in expectation, every $1 per acre of upfront auction bid corresponds to roughly $122 in future royalty revenue (in net present value), and every $100 per acre of auction bid increases the probability of production by roughly 0.6 percentage points (relative to a mean of 3 percent). For the average parcel size of 378 acres, this implies roughly $1 of royalty revenue for every $3 of auction revenue. However, the relationship between bids and expected royalties is highly nonlinear, with a sharp increase in the probability of production and expected revenue for the top 5 percent of bids (in excess of $1,250 per acre). Across the bottom half of the bid distribution, fewer than 1 percent of leases ever produce oil or gas, so most public leases function as low-probability exploratory options that expire undrilled at the end of their five-year primary term. While royalties from the small share of producing tracts make up the largest share of aggregate state revenue at any given point in time, upfront auction bids and annual rental fees make up roughly 90 percent or more of expected revenue for a typical lease. Consequently, modest conservation bids would maximize expected state revenue on leases with small oil and gas bids without materially reducing energy production. In the bottom three deciles of the bid distribution, any positive bid from a conservation group would lead to higher expected revenue, and across the bottom half of deciles a bid of less than $10 per acre would suffice.

This raises the question of why conservation groups would bid on the leases they can afford to win, given that those leases are cheap precisely because they are unlikely to produce oil, gas, or royalties. One conservation lease costs the organization only a fraction of the state's revenue from an oil and gas lease, because the state can still lease the parcel for oil and gas later, and it delays a well by one term rather than preventing it for good. This means that the cost per well prevented equals the state's revenue from one oil and gas lease divided by the probability of a well. Firms bid less for parcels they are unlikely to drill, so this cost varies far less than either bids or the probability of a well. From the bottom two bid deciles to the top decile, the probability of production rises about 40-fold and the state's revenue per acre from a lease rises about 390-

fold, but the cost per well prevented rises only about 10-fold, from $1,586 to $16,048 per acre. A conservation lease on a low-bid parcel prevents a well less often, but each well it prevents costs less. Rent, which the state collects whether or not a lease produces, accounts for about 60 percent of this cost in the bottom three deciles.

We then examine whether the permanent loss from a well can be large on parcels where wells are rare. We analyze two features of conservation value that can make it large, and we measure both in Wyoming. The first is the weakest-link structure of migration corridors (Hirshleifer, 1983). Because a migration fails if any bottleneck on its route is blocked, a well on a single bottleneck parcel jeopardizes the value of the whole corridor, however small the parcel. In our setting, we show that an organization would be willing to pay the state's break-even bid on every bottleneck lease of the Sublette pronghorn corridor if it values the corridor at about $2 million. The second is an ecological threshold. If a habitat fails once disturbance passes a level that is not known in advance, a single well near that level puts at risk the entire population the habitat supports. Sage-grouse core areas, which are common in Wyoming, have this feature.

Empirically, we show that both kinds of habitat are concentrated where the state's opportunity cost is lowest. From the bottom two bid deciles to the top decile, the share of leases in a sage-grouse core area falls from 38 percent to 5 percent and the share that touch a migration corridor falls from 14 percent to zero, and none of the 352 leases that touch a corridor produced. Moreover, the cost per well prevented in the bottom three deciles is within the range that perpetual conservation easements have cost in Sublette County. We also discuss other reasons the loss from a well may be large, including the absence of close substitutes for undisturbed land (Krutilla, 1967; Hanemann, 1991), its rising relative value over time (Sterner and Persson, 2008), and quasi-option value (Arrow and Fisher, 1974; Henry, 1974). Taken together, our theoretical and empirical results show that conservation leasing can simultaneously protect high-value habitat and increase public revenue, and that public agencies can potentially identify these parcels ex ante.

We contribute to three literatures. First, we provide new insights about how governments can raise revenue from natural resources (Garnaut and Ross, 1975; James, 2015) and on the management of state trust lands in particular (Souder and Fairfax, 1996; Culp et al., 2015). Previous work in this vein treats extraction as the source of trust revenue. We show that for most state oil and gas leases the bulk of the revenue at stake consists of the upfront auction bid and rental payments rather than royalties, and we derive the minimum bid at which a conservation lease raises more revenue than the extractive lease it would replace. Second, we contribute to a growing discussion of whether conservation buyers should be able to acquire use rights on public land on the same terms as extractive users (Leonard et al., 2021; Pidot and Peterson, 2021; Regan et al., 2023; Abbott et al., 2025). Whereas Abbott et al. (2025) show in a static cap-and-fee framework that charging conservationists for forgone government fees is necessary to prevent fiscal losses and welfare-reducing buyouts, they note that uncertainty over future production and royalties makes this equivalence difficult to implement for oil and gas. We solve this dynamic pricing problem and quantify what a revenue-neutral conservation lease would have to pay on state oil and gas land.

Third, we build on empirical work showing that bids in oil and gas lease auctions reveal private information about a tract and predict drilling and production (Hendricks and Porter, 1988; Porter, 1995; Bhattacharya et al., 2022; Covert and Sweeney, 2023; Herrnstadt et al., 2024). We extend this literature by showing how private energy bids can be used to price competing non-extractive land uses and by documenting strong negative spatial sorting between firms' oil and gas valuations and sensitive wildlife habitats. Moreover, whereas studies of conservation targeting show that the value of protecting a parcel depends on the probability of development and typically must model that probability (Costello and Polasky, 2004; Newburn et al., 2005; Wilson et al., 2006), oil and gas bids in our setting reveal that probability empirically, with minimal assumptions about future land use scenarios.

The paper proceeds as follows. Section 2 develops the theoretical framework and derives the break-even conservation bid for grazing, timber, and oil and gas leases. Section 3 estimates how oil and gas bids in Wyoming predict royalties and production, and it computes the break-even conservation bid by bid decile. Section 4 explores why a conservation organization would bid on parcels that are unlikely to be drilled by deriving the loss from a well that justifies a conservation lease and examining the factors that could make this loss large even when the probability of drilling is small. Section 5 concludes.

2 The "price" of conservation leases

2.1 Opportunity costs of conservation

To understand the opportunity costs of conservation leasing, we develop a general framework that captures the key features of public land leasing. We consider a typical public lands context where, for a given parcel of land, a land agency offers a series of leases indexed by k, each for a finite number of years T. The parcel has a natural resource stock $x \in \{x_E, x_C\}$ that can either be degraded via extraction x_E or pristine x_C, and provides value for both extractive use and conservation use.[1] In the present period lease ($k = 0$), the stock is assumed to be pristine (x_C), and once extraction occurs, the stock remains in its degraded state (x_E) in perpetuity.[2] We assume that the agency's objective is to maximize the net present value of public revenue, which is consistent with constitutionally mandated rules for state trust lands, where leases are generally awarded at auction.[3] In the context of these lease auctions, a key consideration for land agencies is how to compare conservation lease bids versus extraction lease bids.

[1] In the case of timber and grazing, the same natural resource stock may be directly valued by both uses, albeit in different ways. In the case of mining or oil and gas, the conservationist value derives from the avoided surface disruption that is necessary to reach the stock.

[2] We abstract from many specific features of public lands problems in order to focus on the key economic intuition reflecting the opportunity costs of conservation. For example, oil and gas leases have a finite time to expiration unless extraction occurs, in which case they persist as long as extraction continues. We incorporate and discuss several resource-specific details below.

[3] Federal land agencies face a more complicated set of objectives, but revenue still matters because federal leases must return fair market value.

2.1.1 Private value of public lands

For a land agency to actually collect revenue, private interests ("firms") must find it worthwhile to pay to use a parcel of public land. We distinguish between extractive firms and conservation firms, but for now we do not distinguish between different types of extraction (e.g., timber vs oil vs grazing). For extractive firms, the following model is intended to abstractly represent key features of specific natural resources in a single framework.[4] The core idea is that forward-looking firms are able to account for the discounted stream of value provided by extraction over some lease horizon T, and thus determine the value of the parcel for that extractive use.

Formally, let:

$$v_E = \pi_E(q_E, x, A_E) - D_E \tag{1}$$

represent the *per-lease* private payout from extractive use. For the firm, private extractive profit π_E is increasing in the quantity of extraction q_E, the stock of the resource x, and intrinsic, parcel-specific characteristics related to extraction A_E. The firm's payout is then reduced by the revenue paid to the land agency D_E. A parcel that is not profitable to private firms cannot generate revenue for the land agency. Similarly, demanding too large a payment D_E could make the parcel unprofitable for the firm to develop, whereas highly productive parcels can generate substantial revenue for the land agency. We therefore abstract from the specifics of how the extractive firm manages the parcel. The firm's desire to maximize private profit is aligned with the agency's desire to maximize public revenue, because greater private profits imply greater potential for public revenue collection.[5]

For conservation firms, we consider a framework where conservation firms receive donations in exchange for providing ecosystem services that are valued by donors (Molina et al., 2024):

$$v_C = u_C(x, A_C) - D_C \tag{2}$$

where $u_C(x, A_C)$ can be thought of as the aggregated willingness-to-pay by donors for a conservation lease of length T, which is increasing in the stock x and the intrinsic, parcel-specific characteristics related to conservation A_C. Similar to extraction, the greater the private value, the more public revenue can be collected D_C.[6] Again, we abstract from the internal decisions of the conservation firm because its private objective of providing ecosystem services to its donor base is aligned with the agency's desire to collect public revenue.

Finally, under a competitive auction process, the maximum revenue that can be collected from extraction is $D_E = \pi_E(q_E, x, A_E)$ and the maximum revenue from conservation is $D_C = u_C(x, A_C)$. In other words, given competitive bidding, economic rents on public land (whether in

[4] For resource-specific models, see e.g., the classic dynamic optimization models in Conrad and Clark (1987), and a myriad of more detailed treatments can be found in the academic literature.

[5] Federal grazing under the Taylor Grazing Act is the clearest exception, because grazing permits are tied to ownership of qualifying base property rather than allocated to the highest bidder.

[6] From an efficiency perspective, aggregate donor willingness to pay will be less than social willingness to pay because of (a) the free-rider problem and (b) the finite length of the lease.

terms of extractive value or conservation value) are captured as public revenue.

2.1.2 Land agency revenue—single lease

Given the potential different uses for a parcel of public land, in principle the land agency should allocate the parcel to the use that would generate the greatest NPV of revenue collected. Public land agencies collect revenue through three primary instruments, consisting of lump-sum upfront auction bids B_i, a flow of annual rental fees with discounted present value F_i, and volume-based royalties R_i. For some lease types, royalties are only collected if production occurs, which we will explicitly capture via the probability ρ.[7] In practice, rental fees tend to be identical across uses and royalties are only collected if production occurs, so the public revenue collected by the land agency can be expressed as:

$$\begin{aligned} D_E &= B_E + F + \rho R_E \\ D_C &= B_C + F \end{aligned} \tag{3}$$

Assuming that the rental fees and royalty rates are announced in advance by the land agency, this combined with equations 1 and 2 pins down the respective bids B_E and B_C, which are both increasing in the stock x.

If a parcel could be leased only once, the land agency would simply choose the use that maximizes revenue, $\max\{D_E(x), D_C(x)\}$.

Proposition 1. *For a single period, one-shot lease, a conservation lease bid $B_C(x)$ will maximize public revenue if it exceeds the minimum required bid $\hat{B}_{1P}$, defined by:*

$$\hat{B}_{1P} = B_E(x) + \rho R_E(x) \tag{4}$$

Proof. Simply compare revenues in equation 3. While choosing extraction also degrades the stock, for a single, one-shot lease, the future state of the stock is irrelevant. □

Intuitively, the conservation lease bid must cover both the alternative upfront extraction bid B_E and any expected royalties generated by the extractive use. In the absence of royalties, this condition reduces to a direct comparison of upfront bids.

2.1.3 Land agency revenue—continuous leasing

In practice, many parcels are repeatedly leased, and the provision of sustainable revenue for future generations is an explicit requirement for many public land managers. This creates an important dynamic link between leased uses today and potential revenue from leases in the future via the stock x. Before addressing the dynamics, we first make a series of assumptions regarding the one-shot flow of revenues from extraction and conservation.

[7] For most resources, ρ is simply equal to 1, but for oil and gas in particular, many leases go undeveloped and do not produce royalties, a feature that we explore in depth below.

Assumption 1. $D_E(0) = D_C(0) = 0$, $D'_E(x) > 0$, $D'_C(x) > 0$, $D'_E(0) \geq D'_C(0)$, $D''_C < D''_E < 0$

The first two conditions say that a fully depleted stock generates no revenue from either use, and that revenue from each use rises with the stock. The last two say that extraction revenue rises at least as fast as conservation revenue from a depleted stock, and that conservation revenue levels off faster as the stock grows. Together they ensure that the two revenue curves never cross, so that the flow of revenue from extraction is greater than the flow of revenue from conservation for every positive value of the stock.[8] These assumptions imply the following:

Lemma 1. *Under Assumption 1, $D_E(x) > D_C(x)$ for every $x > 0$. In particular, given a pristine stock x_C, the one-shot, single lease revenue collected by the government from extraction exceeds the revenue that could be obtained from conservation, $D_E(x_C) > D_C(x_C)$.*

Proof. Let $g(x) = D_E(x) - D_C(x)$. By Assumption 1, $g(0) = 0$, $g'(0) \geq 0$ and $g'' = D''_E - D''_C > 0$. Then g' is strictly increasing, so $g'(x) > 0$ for every $x > 0$, and $g(x) = \int_0^x g'(s)\, ds > 0$. □

If this result did not hold, so that single-lease revenue from conservation exceeded single-lease revenue from extraction, the agency would simply lease the parcel for conservation in perpetuity. Lemma 1 focuses attention on the more interesting case, where e.g., a timber lease would bring in $25,000 in immediate revenue at auction, but a conservationist bidding on a conservation lease might only bid $10,000. How does the fact that the conservation lease leaves the trees standing to be leased again affect the comparison of those bids?

To build intuition, consider a two-period lease problem with a pristine starting stock and certain production ($\rho = 1$), which is the tree in Figure 1 with every $1-\rho$ branch removed. Let $\delta = e^{-rT}$ be the discount factor applied to the second-period revenue, for a given discount rate r. The land agency would then compare the revenue from initially choosing an extraction lease V_E with the revenue from initially choosing a conservation lease V_C:

$$\begin{aligned} V_E &= D_E(x_C) + \delta \max\{D_E(x_E), D_C(x_E)\} \\ V_C &= D_C(x_C) + \delta \max\{D_E(x_C), D_C(x_C)\} \end{aligned} \tag{5}$$

A tradeoff emerges immediately. Choosing the conservation lease delays the collection of any revenue from extraction, but it also preserves the salvage value of the underlying stock. In other words, there is an opportunity cost to delaying the extraction of the resource by choosing a conservation lease, but the resource is still there in T years to be leased again (i.e., the trees are still in the forest and the oil is still in the ground). We formalize this tradeoff in our next proposition. Before doing so, we note that Lemma 1 implies that extraction will always occur in the final period when there is no salvage value because the one-shot extraction bid will always exceed the one-shot conservation bid.

[8] Intuitively, these conditions imply that extracting timber from a pristine forest is more profitable than from a degraded forest, pristine forests provide more ecosystem services than degraded forests, and that ecosystem services do not suddenly become more valuable than timber when the forest becomes degraded.

Proposition 2. *Under Assumption 1, for a two-period lease with $\rho = 1$, a conservation lease bid $B_C(x_C)$ will maximize public revenue if it exceeds the minimum required bid $\hat{B}_{2P}$, defined by:*

$$\hat{B}_{2P} = (1-\delta)(B_E(x_C) + R_E(x_C)) + \delta(B_E(x_E) + R_E(x_E)) \tag{6}$$

Proof. Under Assumption 1 and per Lemma 1, the lease revenues can be written as:

$$\begin{aligned} V_E &= D_E(x_C) + \delta D_E(x_E) \\ V_C &= D_C(x_C) + \delta D_E(x_C) \end{aligned} \tag{7}$$

Then $V_C > V_E$ if $B_C(x_C) + F + \delta(B_E(x_C) + F + R_E(x_C)) > (B_E(x_C) + F + R_E(x_C)) + \delta(B_E(x_E) + F + R_E(x_E))$, such that a conservation lease is the revenue-maximizing use if the conservation bid exceeds $\hat{B}_{2P}$ as defined in the proposition above. □

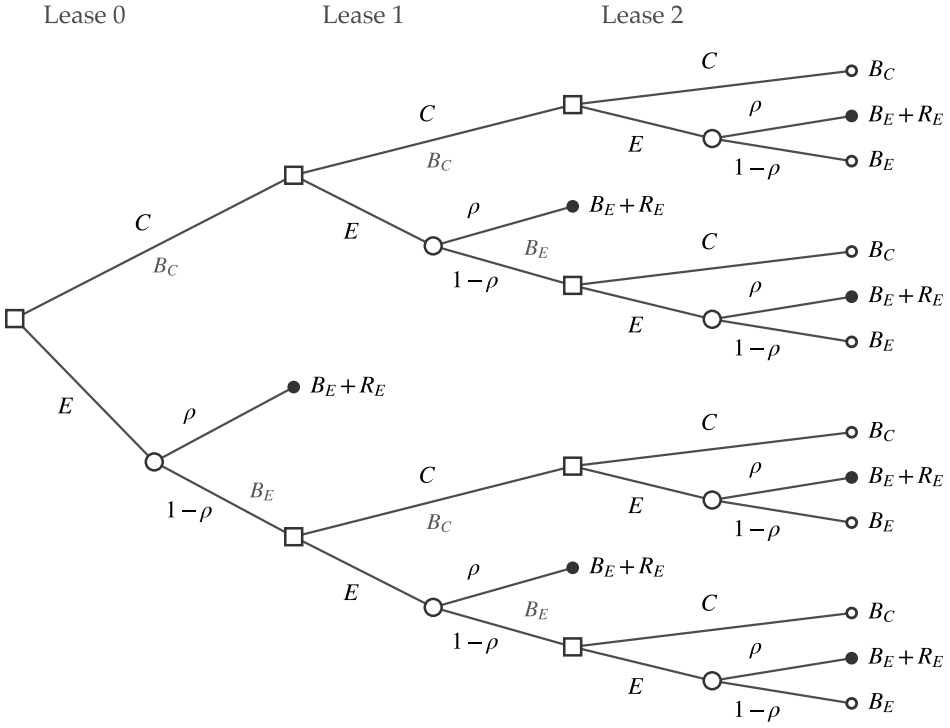
Inspection of the required conservation bid in Proposition 2 yields several useful insights. First, by Assumption 1, the required conservation bid is always less than the one-period extraction value $(B_E(x_C)+R_E(x_C))$, and in the absence of royalties, the minimum required conservation bid $\hat{B}_{2P}$ is always less than the extraction auction bid $B_E(x_C)$. Second, when extraction fully depletes the resource so that a degraded parcel has no future revenue value ($B_E(x_E) + R_E(x_E) = 0$), conservation bids are effectively credited with the discounted salvage value of the pristine stock ($\delta(B_E(x_C) + R_E(x_C))$). Third, the required conservation bid $\hat{B}_{2P}$ is increasing in the length of the lease (approaching the condition in Proposition 1 in the limit), because $\frac{d\delta}{dT} < 0$. Thus, while a longer, more "durable" conservation lease would be more appealing to conservation firms, a longer conservation lease also implies greater opportunity costs and thus greater minimum conservation bids.

