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The Cost of Endangered Species Protection: Evidence from Auctions for Natural Resources

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The Cost of Endangered Species Protection: Evidence from Auctions for Natural Resources

Abstract

This paper examines the effect that endangered species regulation has on natural resource development. Specifically, we use data from competitive auctions to estimate the effect that land-use regulation protecting endangered caribou in the Canadian province of Alberta has on the price producers pay for the right to extract oil. We exploit a regression discontinuity design to evaluate how prices differ along regulation boundaries that constrain resource development. The auction format and the regulation discontinuity allow use to measure the total cost of the regulation. We find that producers pay 24% less on average for oil leases that are regulated and that the total net present value cost of the regulation exceeds $1.15 billion for leases sold between 2003-2012, all of which is borne by the government. In spite of these costs, the populations of endangered caribou remain in widespread decline.

JEL-Codes: Q580, D440, Q520, L710.

Keywords: endangered species regulation, auctions, natural resources, oil.

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1 Introduction

When confronted by the possibility that a species may become extinct, governments typically restrict or prohibit the human activity causing the harm. Though protecting at-risk species in this way can often be quite rigid in practice, few studies quantify the costs of endangered species regulation. As extinction rates continue to rise, governments may face tradeoffs in deciding which species to protect and how.[1] Measuring the cost of endangered species protection is thus becoming increasingly important.[2]

In this paper, we present a new approach to measuring the cost of endangered species protection. In particular, we estimate how auction prices for the right to develop natural resources are affected by endangered species regulations that constrain resource development. We apply this approach to data from the Canadian province of Alberta on auction prices for oil leases and land-use regulations protecting endangered caribou.

Auction prices for natural resources are useful for identifying the cost of endangered species regulation for a number of reasons. First, jurisdictions often sell the right to develop their natural resources through auctions. Auctioned resource rights can be accompanied by restrictions, such as limits on environmental damage from resource development, in certain areas of a given jurisdiction. One can then focus on auctions for resource rights and wildlife regulation that vary within a single jurisdiction, thereby avoiding the empirical challenge of comparing land prices across jurisdictions and how they relate to interjurisdictional differences in wildlife regulation. Second, depending on the format, auctions can reveal the entire cost of the wildlife regulation. In competitive first-price, sealed-bid auctions, bidders will bid their expected value of the object. In the case of resource rights, this value is the expected

[1] A recent study by De Vos et al. (2015) estimates current global extinction rates to be 1,000 times higher than natural background rates, and predicts we will reach 10,000 times the natural background rates of extinction in the future.

[2] Focusing on the US Endangered Species Act, Brown and Shogren (1998) argue that time and funding constraints will force regulators to discriminate between different species and priorities. They also argue that the decision of which species to protect should be based on economics and cost-benefit analysis.

net present value of profits from development. Any regulations restricting development, such as wildlife regulation, may require the rights holder to incur compliance costs. Such costs will affect the expected net present value of profits, and knowing this, bidders will decrease their bids. By comparing the auction price of a regulated land lease to the price of an unregulated but otherwise identical lease, we can identify the effect of wildlife regulation on the value of natural resource development.

Our specific context for studying this issue is the 'oil sands' in Alberta, where firms extract bitumen for production into crude oil. We study this context primarily for two reasons. First, rights for oil development in Alberta are sold through first-price, sealed-bid auctions that are competitive and have been for decades. The oil industry in Alberta, as well as the subindustry that develops oil sands, is well established with a large set of active producers. Oil sands deposits cover a large swath of Alberta, and oil sands reserves are amongst the largest reserves of oil in the world. Although a relatively costly resource that requires unconventional techniques to extract and process, oil sands are highly lucrative once developed.

The second reason is that this context has a natural discontinuity in endangered species regulation that allows us to uncover the causal effect of the regulation on the price producers pay for the right to develop oil sands. In Alberta, oil sands developers are subject to wildlife regulation that varies within the province's boundaries. The regulation aims to protect endangered wildlife – specifically, the caribou – which are endangered in large part because of the immense land disturbances created by the encroaching oil sands development. Like virtually all endangered species regulations in North America, the regulation aims to protect endangered wildlife by restricting development within well-specified geographic zones. Broadly, our approach is to compare auction prices for oil sands leases lying within boundaries of endangered caribou protection zones to auction prices for leases not in the protection zones.