The proof above also reveals a recursive decision structure. By choosing conservation initially, the land agency faces the same choice one lease period later. In Figure 1, if the land agency chooses a conservation lease or if an extraction lease does not produce, the land remains in pristine condition x_C (represented by a square in the figure). Looking forward, every square is the root of a copy of the whole tree, discounted by one more lease period. Extending the tree without limit gives the infinite-horizon problem, in which the problem at each of these squares is identical to the problem at lease 0.

Consider an infinite series of leases indexed by $k = 0, 1, 2, ...$ with certain production ($\rho = 1$). Then leveraging the recursive structure yields the following useful lemma regarding revenues:

Lemma 2. *Under Assumption 1, for an infinite series of leases, if the first lease for extraction occurs in*

Figure 1. The Leasing Problem as a Decision Tree



Notes: Squares are the agency's choice of an extraction (E) or conservation (C) lease, and circles are the chance that an extraction lease produces. A lease that produces pays $B_E + R_E$ and degrades the stock permanently (filled dots). A lease that does not produce pays B_E, and a conservation lease pays B_C, and in both cases the parcel returns to the agency in pristine condition (x_C). Revenue in lease k is discounted by δ^k. When $\rho = 1$, only the production branches remain, as in the two-period problem of Proposition 2 applied to oil and gas. Extending the tree without limit, and letting an unproductive parcel return to auction with probability λ, gives Proposition 4. The figure sets $\lambda = 1$.

lease k, the net present value of revenue can be expressed as:

$$\begin{aligned} V_k &= \sum_{t=0}^{k-1} \delta^t D_C(x_C) + \delta^k (D_E(x_C) + \sum_{t=1}^{\infty} \delta^t D_E(x_E)) \\ &= \frac{1-\delta^k}{1-\delta} D_C(x_C) + \delta^k (D_E(x_C) + \frac{\delta}{1-\delta} D_E(x_E)) \end{aligned} \tag{8}$$

Proof. See Appendix A. □

The proof leverages the fact that extraction is an absorbing state, in that once extraction is the winning lease and the stock variable decreases from x_C to x_E, future lease choices are locked into extraction. In this infinite lease setting, what conservation bid B_C is needed for the government to prefer a conservation lease over an extraction lease?

Proposition 3. *Under Assumption 1, for an infinite series of leases with $\rho = 1$, a conservation lease bid $B_C(x_C)$ will maximize public revenue if it exceeds the minimum required bid $\hat{B}_\infty$, defined by:*

$$\hat{B}_\infty = (1-\delta)(B_E(x_C) + R_E(x_C)) + \delta(B_E(x_E) + R_E(x_E)) \tag{9}$$

Proof. See Appendix A. □

This is the same condition as in the two-period lease case ($\hat{B}_\infty = \hat{B}_{2P}$), because the core economic tradeoff is captured by the "extract now" versus "conserve now and extract later" decision. If the agency makes the "conserve now" decision, they face the same choice again when the lease ends, which is why the infinite-horizon version of the problem reduces to the simple two-period version. Again, whether conservation leasing is preferable depends on the comparison between the opportunity cost of delaying extraction and the salvage value that conservation provides, and this same basic tradeoff applies regardless of how many leasing periods are considered. To further explore this intuition and its application, we now apply this framework to specific resources.

2.2 Conservation pricing in practice across resources

2.2.1 Grazing and agriculture

Grazing provides the simplest context for considering conservation lease pricing, as the annual renewable resource dynamics for grazing use and conservation use are similar. There are no royalties associated with grazing, and in general, the depletion of the stock by grazing is limited, such that $B_E(x_C) \approx B_E(x_E)$ and $\hat{B}^G_\infty \approx B_E(x_C)$. Applying Proposition 3, conservation leasing reduces to a head-to-head comparison of bids, and conservation wins as long as $B_C(x_C) > B_E(x_C)$.[9]

In practice, transitioning from a grazing lease to a conservation lease, or vice versa, would be relatively straightforward, with the conservation group effectively buying out the rancher's grazing lease (Regan et al., 2023). The only dynamic wrinkle emerges if conservation leases improve the quality of the land at the end of the conservation lease, either through natural regeneration or active restoration/mitigation. In that sense, the (discounted) future revenue value of the land is increased by the conservation lease and should be reflected in pricing. There are two options available to reflect that increased value. First, the agency could add a "premium" to the conservation lease bid and compare the total with any grazing bids. If a ten-year conservation lease would raise the discounted future revenue potential by \$400 (in present value terms), then a conservation bidder who bid \$800 for the land would win over a grazing bidder at \$1,000 (\$1,200 versus \$1,000). Alternatively, the agency could provide a "refund" of equivalent present value at the end of the conservation lease (i.e., \$660 in 10 years at a 5% discount rate). Knowing they will receive the future refund (worth \$400 in present value terms), the conservation group would be able to bid \$1,200 upfront, which would beat the grazing bid of \$1,000.

Although both pricing approaches achieve the same revenue-maximizing outcome, they differ in two practical respects. First, under the upfront premium approach, the agency awards the lease to the conservation group even though the group bid less cash upfront. Even when this adjustment is fully consistent with the agency's revenue-maximizing mandate, awarding the lease

[9] If grazing does not degrade the extractive value at all, then $B_E(x_C) = B_E(x_E)$, which violates the strict monotonicity in Assumption 1. In that case, if conservation bids were larger than grazing bids, the conclusion of Lemma 1 would also fail and the land should be leased for conservation in perpetuity.

to a lower nominal bidder may appear to favor conservation interests. Second, under the premium approach, the agency grants the credit at the start of the lease and bears the risk that the conservation group does not carry out the land improvements. The refund approach transfers that risk to the conservation group, which must improve the land to receive the refund. To fund the higher upfront bid under a refund rule, conservation groups could use conservation bonds or other financial instruments backed by the end-of-lease refund.

2.2.2 Timber

Timber leases are a more complex case to consider than grazing, due to the dynamics of timber harvest cycles. Nonetheless, the same basic principles are in place, whereby conservation lease pricing should account for differences in future revenue streams of conservation versus logging. For simplicity, we consider the case where the timber harvester pays an up-front stumpage price. Because there are no royalties and clear-cutting implies $B_E(x_E) = 0$, Proposition 3 implies that conservation bids win provided they exceed $\hat{B}^T_\infty = (1-\delta)B_E(x_C)$.

While grazing leaves future revenue potential for the land, once the trees are cut under a timber lease, there is effectively zero revenue potential for many years (or even many decades in some cases). By contrast, under a conservation lease, the timber can still be cut when the lease expires, but the delayed revenue collection by the state needs to be accounted for. Thus, with timber sales, conservation groups can either receive an upfront premium payment for the discounted revenue value of the future timber $\delta B_E(x_C)$, or a present-value equivalent refund at the end of the lease (if the timber remains). For example, a \$300,000 harvest revenue value of timber today is worth \$182,000 in present value if harvested in 10 years at a 5% discount rate. A conservation group bidding \$135,000 today would then win a bid against a timber bid of \$300,000 today, since \$135,000 + \$182,000 = \$317,000 is greater than \$300,000. Alternatively, the conservation group could receive a refund for the revenue value of the timber of \$300,000 in ten years at the end of the lease, and would then bid \$317,000 accordingly upfront, knowing that refund is down the road.

Two features of conservation pricing for timber warrant emphasis. First, the political difficulty of upfront premiums is particularly acute for timber because much smaller conservation bids will prevail over larger timber bids, especially for shorter leases, even though the underlying economic principles are sound. Second, the forest may burn during the conservation lease, in which case the state would lose that future revenue. This fire risk can be priced into the discount rate used to calculate the upfront premium (Reed, 1984). Alternatively, the refund approach would give conservation groups an incentive to adopt fire-reducing management practices in order to protect their "investment."

2.2.3 Oil and gas

Oil and gas presents a particularly difficult problem because of the multiple sources of time-varying revenue, the fact that royalties are uncertain and paid out in the future after any auction, and the fact that the future extraction value is zero once extracted ($B_E(x_E) = 0$). An up-

front $4,000 bid from a conservation group and a $4,000 bid from an oil and gas company will often have very different present value revenue implications for the state. Nonetheless, with certain production ($\rho = 1$), Proposition 4 below implies that conservation bids win if $B_C(x_C) > (1-\delta)(B_E(x_C) + R_E(x_C)) - \delta F$. That is, the conservation bid has to cover the opportunity cost of delaying the collection of revenues from extraction bids plus royalties. The term $-\delta F$ appears because the conservation lease pays rent this term, which more than covers the cost of delaying the oil and gas lease's own rent by one term. Proposition 3 does not include this term because there the degraded parcel keeps paying rent.

Per equation 3, let ρ be the probability of production, after which there is zero future extraction or conservation value (stock goes to x_E),[10] while with probability $1-\rho$ there is no extraction and the stock remains at x_C. While in principle an unproductive oil and gas lease could be auctioned again, an additional wrinkle is that not every unproductive lease is leased again. Let λ represent the probability that a non-productive oil and gas lease is leased again.[11] This yields a modified condition for a winning conservation bid in the context of oil and gas:

Proposition 4. *Under Assumption 1, for an infinite series of oil and gas leases with probability of production ρ and probability of being leased again λ, and with rent collected only while a lease is in force, a conservation lease bid $B_C(x_C)$ will maximize public revenue if it exceeds the minimum required bid $\hat{B}^O_\infty$, defined by:*

$$\hat{B}^O_\infty = \kappa\big(B_E(x_C) + \rho R_E(x_C)\big) - (1-\kappa)F, \qquad \kappa = \frac{1-\delta}{1-\delta(1-\rho)\lambda}. \tag{10}$$

Equivalently, the conservation lease maximizes public revenue if $D_C(x_C) \geq \kappa D_E(x_C)$.[12]

Proof. See Appendix A. □

The more complicated structure of oil and gas leasing necessitates a more complicated rule for comparing conservation lease bids versus oil and gas bids. In particular, the required conservation auction bid $\hat{B}^O_\infty$ could be greater or less than the oil and gas auction bid $B_E(x_C)$, depending on the parameters and the tradeoff between the costs of delay and the relative salvage value of conservation leasing. However, while in principle the above formula can provide guidance to land agencies looking to compare auction bids, there still remains a fundamental challenge associated with uncertainty. For grazing and timber leases, agencies can directly assess resource conditions on the parcel to evaluate both the opportunity cost of conservation leases and the potential for extractive production. By contrast, oil and gas is harder along both dimensions. When auction bids are compared, the probability of production ρ is uncertain and, conditional on production, so is the level of production and thus the royalties $R_E(x_C)$.

[10] Once a Wyoming state lease produces, its rental rises to $2 per acre per year, but the rental is credited against royalties, so the state collects no rent beyond royalties from a producing lease (Wyoming Board of Land Commissioners Rules, Chapter 18, Section 6; Wyo. Stat. § 36-6-101(c)).

[11] For example, in our data below on Wyoming oil and gas leases, roughly 60% of parcels with an undeveloped oil and gas lease show up again in the sample.

[12] We assume that a parcel returns to auction when a conservation lease ends. An unproductive oil and gas lease is re-leased only with probability λ because the outcome of that lease is informative about the parcel.

2.3 Conservation leasing from theory into practice

While the above derivations abstract from a number of practical considerations, they provide useful insight into the opportunity costs of conservation leases, and how to "price" those leases relative to other extractive uses in a way that reflects the inherent salvage value that conservation leases provide. From the public agency's perspective, grazing presents a straightforward, apples-to-apples comparison of the auction bids it receives. Timber requires additional discounting calculations, but in principle the land agency can compare the bids it receives. By contrast, determining $\hat{B}_{\infty}^{O}$ for oil and gas requires information on the probability of production (ρ) and level of royalties $R_E(x_C)$ that is fundamentally unknown at the time of auction. In the next section, we use an empirical approach to recover predictions of those values, leveraging observed auction bids ($B_E(x_C)$) by oil and gas firms, in order to determine $\hat{B}_{\infty}^{O}$ for parcels leased for oil and gas in Wyoming. The opportunity cost turns out to be low for many parcels and well within the typical budgets of conservation firms. However, this low opportunity cost for many parcels primarily reflects their low probability of production (small ρ), in which case it is not immediately clear why a conservation group would be willing to pay anything. We examine this question in Section 4.

3 Opportunity costs of oil and gas leases

The previous section highlighted that the forgone royalties associated with uncertain development and uncertain production are a key component of the opportunity cost of conservation leases compared to oil and gas leases. This creates an acute empirical challenge for agencies in parcel allocation. In practice, due to the high overall share of oil and gas royalty revenues for states, agencies have often treated the potential for *any* oil and gas development as de facto rationale for precluding conservation leasing. Yet winning auction bids from private oil and gas firms vary across parcels by four orders of magnitude. This variation plausibly reflects firms' private information about the underlying production value of each lease.

In this section, we examine whether the upfront oil and gas auction bids by private firms are predictive of future expected royalties. If so, agencies can use oil and gas bids to compare conservation bids with the revenue they would forgo. In addition, we examine whether the key margin for determining expected future royalties is uncertainty about the probability of production at all or uncertainty about the level of production (conditional on production occurring). Finally, for a given lease, we also determine the average contribution of royalties towards the total revenue collected by agencies.

3.1 Oil and gas lease data

Our data come from Wyoming's Office of State Lands and Investments (OSLI), which oversees the state's trust lands. We leverage two primary datasets: (a) all state trust leases auctioned from 2000 to 2025 along with their winning auction bids, and (b) royalty payments from all producing leases (some of which are nearly 100 years old) from 2010 to 2025. Leases last for five years if

nothing is produced and in perpetuity as long as they continue to produce. Lease identification numbers allow us to connect bids to subsequent royalties for producing leases. The key dependent variables are the royalties paid by each lease and whether or not royalties were produced. We observe all royalties collected from all producing leases, by distribution year, from 2010 to 2025. For the primary regressions below, we calculate aggregate royalties paid ($RoyaltyPaid_{it}$) by lease i auctioned at time t (and discount by 5% as needed for present value calculations). As discussed below, we also estimate the expected future royalties from existing leases for years beyond 2025. The key independent variable for the analysis is the winning auction bid per acre for each lease i auctioned at time t, $AuctionBidPerAcre_{it}$. We also construct an indicator variable $AnyRoyalty_{it}$ if the lease ever produced. In addition, we observe the acreage, county, and winning firm for each lease, which we use as controls in regressions below.

Data availability and the dynamics associated with the auction and production process determine our sample period for the analysis, which consists of all leases auctioned from 2009-2019. We truncate the sample in 2019 on the grounds that any leased parcel after 2019 may not have had time to produce during its five-year lease period. Similarly, we begin the sample in 2009 because leases auctioned before 2009 may have produced royalties before our royalty data begin in 2010.[13] Panel A of Table 1 reports summary statistics by quartile of bid price for all leases.

Table 1. Summary Statistics by Bonus Bid Quartile

Panel A: All leases

Bid quartiles	AuctionBidPerAcre	AnyRoyalty	RoyaltyPaid (mean)	N
1	1	0.0050	1,280	1,404
2	6.972	0.0071	2,395	1,271
3	29.85	0.0237	18,867	1,306
4	826.6	0.1012	167,834	1,314

Panel B: Producing leases

Bid quartiles	AuctionBidPerAcre	RoyaltyPaid (mean)	RoyaltyPaid (median)	N
1	1	256,790	106,173	7
2	5.778	338,271	161,384	9
3	37.40	794,871	98,120	31
4	2,048	1,658,154	827,299	133

Notes: Leases auctioned 2009–2019, with all royalties received 2010–2025. Panel A includes every lease, and Panel B includes only leases that paid any royalties. Quartiles are defined over all leases in both panels (Appendix Table B2). AuctionBidPerAcre is the mean winning bid per acre, AnyRoyalty is the share of leases that paid any royalties, and RoyaltyPaid is total royalties received per lease in dollars, undiscounted.

Bids rise by roughly an order of magnitude from one quartile to the next. The probability of production from a lease is below 1% for the bottom half of leases and much higher for the top quartile. Average royalties paid per lease rise from thousands of dollars to over a hundred thousand dollars. Panel B reports summary statistics by bid quartile for the leases with any production.

[13] We explored including earlier and later leases, and the findings are qualitatively very similar to the results for the preferred sample below.

Although the sample of producing leases is small, particularly for the bottom half of leases, mean royalties per producing lease rise with the auction bid, and median royalties are highest in the top quartile.[14]

3.2 Econometric methods

We first estimate how differences in upfront auction bids predict differences in future royalty revenue collected by the state:

$$Y_{it} = \beta_1 AuctionBidPerAcre_{it} + \beta_2 Acres_{it} + C_i + \eta_i + T_t + \varepsilon_{it} \tag{11}$$

where Y_{it} is the collected royalties ($RoyaltyPaid_{it}$) from lease i auctioned at time t. Controls include the acreage of the lease, as well as fixed effects for county, firm, and the month-year of the auction. The coefficient of interest β_1 is the increase in total collected royalties per dollar increase in auction bid. Because of variation in oil and gas prices and extraction technology over time, we include month-year fixed effects for the specific monthly auction (e.g., all auctions held on April 4, 2012). Given that geology varies across the state, county fixed effects absorb any common features across leases within a county. Finally, we include firm fixed effects to account for compositional differences across extraction firms that may be correlated with both bids and royalties.

We therefore identify β_1 by comparing bids and royalties across leases won by the same firm in the same county during the same month-year auction. Because our identification is cross-sectional, we interpret β_1 as the information about future royalties that is revealed by the upfront bids, conditional on these fixed effects, rather than as a causal effect of the bid itself. Using the specification in Equation 11, we also estimate a linear probability model to determine how bids predict the likelihood of any production and royalties ($AnyRoyalty_{it}$). Standard errors are clustered at the county level to allow for spatial and temporal error correlation between leases within a county.

While the above estimating framework provides a useful mapping of auction bids to average royalties and development probabilities on a per dollar basis, the summary statistics in Table 1 suggest there may be important nonlinearities in royalties collected or the probability of production. To allow more response flexibility, we estimate the following auction bid-decile model:

$$Y_{it} = \sum_{k=3}^{10} \theta_k D_{kit} + \beta_2 Acres_{it} + C_i + \eta_i + T_t + \varepsilon_{it}, \tag{12}$$

where D_{kit} is an indicator variable such that $D_{kit} = 1$ if the auction bid $AuctionBidPerAcre_{it}$ is in the k^{th} decile of the auction bid distribution.[15] The coefficients of interest θ_k correspond to the estimated differences in either the royalties collected or probability of production when auction bids are in the k^{th} decile, relative to the lowest two deciles of bids (both \$1 per acre). We

[14] Producing leases in the highest quartile have bids per acre (\$2,048) that are roughly two and a half times the mean for all leases in the highest quartile (\$826.6).

[15] See Appendix Table B2 for a breakdown of the auction bid values corresponding to each decile.

also estimate a model with 20 bins, or ventiles. Narrower bins (e.g., 50 bins) yield no additional insight.

3.3 Estimating expected future production and royalties

The above discussion focuses on the observed royalties collected by the state for each lease up through 2025 that we can see in our data. One concern is that for recently producing leases (e.g., a lease auctioned in 2018 that started producing in 2023), we cannot observe the full schedule of production and collected royalties that will occur into the future. To address this, we first estimate a common depletion curve based on the observed collected royalties. To recover annual quantities for each lease, note that $R_{it} = \tau_i * p_t * q_{it}$, and we observe annual royalties R_{it} and royalty rates τ_i in the data. Using annual West Texas Intermediate oil prices, we can recover an implied annual production quantity q_{it} for each lease for each year. Appendix Figure B2 plots these implied quantities versus years since production.

Next, we estimate a common depletion curve using within-lease variation as $\ln q_{it} = \gamma a_{it} + \xi_i + \nu_{it}$, where a_{it} indexes the age of production on the lease and ξ_i is a lease fixed effect. We drop each lease's first year of production, which is usually partial, and the partial year 2025, and use the following ten years of production on leases auctioned from 2009. We recover $\gamma = -0.14$, a decline in production of about 13% each year. Finally, we apply this common depletion curve to each lease over a 30-year well life, value production at the average annual West Texas Intermediate price over 2010–2024 ($72.06 per barrel) to calculate annual expected royalties, and then discount the implied royalties by 5% to generate the total expected net present royalties for each lease.[16]

3.4 Econometric results

Estimation results for Equation 11 are presented in Table 2. The first column reports a simple regression with only acreage as a control and finds that every dollar increase in bid per acre corresponds to a statistically significant $114 increase in royalties collected. Columns (2) and (3) add in additional fixed effects controls for years, counties, and month-years, yielding a slightly smaller effect in column (3) of $94 of royalties per dollar of bid. In the preferred specification in column (4), we add firm fixed effects, and each dollar of bid per acre corresponds to roughly $70 in royalty income. Column (5) reports the same specification, but clusters at the finer parcel level instead of county level, with very similar standard errors on the auction bid coefficient. The average leased

[16]Specifically, the maximum production from each lease is used as the "peak" production quantity, which is then reduced by about 13% each year per the depletion curve to get predicted quantities $\hat{q}_{it}$. Relative to the observed implied quantities q_{it} in our data, these predicted quantities are too large by roughly a factor of two. A regression of q_{it} on $\hat{q}_{it}$, excluding 2025, for which we observe only four months of royalties, gives a coefficient of 0.576. The final step scales the predicted quantities by 0.576, such that within the sample, the predicted quantities match the observed quantities on average. See Appendix Figure B1 for demonstration of fit between observed and predicted quantities. We value expected royalties as of each lease's first year of production rather than the year of the auction, because the year production begins varies widely across leases. Among producing leases in our sample, royalties begin a median of five years after the auction. Because the bid and rent are paid earlier, this simplification overstates expected royalties relative to the other revenue sources, and so overstates the conservation bids required in Table 5 and the thresholds in Section 4.

parcel is 378 acres, so an increase in auction bid of $1 per acre is equivalent to a $378 increase in total auction bid revenues. For the preferred specifications in column (4) and (5) and for the average parcel size, this implies an increase in collected royalty revenues of $70 for every additional $378 in auction bid revenues.

Table 2. Auction Bids and Total Royalty Payouts

VARIABLES	(1) RoyaltyPaid	(2) RoyaltyPaid	(3) RoyaltyPaid	(4) RoyaltyPaid	(5) RoyaltyPaid
AuctionBidPerAcre	114.6**	114.1**	94.58**	69.93***	69.93**
	(41.75)	(42.96)	(39.88)	(25.04)	(27.43)
Acres	123.2**	122.4**	140.1*	125.1**	125.1***
	(57.09)	(57.11)	(69.66)	(58.92)	(29.99)
Year FE	N	Y	N	N	N
County FE	N	N	Y	Y	Y
Month-year FE	N	N	Y	Y	Y
Firm FE	N	N	N	Y	Y
Clustering	County	County	County	County	Parcel
Observations	5,295	5,295	5,295	5,148	5,148
R-squared	0.031	0.033	0.050	0.190	0.190

Notes: Robust standard errors in parentheses, clustered as indicated. Leases auctioned 2009–2019, with royalties received 2010–2025. Columns (4) and (5) drop the 147 leases won by firms with a single lease in the sample. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Next, Table 3 runs through a similar exercise, but with the indicator variable for production ($AnyRoyalty_{it}$) as the dependent variable. In the preferred specification in column (4), the statistically significant coefficient implies that for every one-hundred dollars of auction bid per acre, the probability of production increases by 0.63 percentage points, relative to a sample average of roughly 3 percent. Taken together, the above results document a clear linkage between auction bids and royalty outcomes.

The analysis above uses the total royalties collected that we observe in the data.[17] However, this overlooks two critical points. First, in terms of net present revenue, royalties collected long after the initial auction are less valuable than royalties collected sooner, so we discount the stream of observed royalties at 5% to determine the total net present value of royalties for each lease ($RoyaltyNPV_{it}$). Second, as noted above, we fundamentally cannot observe royalties for future years, which will reduce observed royalties for any leases auctioned later in the sample. Using the depletion curve approach outlined above, we calculate the total net present royalty revenue based on expected production ($RoyaltyExpectedNPV_{it}$). Finally, we combine total auction bid revenues, the discounted flow of rental fees, and the discounted expected royalties to calculate the total NPV revenue expected for each lease ($TotalRevenueExpectedNPV_{it}$).

In Table 4, we estimate the relationship between auction bids and these alternative revenue measures using the preferred specification from column (4) of Table 2, which includes fixed effects

[17] We use this measure of royalties in the analysis above to demonstrate the identification strategy and model interpretation because it requires the fewest assumptions to explain.

Table 3. Auction Bids and Share of Leases That Pay Out Any Royalties

	(1) AnyRoyalty	(2) AnyRoyalty	(3) AnyRoyalty	(4) AnyRoyalty	(5) AnyRoyalty
AuctionBidPerAcre	7.95e-05***	8.11e-05***	7.16e-05***	6.33e-05***	6.33e-05***
	(2.49e-05)	(2.45e-05)	(2.12e-05)	(1.25e-05)	(9.55e-06)
Acres	7.15e-06	5.06e-06	1.23e-05	3.78e-06	3.78e-06
	(7.81e-06)	(7.80e-06)	(1.09e-05)	(9.46e-06)	(9.55e-06)
Year FE	N	Y	N	N	N
County FE	N	N	Y	Y	Y
Month-year FE	N	N	Y	Y	Y
Firm FE	N	N	N	Y	Y
Clustering	County	County	County	County	Parcel
Observations	5,295	5,295	5,295	5,148	5,148
R-squared	0.107	0.112	0.160	0.397	0.397

Notes: Robust standard errors in parentheses, clustered as indicated. Leases auctioned 2009–2019, with royalties received 2010–2025. Columns (4) and (5) drop the 147 leases won by firms with a single lease in the sample. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

for county, firm, and month-year of auction (column (1) repeats the $RoyaltyPaid_{it}$ estimate for comparison). In column (2), discounting observed royalties gives an estimate of \$54 in net present value royalties for every \$1 per acre in auction bid. Column (3) uses the expected royalty NPV calculation, finding an increase of \$121.8 in expected net present royalties per \$1 per acre in auction bid, while column (4) reports a \$374.3 increase in total NPV revenue per \$1 per acre bid. Although column (3) requires more assumptions to construct, we focus on it as it is the closest to what state trust land managers care about. From column (3), at the average parcel size of 378 acres, each additional \$1 per acre bid brings in an additional \$378 in auction revenue and \$122 in expected net present royalty revenue, or roughly an additional \$1 in expected net present royalty revenue for every additional \$3 in upfront auction revenue.

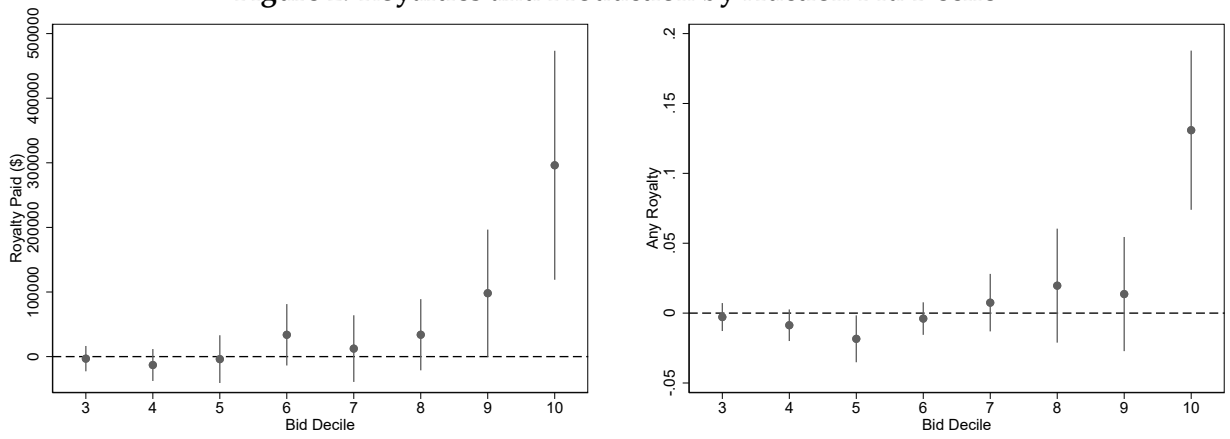
Finally, we relax the linearity assumptions in the above regressions to allow for more flexible responses across deciles as in Equation 12 and depict the results in Figure 2. In general, the results are consistent with the linear approach. Higher bids per acre correspond to higher royalties and probabilities of production. However, most of the increase occurs in the top decile (bids greater than \$500 per acre). For bids in that top decile, royalties paid are roughly \$300,000 higher than in the omitted lowest deciles, and the probability of any production is nearly 15 percentage points higher. When we divide bids into ventiles (Appendix Figures B3 and B4), royalties rise in the 90–95% bin, and the top 5% of bids show a sharp increase of 22 percentage points in the probability of production. Parcels attracting bids above \$1,250 per acre in this top ventile (nearly \$500,000 in total at the average parcel size) are substantially more likely to enter production and pay out royalties.

Table 4. Alternative Royalty Measures—Linear Model

VARIABLES	(1) Royalty Paid	(2) Royalty NPV	(3) Royalty Expected NPV	(4) Total Revenue Expected NPV
AuctionBidPerAcre	69.93***	53.71***	121.8***	374.3***
	(25.04)	(18.66)	(42.24)	(50.39)
Acres	125.1**	83.67**	159.0**	375.5**
	(58.92)	(39.39)	(74.31)	(143.1)
County FE	Y	Y	Y	Y
Month-year FE	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y
Clustering	County	County	County	County
Observations	5,148	5,148	5,148	5,148
R-squared	0.190	0.199	0.207	0.327

Notes: Robust standard errors in parentheses, clustered by county. Leases auctioned 2009–2019, with royalties received 2010–2025. All columns include county, month-year and firm fixed effects. Leases won by firms with a single lease in the sample (147) are dropped. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Figure 2. Royalties and Production by Auction Bid Decile



(a) Royalties Paid

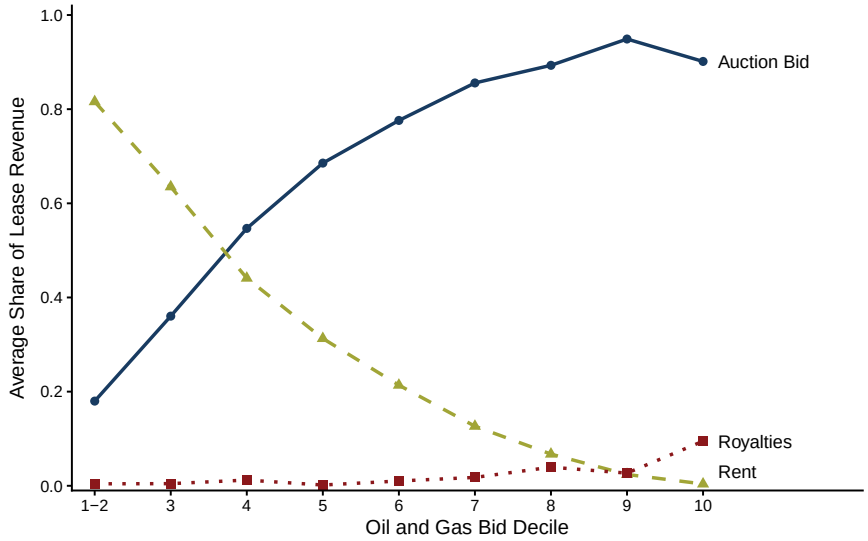
(b) Share of Leases That Pay Any Royalties

Notes: Coefficients on bid-decile indicators from Equation (12), relative to deciles 1 and 2. Bars are 95 percent confidence intervals with standard errors clustered by county.

3.5 Revenue shares

We next examine what these results imply for the shares of expected revenue from royalties, rental fees, and auction bids. Although royalties are the largest source of aggregate revenue for state trust lands at any given point in *time*, state trust land managers must make leasing decisions about individual *parcels*. Figure 3 plots the average share of observed net present value revenue from auction bids, rental fees, and royalties by decile of auction bid.

Figure 3. Revenue Shares by Bid Decile



Notes: Mean across leases of each source's share of the lease's net present revenue. Leases auctioned 2009–2019, with royalties observed through 2025 and discounted to the auction year at 5 percent. Rent is $1 per acre per year, discounted at 5 percent, for the five-year primary term or, on a producing lease, until production begins, after which royalties replace rent.

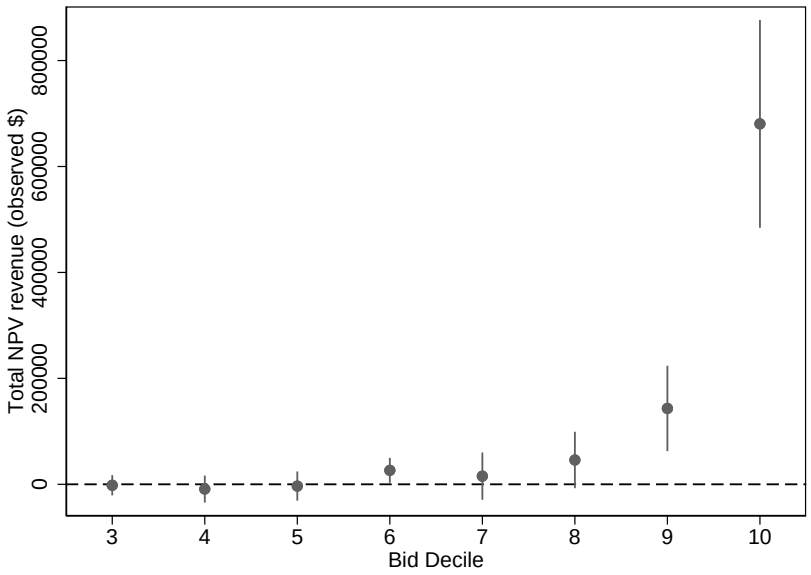
At the lowest auction bid levels (e.g., $1 per acre), rental fees are the largest share of revenue. An auction winner who bids $1 per acre for a 640-acre parcel pays $640 upfront and then $640 in rent each year, before discounting, for the five-year term. The probability of development on these leases is so low (5 in 1,000) that the average share of revenue from royalties is minor. For roughly one-third of all leases, rental fees are the main source of revenues. As auction bids increase, rental fees become less important. From the 4th decile to the 8th decile, auction bids become the dominant source of revenue, with a small share on average coming from royalties due to the small probability of production. At the highest decile, there is a sharp uptick in the share of revenue that comes from royalties on average, due to the sharp uptick in production probability (per Figure 2b). Nonetheless, auction bid revenue remains the primary share of revenue, even at the highest bid deciles with the highest probability of production.