Motivated by the sharp and discontinuous change in endangered species regulation over space, we use a spatial regression discontinuity (RD) approach to identifying the effect of the regulation. Following Dell (2010), we employ a multidimensional RD approach, which uses polynomials in latitude and longitude to control for geographic location, while an indicator variable for whether a lease lies in a caribou protection zone describes the discontinuous regulation treatment. In our preferred specification, we control for geographic location, lease-specific controls, and a suite of fixed effects to identify the effect of the regulation protecting endangered caribou on auction prices.

Based on data from more than 3,000 oil sands leases auctioned between 2003 and 2012, we find that the regulation reduces auction prices, on a per hectare basis, by about 24% on average. At the mean price per hectare, this effect amounts to a decrease of $192 per hectare in 2012 Canadian dollars. Taking the estimated effect and aggregating across lease sizes and years in our sample, we estimate that the total net present value cost of this regulation for leases sold between 2003–2012 is at least $1.15 billion.

The total cost estimate is important for two reasons. The first reason is that, given how the government uses auction revenues and royalties to extract resource rents from producers, this cost is borne entirely by the government in foregone resource revenues. The second is that, despite these considerable costs, the regulation has proven ineffective: the caribou that the regulation aims to protect are experiencing steep population declines (Hervieux et al. (2013)) and, if nothing changes, are likely to soon become extirpated.

This paper makes at least three contributions. First, it contributes to the literature on the economics of endangered species protection. Most of this literature focuses on the effects that wildlife protection, in particular the U.S. Endangered Species Act (ESA), has on target wildlife (see, for example, Ferraro et al. (2007) and Langpap and Kerkvliet (2012)). In contrast, our paper contributes to a small literature that estimates the costs of wildlife protection. For example, Lueck and Michael (2003) find that private forest landowners

prematurely harvest timber to preempt costly land-use restrictions under the ESA should their forests become inhabited by endangered species. Greenstone and Gayer (2009) find that ESA zonal designations for protected species may decrease residential housing values. Zabel and Paterson (2006) find that the number of building permits in municipalities decrease in areas designated as critical habitats. Unlike the existing literature, our focus on auction prices for industrial development allows us to estimate the total cost of endangered species regulation.

Our study is, to the best of our knowledge, the first to use auction data to estimate the cost of environmental regulations or land-use regulations. We believe that this approach is suitable for many different contexts and is not specific to natural resource development or land-use regulations. For any form of regulation on the end-use of an auctioned object, one can estimate the cost of the regulation by comparing the winning auction bids for regulated and non-regulated objects.

Our use of land markets is similar to a literature that uses residential housing markets to estimate the willingness to pay for environmental quality improvements caused by environmental regulation.[3] In contrast, land prices are typically less useful for estimating the cost of regulation to polluting firms. The problem with doing so is because environmental regulation typically only varies across jurisdictions; governments may offer inducements, sometimes unobserved, to mitigate the cost of their regulation in order to lure individual firms to their respective jurisdictions. In comparing land prices across the jurisdictions, these accompanying policies confound estimates of the effect of environmental regulation on polluting firms. Because our approach allows us to focus on one jurisdiction, and a government's objective in auctioning resource rights is to maximize rent extraction, we avoid these identification

[3]See Chay and Greenstone (2005) for an example of how residential housing prices and changes in environmental regulation can be used to estimate the willingness to pay for improved environmental quality. This literature falls within a larger literature that estimates the benefits of local amenities from housing prices; see Kuminoff et al. (2013) for a recent survey of this literature.

problems to estimate the cost of the regulation using land prices.