The small average share from net present royalties for a given lease (no greater than 10% even for the top decile) is somewhat surprising given that royalties are the largest source of revenue for state trust lands in any given year. One concern is that our data miss some collected royalties. This does not appear to be the case, because the annual royalty revenue we observe is consistent

with the mineral revenue reported by the Office of State Lands and Investments (Wyoming Office of State Lands and Investments, 2019).[18]

A remaining concern is that we cannot observe future royalties from existing leases. To see if these unobserved future royalty revenues are driving the relatively small average royalty share, we calculate shares of revenue using expected net present revenues as described above. Per Appendix Figure B5, the average royalty revenue shares are higher using these expected production curves (about 15% at most), but auction bids and rental fee revenues are still the primary share of revenue for the average lease. Finally, Figure 4 plots differences in total net present revenue, using royalties observed through 2025, by bid decile relative to the reference level in the first and second deciles (roughly $3,000 in total net present revenue). The sharp increase in total revenues for the higher bid deciles again reinforces the point that the bulk of state land trust revenues are coming from a relatively small number of parcels with very high bids.

Figure 4. Total Revenue by Bid Decile



Notes: Coefficients on bid-decile indicators from Equation (12), with total net present revenue per lease as the outcome, relative to deciles 1 and 2 (mean of about $3,000). Total revenue is the auction bid, rent ($1 per acre per year for the five-year primary term or, on a producing lease, until production begins) and royalties observed through 2025, discounted to the auction year at 5 percent. Bars are 95 percent confidence intervals with standard errors clustered by county.

3.6 Conservation leasing

These revenue shares clarify the tradeoffs involved in conservation leasing. As shown in Proposition 4, revenue-maximizing state trust land managers should compare the potential revenue from a conservation lease with the opportunity cost of forgoing an extractive lease. One key empirical takeaway is that the opportunity cost of conservation leasing is often smaller than it might at first

[18] In 2019 we observe $133.5 million in royalties across all minerals. The Office reports $175.5 million in mineral lease and royalty revenue for fiscal year 2019, a figure that also includes bonus bids and rentals.

appear. State trust land managers may assume that choosing a conservation lease means giving up significant oil and gas royalties. In practice, however, most parcels never generate royalties at all. What is usually at stake are modest upfront auction bids and rental payments, which conservation bids may be able to exceed.

When balancing these potential revenue sources across different uses, there are three important points from the results above. First, and perhaps most importantly, auction bids themselves act as a signal of expected royalties and production. High bids indicate a parcel where royalties are more likely and more lucrative, while low bids signal the opposite. This gives trust managers a transparent tool for evaluating the tradeoffs of accepting a conservation bid. Second, recognizing the heterogeneity of parcels is essential, as conservation leasing will be most competitive across the broad base of parcels with low to moderate bids, where expected royalties are minimal. A smaller set of parcels with very high auction bids will remain extremely costly for conservationists to compete for. Oil and gas development will likely continue on these parcels, which are precisely the parcels most likely to produce royalties for the state. Finally, conservation leasing should not be viewed as a permanent removal of trust assets from production. Like other leases, conservation leases generate upfront revenue and rental payments, and parcels can return to auction in the future. This means conservation leasing can be a legitimate, revenue-maximizing strategy for meeting trust obligations.

To guide the structuring and evaluation of conservation bids, we calculate the conservation bids that would provide equivalent revenue to the state, given the auction, rental, and expected royalties calculated above. Because this comparison depends on lease length and the probability that undeveloped parcels are auctioned again, we evaluate several scenarios below, each assuming that the conservation lessee pays the annual rental fee of $1 per acre.

Panel A of Table 5 first reports average oil and gas revenues and probability of production by bid decile. Panel B reports the range of oil and gas auction bids per acre within each bid decile, along with the corresponding minimum bid by conservationists that would generate more revenue for the state under different scenarios. For easier comparison to oil and gas auction bids, Panel C normalizes those minimum conservation bids on a per-acre basis.

We first consider a "Cover royalties" scenario, in which the conservationist must bid enough to beat the oil and gas bid *plus* cover the decile average expected royalties (Proposition 1). While straightforward, this scenario ignores the fact that at the end of a conservation lease, the parcel could be auctioned again. In the "5-year lease" scenario, we account for this potential for future re-auction of a conservation lease per the analysis in Section 2. Specifically, we apply the condition in Proposition 4 with $\lambda = 0$, such that conservation leases are re-leased, but an oil and gas parcel that does not produce is never leased again. In reality an unproductive oil and gas parcel could continue to be leased and bid on by either conservationists or oil and gas interests to continue to provide revenue into the future. Empirically, however, not all parcels are leased repeatedly. Roughly 60% of unproductive parcels are leased for oil and gas more than once in our data, and roughly 60% of those are leased more than twice. Hence, we consider a "5-year repeat" scenario,

in which parcels with oil and gas leases can continue to be leased if not developed, but only have a 60% chance of being leased again ($\lambda = 0.6$).[19]

Table 5. Minimum Conservation Bids Required

Panel A: Average O & G $ revenues (NPV)

Decile	Auction revenue	Rental revenue	Royalty revenue	Prob production
1 and 2	376	1,704	902	0.0050
3	1,035	1,776	188	0.0048
4	2,300	1,809	7,692	0.0128
5	4,040	1,821	163	0.0019
6	6,820	1,837	43,299	0.0117
7	12,164	1,758	18,266	0.0249
8	24,268	1,727	54,353	0.0462
9	79,757	1,679	100,466	0.0364
10	535,602	1,453	432,202	0.1942

Panel B: Conservationist needed $ bid (total) by scenario

Decile	O&G bid/acre range	Cover royalties	5-year lease	5-year repeat*
1 and 2	[1-1]	1277	-1045	-472
3	[2-3]	1223	-1112	-536
4	[4-7]	9992	802	3037
5	[8-12]	4203	-488	676
6	[13-22]	50119	9656	19518
7	[23-43]	30431	5362	11322
8	[44-100]	78621	16046	30336
9	[101-500]	180223	38558	71515
10	[501-]	967804	212946	342422

Panel C: Conservationist needed $ bid per acre by scenario

Decile	O & G bid/acre range	Cover royalties	5-year lease	5-year repeat*
1 and 2	[1-1]	3.4	-2.8	-1.3
3	[2-3]	3.1	-2.8	-1.4
4	[4-7]	25.1	2.0	7.6
5	[8-12]	10.5	-1.2	1.7
6	[13-22]	124.5	24.0	48.5
7	[23-43]	78.5	13.8	29.2
8	[44-100]	207.4	42.3	80.0
9	[101-500]	488.2	104.5	193.7
10	[501-]	3108.0	683.9	1099.7

Notes: Conservation bids required to return more revenue to the state in NPV terms. Scenarios assume conservationist pays $1 per acre rental fee annually. Rent is collected only while a lease is in force. Royalties replace rent once a lease produces, and a parcel that is not leased again pays no further rent. Negative values mean that any positive conservation bid returns more revenue to the state. * Assumes 60% of undeveloped leases are leased again based on empirical frequency of re-leased parcels.

Although the minimum required bids are sensitive to the scenario assumptions, the values in the tables should provide reasonable approximations for what a winning conservation bid would need to be. At one extreme, requiring conservationists to fully cover expected royalties implies the largest minimum bids, from $3 an acre to more than $3,000 per acre depending on the oil

[19] Appendix Table B3 reports additional scenarios, including a hypothetical 10-year conservation lease and a case where unproductive oil and gas parcels are always re-leased ($\lambda = 1$).

and gas bid decile. At the other extreme, assuming each parcel will only go up for oil and gas auction once leads to the smallest necessary conservation bids, which are negative in four of the bottom five deciles and $684 per acre in the top decile.[20] The difference reflects the future value of conservation leases, and the fact that parcels under a conservation lease can be returned to auction for revenue generation. Finally, grounding the probability of repeat oil and gas leasing of a parcel to what we empirically observe (60% repeat leases) gives necessary bids that fall between the two extremes, from below zero in the bottom three deciles to more than $1,000 per acre in the top decile. Allowing the agency to be risk averse lowers these break-even bids by less than half of one percent (Appendix E).

4 Why would a conservationist bid?

Table 5 shows that across the bottom eight deciles of the bid distribution a conservation bid of $81 per acre would return more revenue to the state than an oil and gas lease. In the bottom three deciles, any positive bid from a conservationist dominates an extractive bid because the rent the conservationist pays exceeds the cost to the state of delaying the oil and gas lease by one term. However, these parcels are cheap to protect precisely because they are unlikely to be drilled. Only one lease in two hundred in the bottom two deciles ever produces. A conservation organization that wins one of these leases prevents a well from being drilled during the five-year lease term, but because that well would rarely have been drilled in any case, it is not immediately clear what the organization would be paying to avoid. This section addresses that question by characterizing the conservation organization's problem in more detail.

Section 4.1 derives the value of a one-shot lease to a conservationist and the expected loss from drilling that would justify bidding on that lease. Section 4.2 shows that this loss can be large when the lease in question is part of a weakest-link public good, or when habitat fails once disturbance passes a level that is not known in advance, and provides empirical illustrations using migration corridors and sage-grouse core areas in Wyoming. Section 4.4 discusses several other theoretical foundations for the idea that conservation value may be high even where development pressure is low. Section 4.5 explores a channel not included in our model, which is that even leases that do not lead to production may entail temporary surface disturbance that the conservationist may seek to avoid.

4.1 The value of a conservation lease

In our model, the resource stock x changes only when a lease produces. An oil and gas lease that does not produce returns the parcel to the agency in pristine condition (Figure 1), an assumption we return to in Section 4.5. A conservation lease therefore matters to a conservation organization

[20] Both re-auction scenarios count the rent the state forgoes under an oil and gas lease once a parcel produces or leaves the leasing pool, since a conservation lease pays rent in every term it is held. A negative required bid means that *any* auction revenue the state can collect from a conservationist is worth accepting. In those cases the expected royalties are so small that conservation revenue plus future auction revenue exceeds the expected revenue from oil and gas.

only through the wells it prevents. Let Δu_C^{∞} denote the present value, at the time of drilling, of the permanent loss to the organization from a well on the parcel.[21] Because the degraded state x_E is absorbing, that loss is permanent, and a single conservation lease delays the risk of loss by one lease term rather than preventing it permanently.

Proposition 5 (One conservation lease)**.** *Suppose that a parcel under a conservation lease returns to auction when the lease ends. Then*

(i) one conservation lease is worth

$$v_C = \kappa\,\rho\,\Delta u_C^{\infty} - D_C \tag{13}$$

to the conservation organization, with κ as in Proposition 4;

(ii) with competitive bidding, the conservation lease maximizes public revenue if and only if

$$\rho\,\Delta u_C^{\infty} \;\geq\; D_E(x_C); \tag{14}$$

(iii) an organization that plans to hold the parcel in every future term faces the same condition.

Proof: Appendix A.4.

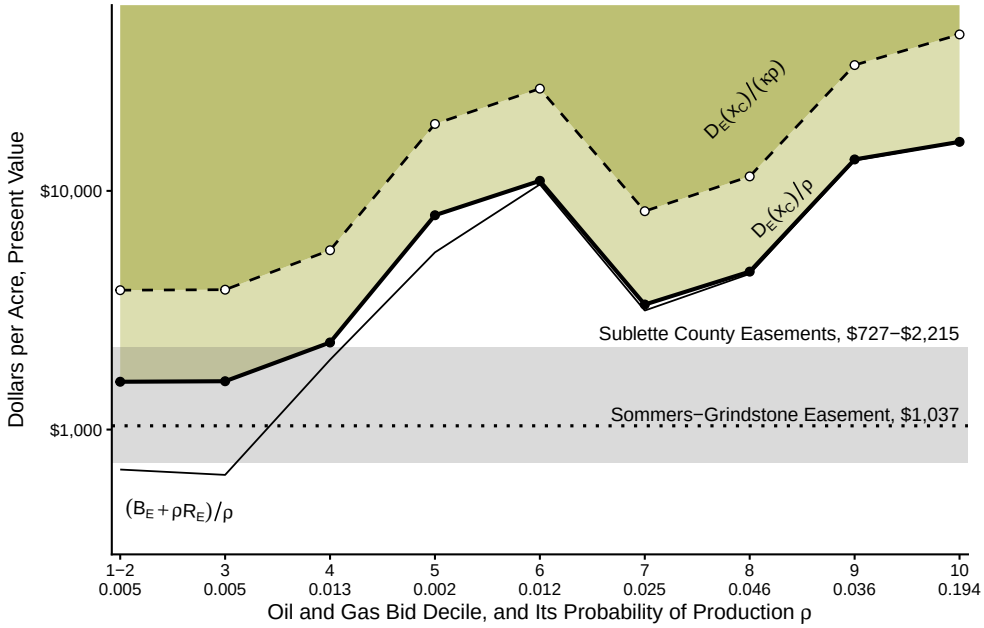
The discount factor, the probability of re-leasing λ and the salvage factor κ all drop out of Equation (14). The organization's payment covers the state's forgone revenue from delaying extraction by one term, and its benefit is a one-term delay in the expected loss from drilling. Because both quantities are scaled by κ, the comparison does not depend on the length of the lease or on how often unproductive parcels are re-leased, and part (iii) shows that the same condition applies whether the organization bids once or plans to win every future auction. The right-hand side of Equation (14) equals the state's single-lease revenue from an oil and gas lease (the upfront auction bid plus rental payments and expected royalties). At the other end, when $\rho\,\Delta u_C^{\infty} \geq D_E(x_C)/\kappa$, the break-even conservation payment exceeds single-lease extraction revenue, the condition in Lemma 1 no longer holds, and the agency would maximize revenue by leasing the parcel for conservation in perpetuity because the one-shot value of conservation is higher than the expected oil and gas revenues.

Dividing both sides of Equation (14) by ρ yields a threshold value that Δu_C^{∞} must exceed to rationalize bidding in excess of the state's break-even value for the conservation bid. Figure 5 plots this threshold, D_E/ρ, per acre by bid decile using the values in Table 5. In the bottom two deciles, a conservation lease exceeds the state's break-even revenue threshold if the permanent loss from a well exceeds \$1,586 per acre. The threshold rises to \$16,048 per acre in the top decile.

[21] We measure ρ as the probability that a lease produces, because production is the event that ends the parcel's value in Proposition 4. A conservation organization cares about whether a well is drilled on the parcel itself. Of the 5,283 sample leases we can match to well records of the Wyoming Oil and Gas Conservation Commission, 84 (1.6 percent) had a new well spudded on their own surface during the lease, compared with 180 producing leases (3.4 percent). The two rates are similar in the bottom six deciles, where dry holes offset production from wells drilled elsewhere, and they diverge at the top, where most producing leases generate royalties through a pooling unit or from a well drilled on another parcel (Appendix Table B1).

For perspective, perpetual conservation easements in Sublette County have cost between $727 and $2,215 per acre. The Sommers–Grindstone easement near Pinedale, the largest, cost $19.7 million for about 19,000 acres in 2010, or $1,037 per acre (Pinedale Online, 2010; Bureau of Land Management, 2012; Ostlind, 2016). Four easements funded by the Wyoming Wildlife and Natural Resource Trust ranged from $727 to $2,215 per acre in total project cost (Wyoming Wildlife and Natural Resource Trust, 2026). In the bottom three deciles, the break-even threshold D_E/ρ lies within this range, whereas permanent losses would have to exceed $3,837 per acre before single-period conservation revenue exceeds single-period extraction revenue and violates Lemma 1.

Figure 5. Threshold Conservation Valuations for Break-Even Bids



Notes: This figure depicts how much a conservation organization would have to value the loss from development in order to issue the break-even bid in each decile. Below the heavy line the oil and gas lease maximizes revenue, and in the light green band the conservation lease does. The darker green band is the region where Lemma 1 does not hold and conservation value dominates extraction revenue even on a one-shot lease. The heavy line is the threshold in Equation (14), $D_E(x_C)/\rho$, by bid decile, from Table 5. The thin line omits rent. The dashed line with open circles is $D_E(x_C)/(\kappa\rho)$, above which the conclusion of Lemma 1 fails. The grey band is the range of per-acre project costs of four perpetual conservation easements in Sublette County funded by the Wyoming Wildlife and Natural Resource Trust, and the dotted line is the Sommers–Grindstone easement near Pinedale (2010). Dollars per acre, present value at the time of drilling, log scale.

Compared to bonus bids and production probabilities, the threshold is relatively flat across bid deciles because ρ enters Equation (14) on both sides. Writing $D_E = B_E + F + \rho R_E$,

$$\frac{D_E}{\rho} = \frac{F}{\rho} + \frac{B_E + \rho R_E}{\rho}. \tag{15}$$

The first term on the righthand side is the rent, which a conservation lease also pays, spread over the chance of a well. It accounts for 57 to 59 percent of the threshold in deciles 1 to 3 and falls as ρ rises. The second term is the state's revenue per producing lease. If oil and gas bids were

proportional to the probability of production such that $B_E = \alpha\rho$, then ρ would completely cancel from this. Across the nine decile groups in Table 5, a regression of $\log(B_E + \rho R_E)$ on $\log \rho$ has a slope of 1.50 (Appendix Table B4), so the state's take per producing lease rises roughly at rate $\rho^{0.5}$. Together the two terms make D_E/ρ rise roughly at rate $\rho^{0.33}$. Hence, a low probability of drilling does not imply a prohibitively high required valuation, because firms also bid less for parcels they are unlikely to drill.

4.2 The structure of conservation value

To examine when Δu_C^{∞} can be large on low-probability parcels, we express the conservation organization's valuation over an ecological service that a landscape of parcels produces,

$$u_C(x, A_C) = V(S), \qquad S = \Phi(x_1, \ldots, x_n; A_C), \tag{16}$$

where $x_j \in \{x_E, x_C\}$ is the state of parcel j, Φ maps the states of the parcels into a level of service such as the passage of a migratory herd, and V is the present value the organization's donors place on that service. The loss from drilling one parcel depends on how far the service falls when that parcel is degraded, which is a property of Φ. One possible structure that could make Δu_C^{∞} large is what Hirshleifer (1983) describes as a "weakest link" public good, whose level is set by the smallest contribution rather than by the sum of contributions. A migration corridor has this feature, because a herd can pass successfully only if every section along its route remains open. We formalize the implications for Δu_C^{∞} in our next proposition.

Proposition 6 (Weakest-link corridor)**.** *Let J be the set of parcels on a corridor, let $S = \phi\big(\min_{j \in J} x_j\big)$ with ϕ increasing, and write $S_C = \phi(x_C)$ and $S_E = \phi(x_E)$. Then for every parcel $j \in J$ the permanent loss from a well on parcel j alone is*

$$\Delta u_C^{\infty,(j)} = V_J \equiv V(S_C) - V(S_E), \tag{17}$$

which does not depend on j, on the parcel's acreage or on the number of parcels in J.

Proof: Appendix A.5.

Proposition 6 says that the conditional loss from a well on any one parcel of the corridor is the value of the whole corridor, however small the parcel. In contrast, the parcel's value in extraction is constrained by what lies within its boundaries. A section on which an oil and gas firm bids a dollar an acre can therefore carry a conditional loss equal to the value of a herd's entire migration. Proposition 6 also implies that a conservation organization cannot protect a corridor by leasing a single parcel, because a well on any other parcel in J ends the service. Instead, the organization must acquire every parcel of J that could be drilled, so the relevant comparison is between the value of the entire corridor and the cost of acquiring all of those parcels.

Ungulate migrations in western Wyoming have the weakest-link structure in Proposition 6. Pronghorn that summer in Grand Teton National Park travel about 150 kilometers each way to

winter range in the Upper Green River Basin, along a route they have used for at least 6,000 years, and the route passes through a bottleneck at Trappers Point about 2 kilometers wide (Berger et al., 2006). The pronghorn have no other route available, because six other historic routes out of the Greater Yellowstone region have been lost, and about 75 percent of the region's migration routes for elk, bison and pronghorn have disappeared (Berger, 2004; Berger et al., 2006). Mule deer that winter in the Red Desert migrate as far as 150 miles one way to summer range around the Hoback Basin (Sawyer et al., 2014). Migrants time their movements to the spring green-up of forage, so the route is itself foraging habitat as well as a path between seasonal ranges (Aikens et al., 2017). Energy development displaces these animals. On the Pinedale Anticline, mule deer avoided gas infrastructure through 15 years of development without habituating to it, and their abundance fell 36 percent despite directional drilling and other on-site mitigation (Sawyer et al., 2017). A well that blocks a bottleneck may therefore destroy the value of an entire migration, which is the corridor value V_J in Equation (17).

Corollary 1 (Corridor break-even)**.** *Let the parcels of J be grouped into lease units with independent probabilities of production ρ_j, and let an organization hold every unit at the state's break-even in every term. To first order in ρ_j, the value of acquiring the corridor clears the state's break-even bid if*

$$V_J \;\geq\; V_J^* \equiv \frac{\sum_{j\in J} w_j\, D_{E,j}}{\sum_{j\in J} w_j\, \rho_j}, \qquad w_j = \frac{1}{1-\delta(1-\rho_j)\lambda}. \tag{18}$$

Proof: Appendix A.5.

Corollary 1 says that the threshold V_J^* is a weighted average of the single-unit thresholds $D_{E,j}/\rho_j$ from Equation (14), with weights $w_j\rho_j$. Because it is a weighted average rather than a pure sum, it does not grow with the number of units in J. Moreover, the scattered nature of state trust lands means that empirically, many migratory corridors that span many miles contain only a handful of state trust parcels.

A second structure for $\Phi(x; A_C)$ that would imply large conservation value is a population threshold. Habitat may support a species or sub-population only until disturbance passes some level and then fail, and the organization may not know in advance where that level lies. The next proposition derives the implications for the conservation value of leases.

Proposition 7 (Thresholds and the safe minimum standard)**.** *Suppose a well on a parcel in habitat area A pushes the service below a viability threshold with probability q, after which the service is S_E in every future term, and let $V_A \equiv V(S_C) - V(S_E)$.*

(i) The permanent loss from a well satisfies $\Delta u_C^{\infty} \geq q\, V_A$.

(ii) Suppose the organization does not know ρ or q, and it holds the lease in every term whenever paying D_C each term for leases that turn out to be unnecessary is a smaller mistake than declining them and losing V_A, net of the payments it saved. It then holds the lease whenever $D_C \leq (1-\delta)V_A/2$. Neither ρ nor q enters this rule.

Proof: *Appendix A.5*.

Part (i) shows that a well that pushes a population below its viable size costs the organization the value of the entire population rather than just a single parcel's share. Part (ii) characterizes the decision rule under uncertainty about the threshold. Ciriacy-Wantrup (1952) proposed that irreversible losses of this kind be governed by a safe minimum standard that avoids the threshold unless the cost of doing so is immoderate, and Bishop (1978) showed that this standard corresponds to the rule in part (ii), which compares the worst mistake from each choice and is known as minimax regret. Under that rule, the probability of a well does not discount the loss. At the break-even payment $D_C = \kappa D_E$, an organization applying the safe minimum standard will bid enough to win a bottom-decile lease if the habitat is worth more than $2\kappa D_E/(1-\delta)$, or about \$11,000, compared with $D_E/\rho \approx \$596{,}000$ under Equation (14) with $q = 1$.

Greater sage-grouse provide an application of the threshold case in Proposition 7. The species has declined across its range, and the U.S. Fish and Wildlife Service found in 2010 that it warranted protection under the Endangered Species Act before concluding in 2015 that federal and state conservation plans made listing unnecessary (U.S. Fish and Wildlife Service, 2010, 2015). Wyoming is home to an estimated 37 percent of the population and more breeding sites than any other state (Bureau of Land Management, 2015). Sage-grouse breed on leks, display grounds that birds return to each spring. In the Powder River Basin, 38 percent of 26 leks inside coal-bed natural gas fields were still active by 2004–2005, compared with 84 percent of 250 leks outside them, and lek losses followed development with a lag (Walker et al., 2007). Across the species' western range, 99 percent of active leks lie in landscapes with less than 3 percent developed land within 5 kilometers (Knick et al., 2013). Habitat around a lek can therefore fail in response to relatively low levels of development. A well that pushes development past that level may trigger a loss of all the birds that breed on that lek rather than the parcel's share of their habitat, which is part (i) with $q \approx 1$.

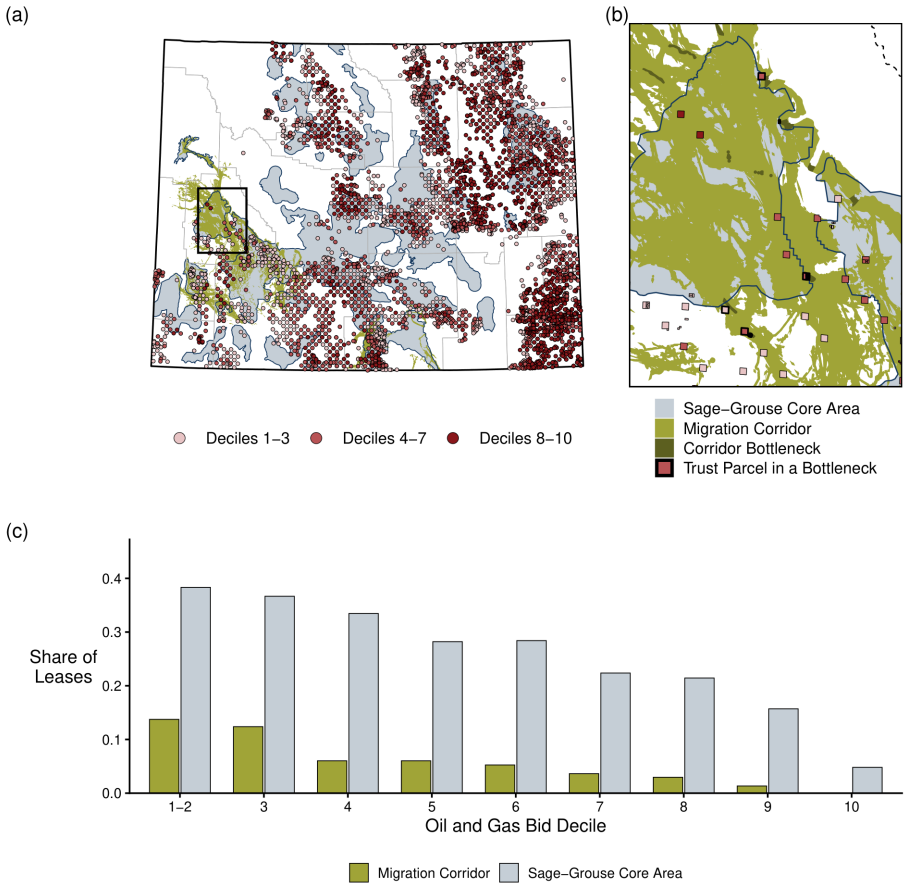
4.3 Habitat characteristics across bid deciles

Section 4.2 implies that the case for a conservation bid is strongest where corridors or critical habitats are concentrated and extraction value is low. The Wyoming Game and Fish Department maps migration corridors for the Sublette pronghorn herd and for the Sublette, Platte Valley and Baggs mule deer herds, in five classes that run from the designated corridor to the bottlenecks where routes converge. The state also maps core areas for sage-grouse leks. We overlay both on the parcels under each lease in our 2009–2019 sample. Figure 6 maps the result and reports, by bid decile, the share of leases that overlap a corridor or a core area.

Across the bid distribution, the break-even conservation bid in Table 5 rises from below zero in the bottom two deciles to \$1,100 per acre in the top decile. Over the same range the share of leases that overlap a migration corridor falls from 14 percent to zero, and the share in a sage-grouse core area falls from 38 percent to 5 percent. The 352 leases that overlap a corridor had a median bid of \$1 per acre, and none of them produced, compared with 180 producers among the other 4,943 leases (3.6 percent). Drilling permits were filed on 1.1 percent of the corridor leases and on 6.1

percent of the others. The parcels on which Proposition 6 gives a conservation organization the most reason to bid are therefore concentrated where the state's opportunity cost is lowest.

Figure 6. Migration Corridors, Sage-Grouse Core Areas and Oil and Gas Leases



Notes: Panel (a) shows each 2009–2019 sample lease as a point at the center of its parcels, shaded by bid decile. Points are not drawn to scale, and higher-bid leases are drawn on top where points overlap. Panel (b) shows the Sublette County bottlenecks, with sample-lease parcels shaded by bid decile (light red deciles 1–3, red 4–7, dark red 8–10). Bottleneck parcels are shaded by the decile of their most recent lease in any year, and parcels last leased over the counter or never leased are in the bottom group, as in Table 6. Core areas are drawn beneath the corridors and outlined in blue. The dashed line is the Sublette County boundary. Panel (c) reports, by bid decile, the share of sample leases with a parcel that overlaps any corridor class or a core area.

We next use Corollary 1 to calculate the break-even corridor valuation V_J^* for each corridor. Twenty trust parcels overlap a mapped bottleneck. We match each to its most recent lease, which yields eight lease units because several parcels were leased together. We assign each lease unit the Table 5 decile of its most recent winning bid, and we place parcels last leased over the counter or never leased in the bottom decile. Table 6 reports V_J^* for each corridor.

For the Sublette pronghorn corridor, an organization would optimally seek to acquire all five lease units at the state's break-even bid if it values the corridor at $2.06 million or more. For the three mapped corridors together, which have eight lease units on their bottlenecks, the break-even valuation is $2.4 to $2.6 million. Ten of the 17 pronghorn parcels were last leased together in 2023

Table 6. Corridor Value That Rationalizes Acquiring Every Bottleneck

Corridor	Lease units	Parcels	Acres	$\sum_j D_{E,j}$	$1 - \prod_j (1 - \rho_j)$	V_J^*
Sublette pronghorn	5	17	2,042	\$147,152	0.070	\$2.06M (\$2.21M)
Sublette mule deer	2	2	720	\$84,883	0.024	\$3.47M (\$3.52M)
Platte Valley mule deer	1	1	640	\$5,076	0.005	\$1.02M
All mapped bottlenecks	8	20	3,402	\$237,110	0.097	\$2.35M (\$2.62M)

Notes: V_J^* from Equation (18), in present value. The value in parentheses uses the exact probability that at least one unit produces in place of the sum of the ρ_j. $D_{E,j}$ is the decile's one-shot oil and gas revenue per acre from Table 5 times the unit's acres. Parcels are those that overlap a bottleneck in the Wyoming Game and Fish Department corridor maps. Each is assigned to its most recent lease.

at \$19 per acre, which places them in the sixth decile, and that is why the pronghorn figure is about twice the \$1 million for a single bottom-decile unit. This calibration also shows when single-period conservation value exceeds single-period extraction value so that Lemma 1 no longer holds. By Proposition 5, this occurs on unit j when V_J exceeds $D_{E,j}/(\kappa_j \rho_j)$. For the two smallest pronghorn units, which cover 121 acres between them, these upper bounds are \$195,000 and \$573,000. At a corridor value of \$2 million, the break-even conservation payment on those two units exceeds single-lease oil and gas revenue, and the agency would maximize revenue by leasing them for conservation in perpetuity.

4.4 Other reasons a conservation organization may bid

This section has focused primarily on determinants of potentially high conservation value that we are able to measure in Wyoming. Several other features of conservation value could raise the permanent loss from a well. We describe them here and develop each in Appendix D. None of them changes the rule in Equation (14), but each depends on information about the organization's donors that we cannot speak to empirically.

The first is the absence of substitutes. Krutilla (1967) argued that natural environments, unlike the outputs of extraction, have few substitutes. Building on this, Hanemann (1991) showed that the elasticity of substitution between an environmental good and other consumption, rather than the good's share of the budget, governs what people will pay to avoid losing it. When a corridor's services have close substitutes, losing the corridor costs donors an amount proportional to its small share of their budget. When those services have no close substitutes, as for a migration route that passes through a single crossing, the loss can be a substantial share of donors' wealth (Proposition 8). Krutilla also argued that the relative value of undisturbed land rises over time as the supply of extraction output grows, which raises the present value of a permanent loss further (Sterner and Persson, 2008).

A natural objection is that risk aversion alone could explain why an organization would pay to remove a small chance of a large loss. Under expected utility, risk aversion raises the payment by a factor that depends on the size of the loss relative to donors' wealth but not on its probability, and that factor is close to one unless the loss is a large share of wealth. Risk aversion therefore adds to the magnitude only where irreplaceability already makes it large, which is the conclusion of the

option-value literature (Schmalensee, 1972; Graham, 1981; Bishop, 1982). By contrast, quasi-option value arises even under risk neutrality. When development is irreversible and information about the value of preservation arrives over time, keeping a parcel undeveloped for another term has value in its own right (Arrow and Fisher, 1974; Henry, 1974). Because a conservation lease delays potential development by one term, quasi-option value raises the lease's value to the organization without changing the structure of the rule.

It is important to note that important forces work in the opposite direction, reducing the conservationists' net willingness-to-pay. Specifically, the value that enters a conservation bid is what the organization can raise from its donors, not the social value of the lease. The values associated with conservation are public goods subject to free-riding, and an organization realizes only part of the value its potential donors place on the corridor (Abbott et al., 2025). This is consistent with conservation bids being rare even where Proposition 6 implies a large loss. It also bears on Lemma 1 because a lease whose social value would violate the conclusion of the lemma on some parcels may still satisfy it once free riding is taken into account. A related practical implication is that conservation budgets are often constrained. An organization with a limited budget must also choose which leases to acquire. The organization should hold leases in decreasing order of the ratio of their value to the break-even value, which is the criterion of Weitzman (1998).

4.5 Does leasing without drilling disturb the surface?

Our theoretical model assumes that an oil and gas lease that does not lead to production returns the parcel to the agency undisturbed. Exploration, failed wells, and access roads could disturb the surface even when there is no producing well. In this case, part of the value of a conservation lease could derive from averting these transitory impacts, in addition to the expected permanent disturbance associated with a well. Because any surface disturbance from leasing alone increases what a conservation lease is worth to the organization, ignoring this channel outside the model makes the threshold in Equation (14) an upper bound on the permanent loss a well must cause to rationalize break-even conservation bids.

To see whether pre-drilling activity drives surface disturbance, Appendix C tracks all state trust mineral parcels using satellite land-cover data (NLCD, 2001–2021) and quarterly cell phone pings (2019–2025). While a first spud raises the probability of developed land on a parcel by 45.7 percentage points, an un-drilled lease shifts it by just 0.11 percentage points (SE = 0.08) and brings no clear rise in cell phone traffic. Without a rig, a lease leaves the surface largely untouched. For low-bid leases, the expected disturbance from drilling and non-drilling looks similar on a per-lease basis, but only because so few of them are ever drilled. In the bottom two deciles, just 0.43 percent of leases see a spud—translating to 0.20 percentage points of developed land per lease from drilling, versus 0.11 from leasing alone. Because that 0.11 estimate is noisy and the satellite data picks up any cleared pixel alongside full well pads, we do not adjust Equation (14), treating the existing threshold as conservative.