A third contribution is to the literature that estimates the cost of emissions or pollution abatement. Typically in this literature, abatement is caused by environmental regulation, and the cost of abatement is measured from the estimated effect of regulation on polluting firms' activities. Instead of using land prices – for the reasons noted above – economists have estimated the effect of environmental regulation by focusing on individual margins of firm response. Examples include firm entry and exit (Becker and Henderson (2000)), firm output and growth (Greenstone (2002)), and changes in total factor productivity (Greenstone et al. (2012)). Yet, unlike the price-based approach, examining these margins may provide only a partial picture of the total cost if firms respond to environmental regulation in several ways.

The remainder of the paper is organized as follows. We start by providing an overview of the Alberta oil sands industry and the endangered caribou regulation. In the following sections, we describe the data and our empirical strategy. We present the empirical results in section 5, while the subsequent section offers a discussion. The last section concludes the paper.

2 Overview of oil sands development and endangered species protection

The Canadian province of Alberta lies above the Western Canadian Sedimentary Basin, a geological formation rich in underground deposits of hydrocarbons. In the northern half of Alberta, most of the hydrocarbons are bitumen, mixed with sand and water, that is typically referred to as 'oil sands.' Processing isolates the bitumen, which is then upgraded to synthetic crude oil. As of 2013, about 170 billion barrels of oil are considered recoverable given current technology and prices, third only to Saudi Arabia and Venezuela (ERCB (2013)). In 2014, approximately 2 million barrels of oil per day were produced from oil sands; by 2030 that

number is expected to triple (CAPP (2013)).[4] Oil sands, directly and indirectly, contributed nearly 5% of Canada's gross domestic product in 2012 (IHS CERA (2014)).

Most of the mineral wealth in Alberta – as in all provinces in Canada – falls under provincial jurisdiction and is collectively owned by the residents of Alberta. The provincial government administers the extraction of the hydrocarbon reserves and maintains the monetized wealth resulting from extraction. Although the reserves are publicly owned, the province has chosen to delegate production to private firms and recoup some of the monetized wealth by auctioning land rights for mineral extraction and imposing royalty taxes on production.

To produce oil sands in Alberta, a firm must lease the parcel of land below which the resource resides. To obtain a lease for a given land parcel, a firm must win a first-price, sealed-bid auction for that parcel. Prior to the auction, a given land parcel is publicly announced by Alberta's Department of Energy as being up for lease for any entity interested in purchasing its land lease rights. Information about the parcel – its location, the conditions of the lease, mineral analysis results from core samples, nearby encumbrances such as abandoned wells, and relevant environmental regulations – are included in the announcement.[5] This announcement provides a potential bidder with a comprehensive set of information from which to estimate the profitability of the parcel. Bidders can bid on and win as many parcels as they would like. Once a lease is obtained, firms can hold it indefinitely, but must pay an escalating rent if the lease is non-producing. After the lease starts producing, the firm holds the right until production ceases. The escalating rent structure, where the annual payment for keeping a non-producing lease doubles every third year, gives strong incentives to either start producing fairly soon or give up the lease. The rent structure also compensates

[4]Total Albertan conventional oil production in 2013 was 1.6 million barrels per day, and this is forecasted to remain constant through 2030 (CAPP (2013)).

[5]Potential lease holders must obtain an account to do business electronically with the Alberta Department of Energy through its Electronic Transfer System, which also houses all the information about land postings.

the government for foregone bonus bids had the development rights been re-leased to a new firm.

The government maintains that the auctions for oilsands development rights are competitive (Government of Alberta (2009)).[6] Between 2003 and 2012, the government issued more than 3,000 leases for oil sands production and generated nearly $4 billion, in 2012 Canadian dollars, in auction revenue.[7]

Oil sands production has significant effects on the environment. Although the scale and production techniques of oil sands projects may be best known internationally as having relatively high greenhouse gas emissions per barrel of oil (see Brandt (2011)), they also have significant effects on the local environment, threatening ecosystems and wildlife (the regions containing oil sands are mostly uninhabited by humans).

Perhaps the most salient local effect that oil sands have on the environment is the risk of extirpation of woodland caribou (*Rangifer tarandus caribou*).[8] The woodland caribou is one of three major types of caribou found in Canada, but the only caribou species that can be affected by Alberta's oil sands industry.[9] This species has been listed as endangered provincially since 1987.[10] ASRD and ACA (2010) estimate that approximately 70% of woodland caribou populations in Alberta are in decline. Figure 1 shows the continued decline of the

[6]Watkins (1975) and Watkins and Kirby (1981) estimated that Alberta's oil and gas auctions were competitive. Though these studies were conducted in the 1970s, the industry has only grown since then.