5 Conclusion

We derive the conservation bid at which a revenue-maximizing agency should prefer a conservation lease to an extractive one, and we apply it to oil and gas leasing on Wyoming state trust land. Because a finite conservation lease delays extraction rather than permanently removing the resource stock, its opportunity cost to the public agency is the cost of delaying extraction net of the salvage value that conservation preserves. Both quantities must be estimated for state agencies to make accurate comparisons across different types of bids.

In our empirical analysis of Wyoming oil and gas auctions, winning bonus bids by energy firms strongly predict both the probability of drilling and net present royalty revenue, but that relationship is highly skewed. Most expected production and royalty revenue comes from the top 10 percent of leases, with bids above $500 per acre, whereas across the bottom half of the bid distribution upfront bids and annual rental payments account for more than 98 percent of expected state revenue from the average lease and the break-even conservation bid is below $10 per acre. In the bottom three deciles, any positive bid by a conservationist maximizes expected revenue for the state. Because the parcels with the lowest opportunity cost to the state are those least likely to be drilled—and because leasing without drilling causes no detectable permanent surface disturbance—the case for purchasing a conservation lease rests on the magnitude of the permanent loss that a well would cause. When a parcel lies in a migration bottleneck or supports a population near an uncertain ecological threshold, even a small probability of drilling can justify a conservation bid well above the state's break-even threshold. In Wyoming, mapped migration corridors and sage-grouse core areas are concentrated in the lowest deciles of the oil and gas bid distribution, indicating that the parcels with the highest ecological sensitivity are often those with the lowest extractive opportunity cost.

These findings add nuance to recurring debates over energy development and conservation on public lands. Industry groups and Western state officials have opposed recent federal and state proposals to allow conservation leasing out of concern that non-use leases would lock up productive energy acreage and reduce public revenues (Abbott et al., 2025). Our empirical results suggest that requiring conservation bidders to meet a revenue-equivalent price could address this concern. On high-bid tracts in proven energy basins, accounting for expected royalties raises the break-even conservation bid above $1,000 per acre in the top decile (and above $3,000 per acre if conservationists must cover royalties without a salvage credit), making it unlikely that donor-funded conservation groups would displace profitable oil and gas production where energy values are highest. Conversely, a large share of public oil and gas leases are low-probability exploratory tracts that generate minimal expected royalties. Allowing conservation bidders to compete on these tracts under a revenue-neutral pricing rule protects the government's fiscal position while shifting the lowest-value energy leases toward habitat conservation when donor willingness to pay exceeds the state's break-even threshold.

Our framework also points to practical ways that state trust land boards and federal agencies

such as the Bureau of Land Management could implement conservation pricing without having to forecast subsurface reserves on each parcel in advance. Because private oil and gas bids aggregate firms' geological information at auction, an agency that observes competing bids can use the empirical relationship between bonus bids and expected royalties to score oil and gas bids and conservation bids on an equivalent present-value basis. Where awarding a lease to a conservation group whose nominal upfront bid is lower than an extractive bidder's raises political or legal objections—as can occur in timber or low-bid oil and gas auctions when the salvage credit is applied upfront—the agency can instead require the conservation bidder to pay the full one-shot break-even amount upfront and issue a refund at the end of the lease term conditional on the resource remaining intact. Even a simpler administrative rule would capture most of the potential gains in our setting. Because the break-even conservation bid is negative in the bottom three deciles of the oil and gas bid distribution and below $10 per acre across the bottom half, simply allowing qualified conservation organizations to bid in standard auctions subject to a modest reserve price (or on parcels that would otherwise be leased at $1 per acre, the winning bid on 27 percent of the leases in our sample) would increase public revenue while opening 80 percent of the leases that overlap mapped migration corridors and two-thirds of those in sage-grouse core areas to voluntary conservation.

There are several caveats to our findings that lead to opportunities for future research. First, our condition for a conservation lease to maximize public revenue relies on the willingness to pay that a conservation organization can raise from its donors rather than the full social value of preservation. Because habitat protection is a public good subject to free-riding, private conservation bids will generally understate social damages from development (Abbott et al., 2025). As a result, clearing the state's break-even bid is a sufficient condition for a conservation lease to improve social welfare, but free-riding may still prevent conservation groups from winning leases on some parcels where social conservation value exceeds extractive value. Second, state trust lands are typically scattered in one-square-mile sections across a mosaic of federal and private ownership, and our well data show that producing leases in the highest bid deciles are often developed via directional drilling or pooling units from adjacent parcels. Protecting a weakest-link migration corridor or a sage-grouse lek in practice therefore requires coordinating conservation leases on state parcels with federal land management and private conservation easements on neighboring land. Future research could test whether donor-funded organizations are willing to pay these break-even amounts in live or experimental auctions and examine how recent increases in federal onshore oil and gas minimum bids, rental rates, and royalty rates under the Inflation Reduction Act of 2022 alter the opportunity cost of conservation on federal mineral estates. Extending our framework to renewable energy leasing on public lands—where wind and solar projects entail certain, immediate surface occupation ($\rho = 1$) rather than probabilistic drilling—is another natural next step.

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A Proofs

A.1 Proof of Lemma 2

Let $a = D_E(x_E)$, $b = D_C(x_E)$, $c = D_E(x_C)$, and $d = D_C(x_C)$. By Assumption 1 and per Lemma 1, we have $c > a$, $d > b$, $c > d$, and $a \geq b$, with $a = b = 0$ when $x_E = 0$. Out to $k = 2$, there are 8 possible payoffs depending on the sequence of extraction or conservation choices:

$$\begin{aligned} V(e,e,e) &= c + \delta a + \delta^2 a \\ V(e,e,c) &= c + \delta a + \delta^2 b \\ V(e,c,e) &= c + \delta b + \delta^2 a \\ V(e,c,c) &= c + \delta b + \delta^2 b \\ V(c,e,e) &= d + \delta c + \delta^2 a \\ V(c,e,c) &= d + \delta c + \delta^2 b \\ V(c,c,e) &= d + \delta d + \delta^2 c \\ V(c,c,c) &= d + \delta d + \delta^2 d \end{aligned} \tag{19}$$

By the assumptions above, five of these eight payoffs can be eliminated, leaving just:

$$\begin{aligned} V(e,e,e) &= c + \delta a + \delta^2 a \\ V(c,e,e) &= d + \delta c + \delta^2 a \\ V(c,c,e) &= d + \delta d + \delta^2 c \end{aligned} \tag{20}$$

which says the agency either leases for extraction right away ($k = 0$), waits one period and then leases for extraction ($k = 1$), or waits two periods and then leases for extraction ($k = 2$). This is a useful recursive structure, as depending on which period k the parcel is leased for extraction, the discounted revenue can be expressed as:

$$\begin{aligned} V_k &= \sum_{t=0}^{k-1} \delta^t d + \delta^k (c + \sum_{t=1}^{\infty} \delta^t a) \\ &= \frac{1-\delta^k}{1-\delta} d + \delta^k (c + \frac{\delta}{1-\delta} a) \end{aligned} \tag{21}$$

where $V_0 = c + \frac{\delta}{1-\delta} a$ is the revenue from leasing for extraction immediately.

A.2 Proof of Proposition 3

In order for a conservation lease to be revenue-maximizing today, it must be the case that waiting to extract for an arbitrary n periods is better than extracting right now at k. From Lemma 2, this is

true if $V_{k+n} > V_k$, which is true if:

$$\begin{aligned}
\frac{1-\delta^{k+n}}{1-\delta}d + \delta^{k+n}(c + \frac{\delta}{1-\delta}a) &> \frac{1-\delta^{k}}{1-\delta}d + \delta^{k}(c + \frac{\delta}{1-\delta}a) && (22)\\
(\frac{1-\delta^{k+n}}{1-\delta} - \frac{1-\delta^{k}}{1-\delta})d &> (\delta^k - \delta^{k+n})(c + \frac{\delta}{1-\delta}a) && (23)\\
(1-\delta^{k+n} - 1 + \delta^k)d &> (1-\delta)(\delta^k - \delta^{k+n})(c + \frac{\delta}{1-\delta}a) && (24)\\
d &> (1-\delta)(c + \frac{\delta}{1-\delta}a) && (25)
\end{aligned}$$

Going back to the original definitions, then we have a winning conservation bid if:

$$B_C(x_C) > (1-\delta)(B_E(x_C) + R_E(x_C)) + \delta(B_E(x_E) + R_E(x_E)) \tag{26}$$

A.3 Proof of Proposition 4

Just like in the proof of Proposition 3, only $V(e,e,e)$, $V(c,e,e)$, or $V(c,c,e)$ are plausible decisions given the assumptions. This problem has the recursive structure as above (extract immediately, conserve once and then extract, conserve twice and then extract, and so on), with the distinction that (a) with probability $(1-\rho)\lambda$, an extraction lease that was unproductive is re-leased (with the stock variable remaining pristine x_C), and (b) with probability ρ the lease produces oil and gas and there is no future lease value. Rent is collected only while a lease is in force, so each oil and gas lease pays $D_E(x_C) = B_E(x_C) + F + \rho R_E(x_C)$ and each conservation lease pays $D_C(x_C) = B_C(x_C) + F$. This allows us to write down a "switch to oil in lease k" expression as:

$$\begin{aligned}
V_k^o &= \sum_{t=0}^{k-1} \delta^t D_C(x_C) + \delta^k D_E(x_C) \sum_{t=0}^{\infty} \delta^t (1-\rho)^t \lambda^t && (27)\\
&= \frac{1-\delta^k}{1-\delta} D_C(x_C) + \frac{\delta^k D_E(x_C)}{1-\delta(1-\rho)\lambda}
\end{aligned}$$

Again, conservation leasing is revenue maximizing if it is better to wait to lease for oil and gas for an arbitrary n leases rather than extracting right now at k. This is true if $V_{k+n}^o > V_k^o$, which is true if:

$$\begin{aligned}
(\frac{1-\delta^{k+n}}{1-\delta} - \frac{1-\delta^{k}}{1-\delta})D_C(x_C) &> (\delta^k - \delta^{k+n})\frac{D_E(x_C)}{1-\delta(1-\rho)\lambda} && (28)\\
D_C(x_C) &> \frac{1-\delta}{1-\delta(1-\rho)\lambda} D_E(x_C) = \kappa D_E(x_C) && (29)
\end{aligned}$$

Substituting $D_C = B_C + F$ and $D_E = B_E + F + \rho R_E$ gives $B_C(x_C) > \kappa\big(B_E(x_C) + \rho R_E(x_C)\big) - (1-\kappa)F$.

A.4 Proof of Proposition 5

Suppose the parcel is leased for oil and gas now and in every later term in which it is still pristine and returns to auction. In each term the lease produces with probability ρ, in which case the organization loses Δu_C^∞. Otherwise the parcel returns to auction with probability λ and leaves the pool pristine with probability $1-\lambda$. The expected present value of the organization's loss is therefore

$$L = \rho\,\Delta u_C^\infty \sum_{t\geq 0} \big[\delta(1-\rho)\lambda\big]^t = \frac{\rho\,\Delta u_C^\infty}{1-\delta(1-\rho)\lambda}.$$

If the parcel is instead held under one conservation lease, it returns to auction pristine one term later and faces the same process, so the expected loss is δL. One conservation lease is worth $L - \delta L - D_C = (1-\delta)L - D_C = \kappa\rho\,\Delta u_C^\infty - D_C$, which is part (i).

For part (ii), competitive bidding drives v_C to zero, so the conservation organization pays $D_C = \kappa\rho\,\Delta u_C^\infty$. By Proposition 4 the conservation lease maximizes public revenue if and only if $D_C \geq \kappa D_E(x_C)$, which is $\rho\,\Delta u_C^\infty \geq D_E(x_C)$.

For part (iii), holding the parcel in every term costs $D_C/(1-\delta)$ and avoids the loss L, so the organization's value is $L - D_C/(1-\delta) = v_C/(1-\delta)$, which has the same sign as v_C. □

A.5 Proofs of Propositions 6 and 7 and Corollary 1

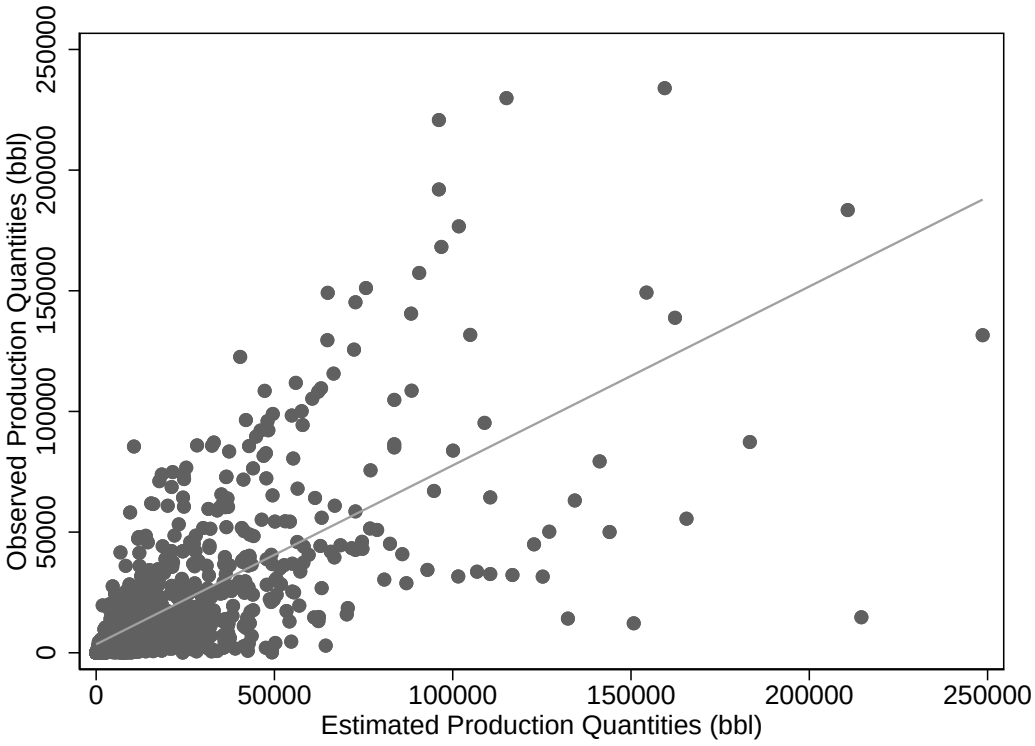
With every parcel of J pristine, $\min_{j\in J} x_j = x_C$ and $S = S_C$. A well on any single $j \in J$ sets $\min_{j\in J} x_j = x_E$ and $S = S_E$, whichever parcel it is, so the loss is $V(S_C) - V(S_E)$ and depends only on S_C and S_E.

For the corollary, an organization that holds unit j at the state's break-even pays $D_{C,j} = \kappa_j D_{E,j}$ per term, and holding it forever costs $\kappa_j D_{E,j}/(1-\delta) = w_j D_{E,j}$ in present value. If the organization holds nothing, unit j follows the oil and gas path of Proposition 4. In each term it produces with probability ρ_j and otherwise returns to auction with probability λ, so the present value of the probability that unit j is eventually drilled is $\rho_j \sum_{t\geq 0}[\delta(1-\rho_j)\lambda]^t = w_j\rho_j$. A well on any unit costs V_J by Proposition 6. Ignoring the event that two units are drilled, which is of second order in ρ, the expected present-value loss from holding nothing is $V_J \sum_j w_j\rho_j$. Holding every unit clears the break-even when this loss is at least $\sum_j w_j D_{E,j}$, which is Equation (18). □

For Proposition 7, part (i) follows because with probability q the service falls from S_C to S_E in every future term, a loss of V_A, and with probability $1-q$ the loss is non-negative. For part (ii), the organization either acquires the parcel in every term or does not acquire it at all, and there are two states. In the first a well is eventually drilled and crosses the threshold, and in the second it is not. Holding costs $D_C/(1-\delta)$ in present value in both states. Not holding costs V_A in the first state and nothing in the second. The regret from holding is therefore $D_C/(1-\delta)$, incurred in the second state, and the regret from not holding is $V_A - D_C/(1-\delta)$, incurred in the first. Minimax regret holds the lease when $D_C/(1-\delta) \leq V_A - D_C/(1-\delta)$, that is, when $D_C \leq (1-\delta)V_A/2$. Neither ρ nor q appears, because the rule compares worst cases rather than expected values. □

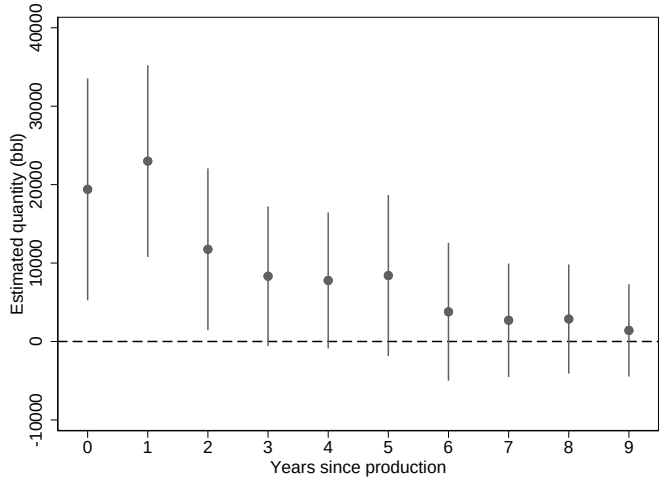
B Appendix figures and tables

Figure B1. Predicted and Observed Production



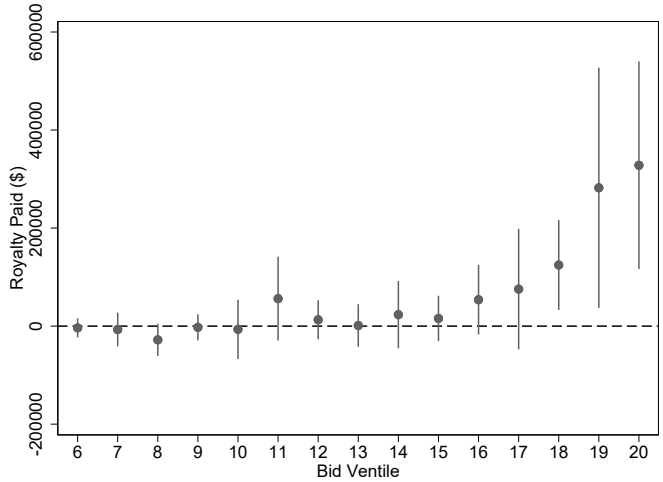
Notes: Each point is a producing lease-year from 2010–2024. Observed production is implied by annual royalties, the royalty rate and the Cushing WTI spot price. Predicted production starts from the lease's peak year, declines about 13 percent per year and is scaled by 0.576, as described in Section 3. Lease-years with observed production above 250,000 barrels (7 of 1,164) are not shown. The line is a linear fit.

Figure B2. Production by Years Since Production Began



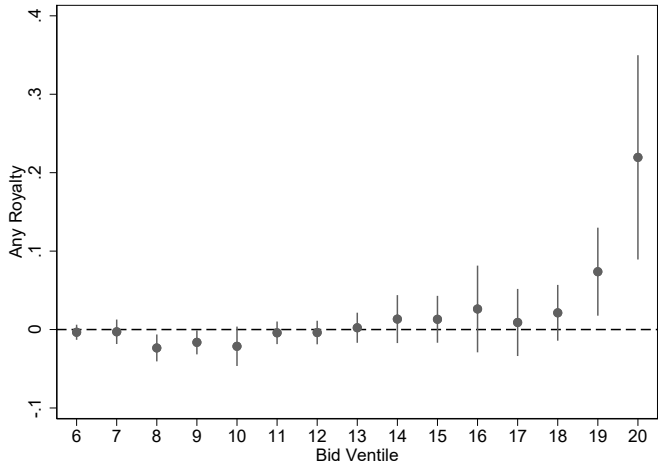
Notes: Coefficients on indicators for years since production began, from a regression of estimated annual production (barrels) on those indicators and lease fixed effects over the first ten years of production. Year 10 is the omitted category. Bars are 95 percent confidence intervals with standard errors clustered by lease.

Figure B3. Royalties Paid by Bid Ventile



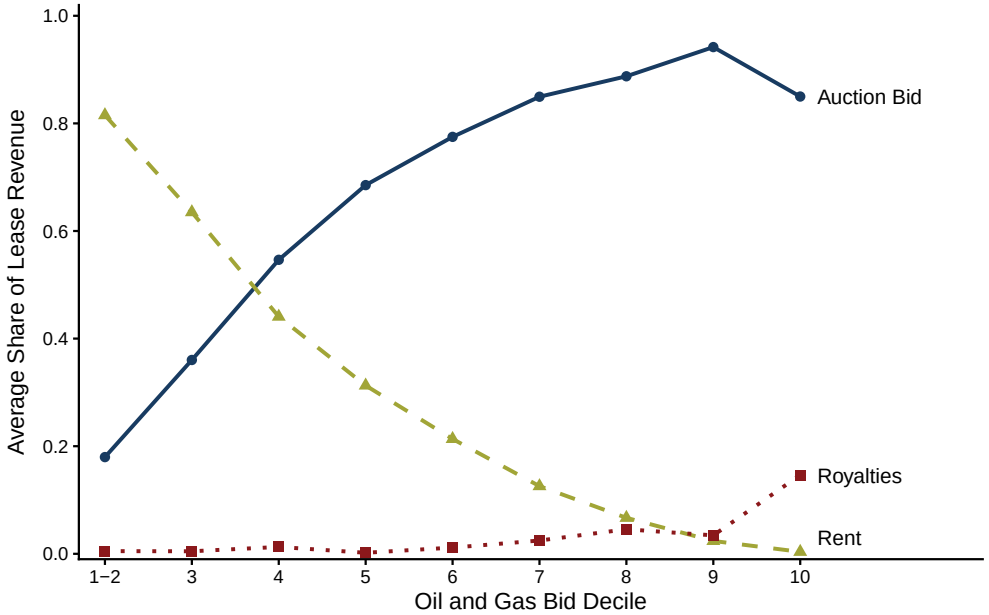
Notes: Coefficients on bid-ventile indicators from Equation (12) with ventiles in place of deciles, relative to ventiles 1–5, all of which bid $1 per acre. Bars are 95 percent confidence intervals with standard errors clustered by county.

Figure B4. Share of Leases That Pay Any Royalties by Bid Ventile



Notes: Coefficients on bid-ventile indicators from Equation (12) with ventiles in place of deciles and an indicator for any royalties as the outcome, relative to ventiles 1–5, all of which bid $1 per acre. Bars are 95 percent confidence intervals with standard errors clustered by county.

Figure B5. Revenue Shares by Bid Decile with Expected Future Royalties



Notes: As in Figure 3, except that every producing lease is assigned $1.8 million in royalties, the present value at 5 percent of a 30-year well that yields $312,628 in its first year and declines about 13 percent per year.

Table B1. Probability of Production and of a New Well on the Lease, 2009–2019 Auctions

Bid decile	Leases	Produced (ρ)	New well on own surface	Rate	Of which never produced
1–2	1,404	0.0050	6	0.0043	2
3	210	0.0048	1	0.0048	0
4	547	0.0128	8	0.0147	4
5	514	0.0019	4	0.0078	3
6	514	0.0117	8	0.0156	4
7	523	0.0249	7	0.0134	2
8	541	0.0462	12	0.0222	5
9	522	0.0364	12	0.0230	4
10	520	0.1942	26	0.0501	1

Notes: A new well is one spudded on the surface of the lease's own parcels during the lease term. Of the 180 producing leases, 59 have such a well, 43 are drilled under from a pad on another parcel, and 78 have neither, mostly because they produce from wells that predate the lease. Well records are from the Wyoming Oil and Gas Conservation Commission, and 5,283 of the 5,295 sample leases match. The rate divides by the leases in each decile that match.

Table B2. Auction Bids by Bonus Bid Quartile, Decile, and Ventile

Bid quartiles	AuctionBidPerAcre (mean)	AuctionBidPerAcre (median)	AuctionBidPerAcre (min)	AuctionBidPerAcre (max)
1	1	1	1	1
2	7	7	2	12
3	30	27	13	57
4	826	302	58	15,001
deciles				
1-2	1	1	1	1
3	3	3	2	3
4	6	6	4	7
5	10	10	8	12
6	17	17	13	22
7	32	31	23	43
8	63	58	44	100
9	227	201	101	500
10	1,822	1,300	501	15,001
ventiles				
1-5	1	1	1	1
6	3	3	2	3
7	5	5	4	6
8	7	7	7	7
9	9	9	8	10
10	11	11	11	12
11	14	14	13	16
12	19	20	17	22
13	27	26	23	30
14	36	36	31	43
15	51	52	44	57
16	75	75	58	100
17	130	124	101	193
18	315	302	195	500
19	772	700	501	1,258
20	2,840	2,350	1,273	15,001

Notes: Winning bids in dollars per acre for the 5,295 leases auctioned 2009–2019. Quartiles, deciles and ventiles are defined over all leases. Deciles 1 and 2 and ventiles 1–5 all bid $1 per acre and are pooled.

Table B3. Minimum Conservation Bids Required—All Scenarios

	Average O & G revenues (NPV)				
Decile	Auction	Rental	Royalty	Acres	Prob production
1 and 2	376	1704	902	376	0.0050
3	1035	1776	188	392	0.0048
4	2300	1809	7692	398	0.0128
5	4040	1821	163	401	0.0019
6	6820	1837	43299	403	0.0117
7	12164	1758	18266	387	0.0249
8	24268	1727	54353	379	0.0462
9	79757	1679	100466	369	0.0364
10	535602	1453	432202	311	0.1942

	Conservationist needed bid (total) by scenario				
Decile	Cover royalties	10-year lease	5-year lease	5-year repeat, $\lambda = 1$	5-year repeat, $\lambda = 0.6$
1 and 2	1277	-1858	-1045	1226	-472
3	1223	-1979	-1112	1173	-536
4	9992	1426	802	9483	3037
5	4203	-869	-488	4162	676
6	50119	17176	9656	48068	19518
7	30431	9538	5362	27840	11322
8	78621	28543	16046	67378	30336
9	180223	68586	38558	159560	71515
10	967804	378788	212946	574167	342422

	Conservationist needed bid per acre by scenario				
Decile	Cover royalties	10-year lease	5-year lease	5-year repeat, $\lambda = 1$	5-year repeat, $\lambda = 0.6$
1 and 2	3.4	-4.9	-2.8	3.3	-1.3
3	3.1	-5.0	-2.8	3.0	-1.4
4	25.1	3.6	2.0	23.8	7.6
5	10.5	-2.2	-1.2	10.4	1.7
6	124.5	42.7	24.0	119.4	48.5
7	78.5	24.6	13.8	71.9	29.2
8	207.4	75.3	42.3	177.8	80.0
9	488.2	185.8	104.5	432.3	193.7
10	3108.0	1216.4	683.9	1843.9	1099.7

Notes: Minimum conservation bids that return at least as much revenue to the state in present value. Every scenario except "Cover Royalties" charges the conservation organization the rent F for each term it holds the lease. The 10-year lease is a hypothetical conservation lease of two five-year terms, followed by one oil and gas lease ($\lambda = 0$). Wyoming oil and gas leases run five years. The 5-year lease applies Proposition 4 with $\lambda = 0$. The two 5-year repeat columns apply Proposition 4 with unproductive parcels always re-leased ($\lambda = 1$) and re-leased with probability 0.6 ($\lambda = 0.6$, as in Table 5). Negative values imply that any positive bid should be accepted.

Table B4. Revenue and the Probability of Production across Bid Deciles

Dependent variable (log, per acre)	(1) B_E	(2) $B_E + \rho R_E$	(3) D_E	(4) D_E/ρ
$\log \rho$	1.42	1.50	1.33	0.33
	(0.31)	(0.26)	(0.21)	(0.21)
Constant	9.04	10.32	9.86	9.86
	(1.35)	(1.14)	(0.92)	(0.92)
p-value, proportional to ρ	0.22	0.10	0.17	0.17
R^2	0.75	0.83	0.85	0.25
Observations	9	9	9	9

Notes: Each column regresses the log of a revenue component on the log probability of production, $\log \rho$, across the nine decile groups in Table 5 (deciles 1 and 2 combined). Column (1) is the auction bid, column (2) adds expected royalties, column (3) adds rent to give single-lease revenue $D_E = B_E + F + \rho R_E$, and column (4) is the threshold D_E/ρ in Equation (15). Revenues are present values from Table 5 divided by mean acres per lease in Table B3. Column (4) equals column (3) less $\log \rho$, so the two share a constant and a standard error. Conventional standard errors in parentheses. The p-value tests a slope of 1 in columns (1)–(3) and a slope of 0 in column (4), which is the case in which ρ cancels from D_E/ρ.

C Surface disturbance from leasing without drilling

Section 4.5 summarizes this appendix. The model in Section 4.1 assumes that an oil and gas lease that is not drilled leaves the surface of the parcel as it found it. This appendix describes the data and design we use to test that assumption and reports the results.

C.1 Data

Parcels and leases. The unit of observation is the state trust mineral parcel, of which there are 21,544. A lease covers about two parcels on average, and a parcel has been under about two leases over time, and we treat parcels leased twice as one parcel with two lease spells. Lease spells come from the same Office of State Lands and Investments records as the auction sample in Section 3. We obtain data on actual wells and their spud dates come from the Wyoming Oil and Gas Conservation Commission. We use only wells whose surface location lies inside the parcel, and we drop parcels developed from a pad on another parcel rather than placing them in the comparison group.

Land cover. We compute, for every parcel, the share of 30-meter pixels in each land-cover class of the National Land Cover Database (Homer et al., 2020; Dewitz, 2023). The headline outcome is an indicator that any pixel on the parcel is classified as developed. The legacy product classifies each of nine epochs independently (2001, 2004, 2006, 2008, 2011, 2013, 2016, 2019 and 2021), so a well pad that appears between two epochs cannot be spread across earlier years. We also use the annual product, which assigns a class to every year using each pixel's full time series (Fleckenstein et al., 2026; U.S. Geological Survey, 2024). The annual product interpolates between years in the legacy product, however.

Human presence. Spectus supplied counts of mobile devices observed on each parcel in each month from 2019 to 2025, which we aggregate to quarters. Because 93.5 percent of parcel-quarters are zero, we use the inverse hyperbolic sine of the count, and we report an indicator for any presence as a check. The presence data can detect activity that does not affect land cover, such as surveying, staking or travel on an existing road, but they only begin in 2019.

C.2 Design

Leasing is not an absorbing treatment. Parcels go on and off lease, and most leased parcels have more than one leasing spell, so we estimate stacked difference-in-differences regressions (Cengiz et al., 2019; Wing et al., 2024). Each cohort s of lease openings forms a stack containing its treated parcels and a comparison group of parcels with no lease opening and no well inside the cohort's

window. Within stack s we estimate

$$y_{ist} = \alpha_{is} + \gamma_{st} + \sum_{k \neq -1} \beta_k \, \mathbf{1}[t - E_s = k] \, D_{is} + \varepsilon_{ist}, \tag{30}$$

where y_{ist} is the outcome on parcel i in period t, α_{is} and γ_{st} are stack-by-parcel and stack-by-period fixed effects, E_s is the cohort's event period and D_{is} indicates a treated parcel. Event time counts observed periods, which are land-cover epochs or quarters. Standard errors are clustered by township, of which there are about 2,100. Clustering by county, of which there are 23, gives similar inference (Table C1).

Our primary leasing specification retains a treated parcel only while the initiating lease remains active and drops any parcel whose event window contains a spud. This estimate therefore describes a parcel that is leased and not drilled, which is the counterfactual relevant to a conservation lease. Because dropping drilled parcels conditions on an outcome realized after the lease opens, we also report a specification that retains every newly leased parcel. A null on leasing is informative only if the outcome and the design can detect disturbance when it occurs, so we estimate the same regression with the first spud on a parcel as the event.

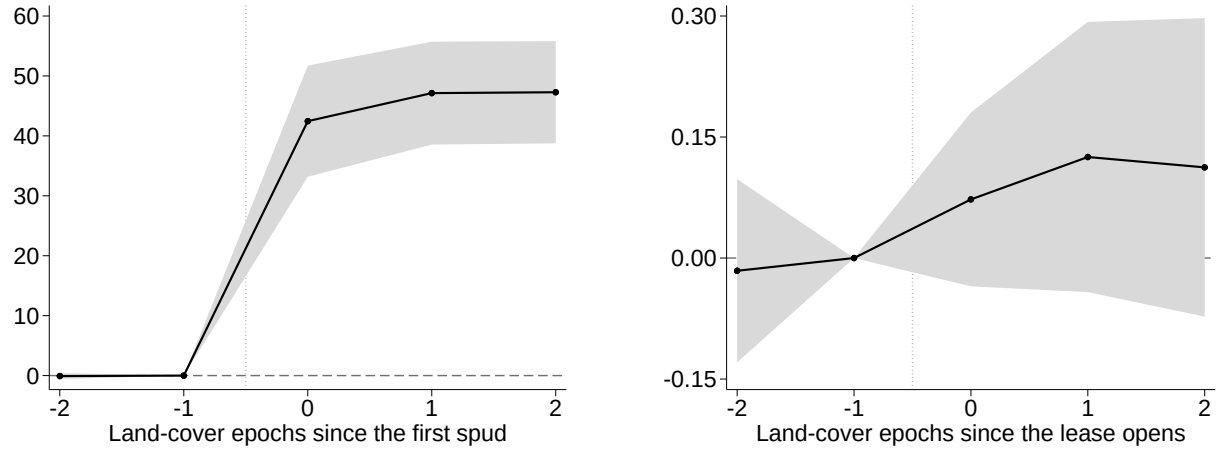
C.3 Results

Figure C1 reports the land-cover results. A spud raises the probability that a parcel contains developed land by 45.7 percentage points (standard error 4.4), a 257 percent increase on the pre-period mean of 17.8 percent, and almost all of the change appears in the first epoch after the well. A lease opening on a parcel that is not drilled raises the same probability by just 0.11 percentage points (standard error 0.08), or 0.6 percent of the mean. In both panels the coefficient two epochs before the event is close to zero. The leasing effect is 0.24 percent of the spud effect, with a 95 percent confidence interval from -0.10 to 0.59 percent.

Using the annual NLCD product yields a similar leasing estimate, 0.08 percentage points (standard error 0.12), but a much smaller spud benchmark of 5.7 percentage points that rises for several years before the well. The annual product assigns each year's class using the pixel's full multi-year record, so this pattern is consistent with the classifier spreading a well across neighboring years. Site preparation before the spud could produce a similar rise, but the legacy epochs show no such rise before the well. On the annual product the upper end of the confidence interval on the leasing effect is 5.7 percent of the spud effect.

Figure C2 plots human presence around lease openings over the five-year primary term, compared with parcels that are never leased. Presence is flat for the first two years of a lease and rises after that. The average effect over the term is 0.023 (standard error 0.016), about a fifth of the comparison mean of 0.116. Comparing parcels leased now with parcels leased later gives 0.022 (standard error 0.019), and the effect on the probability of any presence is 0.003 (standard error 0.006). We cannot benchmark these estimates to the impact of the spudding of a new well in the

Figure C1. Developed Land Cover around a Well and around a Lease



(a) The first spud on the parcel

(b) A lease opening on ground not yet drilled

Notes: Coefficients β_k from Equation (30), in percentage points, for an indicator that any 30-meter pixel on the parcel is classified as developed in the legacy National Land Cover Database. Event time counts land-cover epochs, and the epoch before the event is omitted. Shaded bands are 95 percent confidence intervals clustered by township. Panel (b) keeps a parcel only while it is leased and not drilled. Its vertical scale is about one two-hundredth of the scale in panel (a).