[7]For a brief statistical description of auctions for oil sands leases in Alberta, see `http://www.energy.alberta.ca/Tenure/865.asp`.

[8]A Canadian Broadcasting Corporation documentary entitled *Billion Dollar Caribou* describes the tension between oil sands development and caribou survival.

[9]The two other caribou types are the barren-ground caribou and the Peary caribou. The barren-ground caribou mainly live in the tundra rather than the boreal forest, where it can be found in large numbers (some herds count hundreds of thousands), while the Peary caribou are only found on the islands of the Canadian Arctic Archipelago, far away from Alberta's oil sands industry.

[10]Unlike under the U.S. Endangered Species Act, there is little scope for strategic listing of endangered species in order to affect resource development. A species is listed as endangered in Alberta at the discretion of the Minister of Environment and Sustainable Resource Development. His or her decision is based off a listing recommendation made by the Endangered Species Conservation Committee, a publicly-appointed and independent advisory body. The endangered status of caribou was updated to a new category, 'threatened,' in 1997 (Dzus (2001)). The legal distinction between 'endangered' and 'threatened' is vague; see Fluker and Stacey (2012) for an overview and analysis.

woodland caribou, and how several of the herds currently are at serious risk of extirpation.

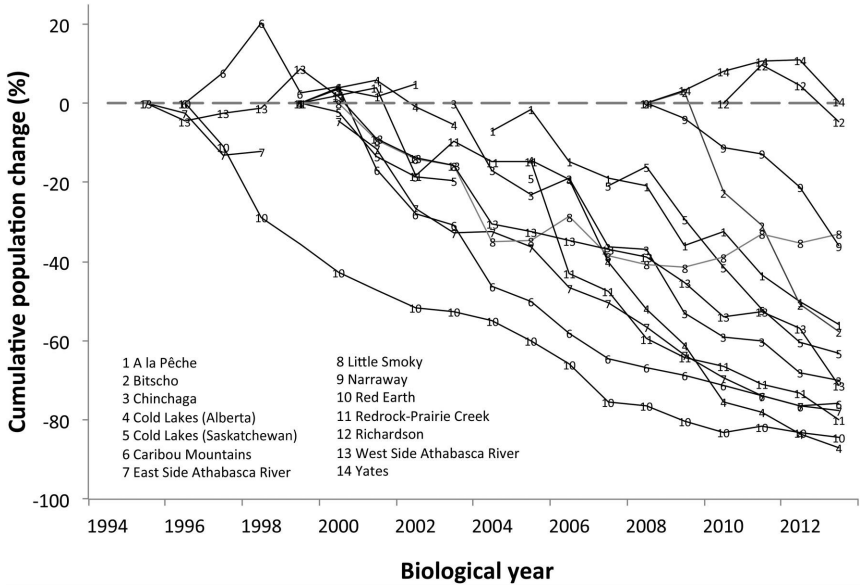


Figure 1: Population trends for various herds. Source: Hervieux et al. (2013).

The production of oil sands has caused this population decline for two reasons. The first is that forests have been cleared to make way for facilities and/or mines: many of the areas producing oil sands are old-growth forests, which are critical habitats for caribou. Second, by constructing seismic lines and transport routes, oil sands projects block herd migration routes and make it easier for predators, and particularly wolves, to access caribou herds.[11]

Before we explain how these two factors affect the caribou in more detail, note that the wolf and the caribou have coexisted for centuries in Alberta. However, anthropogenic and natural (fire) habitat disturbances, along with climatic change, have gradually changed the ecological system. Earlier, wolves and their main prey mainly lived in areas that were uninhabited by the woodland caribou. Over time, habitat disturbances have increased the population sizes of species the wolf and other carnivores prey on (mainly moose and deer), in the areas of the caribou. This has raised the wolf density in these areas, and consequently,