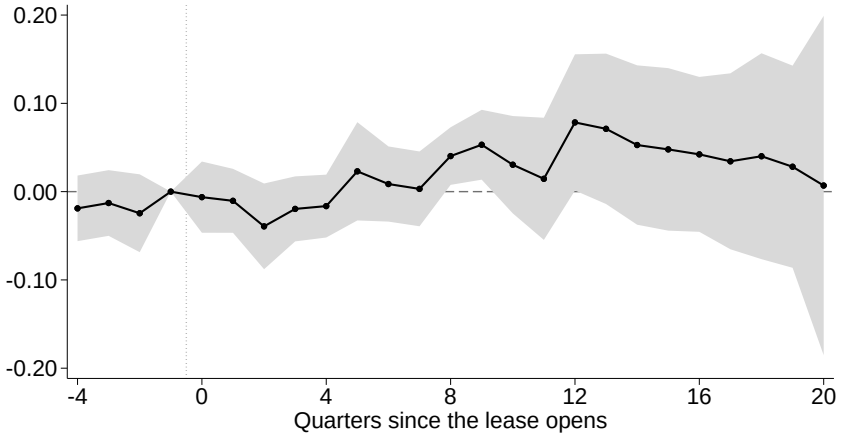
same way we could for the NLCD data because only 18 parcels are spudded after it begins, and none of the lease windows it contains includes a spud (e.g., the 18 spuds we do see are associated with leases that began before 2019). Within those 18 parcels a spud raises presence by 1.32 (standard error 0.32), which shows that the measure responds to drilling. The upshot is that the presence data provide weak evidence of transient activity on leased parcels that leaves no mark on land cover.

Table C1. Surface Disturbance from a Well and from a Lease

Outcome and product	Event	Estimate	SE (township)	SE (county)	Treated parcels
Any developed, legacy	First spud	0.4566	0.0440	0.0575	399
Any developed, legacy	Lease, not drilled	0.0011	0.0008	0.0006	5,919
Any developed, legacy	Lease, all	0.0019	0.0014	0.0014	6,165
Any developed, annual	First spud	0.0570	0.0088	0.0168	825
Any developed, annual	Lease, not drilled	0.0008	0.0012	0.0011	9,800
Presence (asinh), quarterly	Lease, never-leased controls	0.0230	0.0160	0.0126	464
Presence (asinh), quarterly	Lease, leased-later controls	0.0220	0.0186	0.0205	773
Any presence, quarterly	Lease, never-leased controls	0.0033	0.0062	0.0056	464

Notes: Average post-event coefficients from Equation (30). Land-cover outcomes are indicators, so 0.0011 is 0.11 percentage points. "Lease, not drilled" keeps a parcel only while it is leased and not drilled. "Lease, all" keeps every newly leased parcel. Leased-later controls are parcels leased after the cohort's window, so that only the timing of leasing identifies the effect.

Figure C2. Human Presence around the Opening of a Lease



Notes: Coefficients β_k from Equation (30) for the inverse hyperbolic sine of the number of people present on the parcel in the quarter, 2019–2025. The comparison group is ground never leased, parcels already under lease in 2019 are excluded, and a parcel leaves a stack at a spud or a second lease opening. There are 464 treated parcels. Shaded bands are 95 percent confidence intervals clustered by township.

C.4 Per well and per lease

The comparisons above are per event. A conservation lease buys protection per lease. A well occurs only on a fraction of leases, but every lease that is not drilled contains the leasing effect. Table C2 puts the two on the same footing by multiplying the spud effect by the probability that a new well is spudded on the lease's own surface (Table B1). In the bottom two deciles wells add about 0.20 percentage points of developed land per lease, and leasing alone adds 0.11, with a confidence interval that runs from below zero to 0.27. Across all leases and in the top decile the leasing effect is a small share of the well effect. Two features of the outcome limit what the per-lease comparison means. The leasing estimate is not distinguishable from zero, and an indicator for any developed pixel cannot distinguish a cleared site from a producing pad. Since any disturbance from leasing alone adds to what a conservation lease buys, we do not adjust the threshold in Equation (14) and treat it as conservative.

Table C2. Developed Land Cover per Lease from Wells and from Leasing Alone

	New well on own surface	From wells (pp)	From leasing alone (pp)	Ratio
Deciles 1–2	0.0043	0.20	0.11 (−0.05, 0.27)	0.56
All leases	0.0159	0.73	0.11 (−0.05, 0.27)	0.15
Decile 10	0.0501	2.29	0.11 (−0.05, 0.27)	0.05

Notes: "From wells" is the probability of a new well on the lease's own surface times the legacy spud effect of 45.7 percentage points. "From leasing alone" is the legacy estimate for a lease that is not drilled, with its 95 percent confidence interval. The ratio uses the point estimates.

D Other reasons the permanent loss may be large

Section 4.4 describes the mechanisms in this appendix qualitatively. The main text keeps to the results we can calibrate with Wyoming data, and this appendix examines four further reasons a conservation organization may place a large value on the permanent loss Δu_C^{∞} from a well, in addition to a result on how an organization with a limited budget should choose among corridors.

D.1 Irreplaceability

Krutilla (1967) argued that natural environments, unlike the outputs of extraction, have few substitutes. Building on this, Hanemann (1991) showed that the elasticity of substitution between an environmental good and other consumption, rather than the good's share of the budget, governs what people will pay to avoid losing it. Proposition 8 applies the second result to any service a well could end, such as a migration corridor or a breeding population.

Proposition 8 (Irreplaceability)**.** *Let donors have CES preferences over a conservation service S and a numeraire, with elasticity of substitution σ, share parameter α and wealth y, and let $\eta = (\sigma-1)/\sigma$. If a well reduces the service from S_C to S_E, the permanent loss to donors is*

$$V(S_C) - V(S_E) = y - \left[y^{\eta} - \tfrac{\alpha}{1-\alpha}\left(S_C^{\eta} - S_E^{\eta}\right)\right]^{1/\eta} \tag{31}$$

when the bracket is positive, and y otherwise. Moreover,

(i) if $\sigma < 1$, then $V(S_C) - V(S_E) \to y$ as $S_E \to 0$, and as $\sigma \to 0$, $V(S_C) - V(S_E) \geq y\,(1 - S_E/S_C)$ whenever the service is the binding input at (S_C, y);

(ii) if $\sigma \geq 1$ and α is small, $V(S_C) - V(S_E)$ is proportional to α, and at $\sigma = 1$ it equals $\frac{\alpha}{1-\alpha}\, y \ln(S_C/S_E) + O(\alpha^2)$.

When the service has close substitutes ($\sigma \geq 1$), losing it costs the donors an amount proportional to its small share of their budget. When it has none ($\sigma < 1$), losing it costs a share of their wealth, and the budget share no longer matters. A corridor that funnels through a single crossing, or a population with no other habitat, falls in the second case. Calibrating Equation (31) would require the wealth of the organization's donors and their elasticity of substitution, and we have neither.

Proof. Write donor utility as $U(S, m) = \left[\alpha S^{\eta} + (1-\alpha) m^{\eta}\right]^{1/\eta}$ with numeraire m. The loss is the payment c that leaves donors indifferent between keeping the service at S_C and losing it to S_E, $U(S_C, y - c) = U(S_E, y)$, so

$$\alpha S_C^{\eta} + (1-\alpha)\left(y - c\right)^{\eta} = \alpha S_E^{\eta} + (1-\alpha) y^{\eta},$$

which rearranges to Equation (31) when the bracket is positive. When the bracket is not positive, no payment of at most y restores the donors' utility, and they would pay y.

For part (i), $\sigma < 1$ implies $\eta < 0$, so $S_E^{\eta} \to \infty$ as $S_E \to 0$. The bracket then diverges, its $1/\eta$ power tends to zero and $c \to y$. As $\sigma \to 0$ utility tends to the Leontief form $\min\{S/a,\, m/b\}$ for constants $a, b > 0$, with S the constraining input at the initial point so that $bS_C/a \le y$. The value is then $y - bS_E/a = y - (S_E/S_C)(bS_C/a) \ge y\,(1 - S_E/S_C)$.

For part (ii), at $\sigma = 1$ the Cobb–Douglas form gives $c/y = 1-(S_E/S_C)^{\alpha/(1-\alpha)} = \frac{\alpha}{1-\alpha}\ln(S_C/S_E)+ O(\alpha^2)$. For $\sigma > 1$ the bracket is positive for small α, and a first-order expansion in α gives $c = \frac{\alpha}{1-\alpha}\, y^{1-\eta}\big(S_C^{\eta} - S_E^{\eta}\big)/\eta + O(\alpha^2)$, which is proportional to α. □

D.2 A rising relative value

Krutilla (1967) also argued that the relative value of natural environments rises over time, because the supply of extraction output and its substitutes grows while the supply of undisturbed land does not. Sterner and Persson (2008) provide a modern treatment in the discounting literature. Suppose the value of the conservation service grows at rate g per lease term, with $\delta(1+g) < 1$. A well that ends the service at the start of a term then costs $V/(1-\delta(1+g))$ rather than $V/(1-\delta)$, where V is the current per-term value of the service. Growth raises Δu_C^{∞} by the factor $(1-\delta)/(1-\delta(1+g))$ and leaves Equation (14) unchanged. We do not attempt to develop an estimate of g for Wyoming.

D.3 Risk aversion

A reader may expect risk aversion to explain why an organization would pay to remove a small probability of a permanent loss. Under expected utility it does raise the payment, but only by a factor that depends on the size of the loss relative to wealth and not on its probability.

Remark 1 (Risk aversion). *Let donor utility $U(w, x)$ be smooth and concave in wealth w, let c be the compensating variation for a certain loss of the stock, $U(w-c, x_C) = U(w, x_E)$, and let π be the most donors will pay to remove a probability-ρ loss, $U(w-\pi, x_C) = (1-\rho)U(w, x_C) + \rho\, U(w, x_E)$. Then*

$$\pi = \rho\, c\, \Lambda + O(\rho^2), \qquad \Lambda \equiv \frac{U(w, x_C) - U(w-c, x_C)}{c\, U_w(w, x_C)} \ge 1, \tag{32}$$

where Λ depends on the curvature of U over $[w-c, w]$ and not on ρ. With constant relative risk aversion $\gamma \neq 1$ and a loss equal to a share ℓ of wealth,

$$\Lambda = \frac{(1-\ell)^{1-\gamma} - 1}{(\gamma - 1)\,\ell},$$

which is 1.11 at $\gamma = 2$ and $\ell = 0.1$, and 2 at $\gamma = 2$ and $\ell = 0.5$.

Risk aversion therefore scales the expected loss $\rho\, c$ by a factor that is close to one unless the loss is a large share of the donors' wealth. A loss of that size is the irreplaceable case of Proposition 8, so risk aversion adds to the magnitude only where irreplaceability already suggests it is quite large. Option value in the sense of Schmalensee (1972), Graham (1981) and Bishop (1982) is the

term $\rho\, c\,(\Lambda - 1)$, which is proportional to the expected loss. The remark concerns the conservation organization's donors. Appendix E considers risk aversion on the part of the agency, which lowers the break-even bid rather than raising the conservation bid.

Proof. Expand the left side of the defining equation for π and use $U(w, x_E) = U(w - c, x_C)$ on the right side. The left side is $U(w, x_C) - \pi\, U_w(w, x_C) + O(\pi^2)$ and the right side is $U(w, x_C) - \rho\,[U(w, x_C) - U(w - c, x_C)]$. Equating the two gives $\pi = \rho\,[U(w, x_C) - U(w - c, x_C)]/U_w(w, x_C) + O(\pi^2) = \rho\, c\,\Lambda + O(\rho^2)$, since $\pi = O(\rho)$. Concavity in wealth gives $U(w, x_C) - U(w - c, x_C) \geq c\, U_w(w, x_C)$, so $\Lambda \geq 1$. For $U = w^{1-\gamma}/(1-\gamma)$ and $c = \ell w$, $U(w) - U(w - c) = w^{1-\gamma}\big[1 - (1 - \ell)^{1-\gamma}\big]/(1-\gamma)$ and $c\, U_w = \ell\, w^{1-\gamma}$, and the ratio is the stated Λ. □

D.4 Quasi-option value

Arrow and Fisher (1974) and Henry (1974) show that when development is irreversible and information about the value of preservation arrives over time, keeping the reversible option open has a value that an expected-value comparison made today omits. A conservation lease in our model creates exactly that option. It keeps the parcel pristine for one more term, and the parcel returns to auction at the end of it. If the organization or the agency learns about Δu_C^{∞} during the term, the conservation lease is worth more than $\kappa\rho\,\Delta u_C^{\infty} - D_C$ by the expected value of that information. This raises the value of a conservation lease without changing the structure of Equation (14), and we have no basis for estimating how fast such information arrives.

D.5 Choosing among projects with a limited budget

Weitzman (1998) asks how a planner with a fixed budget should allocate protection across species when each project changes a survival probability. The answer ranks projects by the expected value protected per dollar and protects each fully, in rank order, until the budget binds. The same logic applies to an organization choosing which leases to hold. The unit of the ranking is a project, a set of lease units whose value is lost if any one of them is drilled. A project is a single parcel when its value does not depend on its neighbors, a whole corridor under Proposition 6, and the leases around a breeding site under Proposition 7, because holding some units of a project and not others protects nothing.

Proposition 9 (Ranking projects)**.** *Let an organization with budget M choose among projects $J_1, \ldots, J_K$, where project k is a set of lease units whose conservation value V_{J_k} is lost if any unit is drilled. Each project is held at the state's break-even on every unit, at present-value cost $C_k = \sum_{j \in J_k} w_j D_{E,j}$ with w_j as in Corollary 1. To first order in ρ, holding project k avoids an expected loss of $V_{J_k} \sum_{j \in J_k} w_j \rho_j$. The organization holds projects in decreasing order of $R_k = V_{J_k}/V_{J_k}^{*}$, the ratio of the project's value to its break-even value in Corollary 1, until the budget binds, and a project clears the state's break-even if and only if $R_k \geq 1$. For a single parcel, $V_{J_k} = \Delta u_C^{\infty}$ and $R_k = \rho\,\Delta u_C^{\infty}/D_E(x_C)$, so the break-even condition is Equation (14).*

Proof. The expected loss avoided per dollar spent on project k is $V_{J_k} \sum_j w_j \rho_j / \sum_j w_j D_{E,j} = V_{J_k}/V^*_{J_k}$. Holding a project is an all-or-nothing choice, so the problem is a knapsack problem. When each project's cost is small relative to M, the greedy rule that ranks by value per dollar is approximately optimal, and this is Weitzman's ranking. The break-even statement is Corollary 1. □

E Risk-adjusted break-even bids

A risk-averse agency should value a lease's uncertain revenue at less than its expected value. We approximate the difference with the Arrow–Pratt certainty-equivalent premium $CEP = \frac{1}{2}\gamma \operatorname{Var}(V)/W$, where $\operatorname{Var}(V)$ is the variance of the present value of the agency's revenue from a parcel under the five-year-repeat scenario, counting the bid, rent and royalties of every future lease, $\gamma = 2$ is the coefficient of relative risk aversion, and W is the agency's wealth. Because V is a present value, W must also be expressed in present-value terms. We set W to the present value of the agency's mean annual mineral royalty income of $160.5 million in the complete distribution years 2011–2024. Discounted at 5%, this gives $W = \$3.3$ billion. This understates the agency's wealth, since it leaves out bonus bids, rent, surface income and the balance of the permanent fund. Hence, the risk premium we report here is an upper bound. Since V covers the whole sequence of leases, replacing its expected value with its certainty equivalent in the proof of Proposition 4 lowers the five-year-repeat break-even by $(1 - \delta)\, CEP$. Table E1 reports the result. Agency risk aversion has a negligible effect on the break-even bids. The premium is under a dollar per lease in the bottom two deciles, because a lease that almost never produces has little variance. The largest reduction, in decile 6, is 0.37 percent.

Table E1. Risk-Adjusted Minimum Conservation Bids

Panel A. Average oil and gas revenues per lease (NPV, dollars)

Bid decile	Auction	Rental	Royalty	ρ	Risk premium
1–2	376	1,704	902	0.005	0
3	1,035	1,776	188	0.005	—
4	2,300	1,809	7,692	0.013	4
5	4,040	1,821	163	0.002	—
6	6,820	1,837	43,299	0.012	323
7	12,164	1,758	18,266	0.025	31
8	24,268	1,727	54,353	0.046	80
9	79,757	1,679	100,466	0.036	399
10	535,602	1,453	432,202	0.194	1,035

Panel B. Conservation bid required per acre, by scenario (dollars)

Bid decile	Cover royalties	5-year lease	5-year repeat	Risk-adjusted
1–2	3.4	-2.8	-1.3	-1.3
3	3.1	-2.8	-1.4	—
4	25.1	2.0	7.6	7.6
5	10.5	-1.2	1.7	—
6	124.5	24.0	48.5	48.3
7	78.5	13.8	29.2	29.2
8	207.4	42.3	80.0	80.0
9	488.2	104.5	193.7	193.5
10	3108.0	683.9	1099.7	1098.9

Notes: Leases auctioned 2009–2019, grouped by the deciles of Table B2. Deciles 1 and 2 are pooled because every lease in both bid $1 per acre. The risk premium is $\frac{1}{2}\gamma \operatorname{Var}(V)/W$ with $\gamma = 2$, $W = \$3.3$ billion (the present value at 5 percent of $160.5 million a year) and the five-year discount factor $\delta = e^{-0.25}$. The risk-adjusted column subtracts $(1 - \delta)$ times the premium per acre from the 5-year repeat column. Deciles 3 and 5 contain one producing lease each, so the variance of conditional royalties is undefined and no premium is reported.