[11] Although oil sands is the significant cause of woodland caribou population declines, other industries contribute to the declines as well. As Dzus (2001), among others, describes, forestry and agriculture disturb critical habitats and create linear land disturbances enabling easier access to caribou for predators.

led to higher predation risk for the woodland caribou in Alberta. This type of species interaction is known as *apparent competition* Holt (1977); larger population sizes of the main prey of the wolf, the species' common predator, has caused a decline in the caribou stock. The development of linear seismic lines and transport routes is another factor behind the increased predation risk for caribou. The extensive grid of roads, pipelines, and seismic lines created by the oil and gas industry, has greatly increased the mobility of the wolves, thereby increasing each caribou's number of wolf encounters, and thus, their mortality rate.

Because the woodland caribou has been designated as endangered in Alberta since 1987, the provincial government has been legally required under the *Wildlife Act* to develop a population recovery plan for the caribou (Alberta Woodland Caribou Recovery Team (2005), Government of Alberta (2013)).[12] The goal of the regulation has always been to sustain caribou herd populations within their respective ranges. This species does not migrate from its individual range and is too sensitive to be relocated to another range or introduced to another herd (Dzus (2001)). Given the key role of wolves in the decline of the caribou, wolf removal has been proposed as one of several actions to save the caribou from extirpation. In addition, the provincial caribou recovery plan calls for habitat protection and restoration of seismic lines, transport routes and well sites to conditions that would reduce the densities of deer, moose and wolf in these areas, and thus allow the caribou population to recover (Muhly et al., 2015). The primary instrument to do so has been the use of industrial land use regulations within designated areas critical for caribou habitat and populations.

These caribou protection zones follow the approach to wildlife conservation that has been taken in North America for the past century. The geographic area of a protection zone is determined by the location of a given caribou herd's critical habitat, all of which

[12]In Canada, protection of the environment falls mostly under provincial jurisdiction as long as there are no transboundary issues. For wildlife protection, the federal *Species at Risk Act* (*SARA*) does not apply unless provincial regulations failed to effectively protect endangered species. In the case of woodland caribou in Alberta, *SARA* came into effect in 2013, taking primacy over provincial regulations.

were mapped from surveys in the late 1970s and early 1980s (Alberta Woodland Caribou Recovery Team (2005)).[13] Since 1991, the zones have incrementally expanded without ever having contracted; the last changes were made in 2002 and 2013. Currently, there are 31 geographically distinct caribou protection zones in Alberta. About 17 of these are in oil sands–producing regions.

Firms seeking to lease lands for oil sands production in the protection zones must satisfy the land use regulations specified by the regulator. While the regulatory framework is the same across the different caribou protection zones, there will be differences across regulated parcels in how these regulations constrain oil development. Within the boundaries of a caribou protection zone, all firms must develop strategic plans to mitigate adverse effects on caribou habitat and migration, and these plans must be approved by the provincial regulator. Operationally, the zones impose constraints on activities that support extraction, meaning that producers incur costs they would not incur outside the zones.[14] Examples include limiting the clear cutting of forests, specifying how transport routes – such as roads and pipelines – must circumvent caribou migration routes and habitats, and limiting the seismic disturbances from drilling by restoring seismic lines and well sites to original conditions as soon as possible. All these costly activities come in addition to what the firms would do in the same situation but outside the caribou protection zone.

The existing regulations do not specify exactly which activities firms must undertake to protect the caribou or under what circumstances. Instead, firms decide on measures to protect the caribou in their applications for project approval to the Alberta Energy Regulator (formerly, the Energy Resources Conservation Board). Firms need approval before they are allowed to initiate any mining-related oilsands projects, and such approval requires that the

[13] Unlike boreal caribou, woodland caribou do not migrate large distances.

[14] Although there are no available statistics on the costs of these regulations, a member of the industry told us that his company incurred millions of dollars in costs every year from complying with the caribou protection regulations.

caribou is not severely affected by the project. As the original regulation states, "[oil and gas] development activities can occur on caribou range, provided the integrity of the habitat is maintained to support its use by caribou" (Alberta Energy (1991)).

3 Data

Having established the context for our study, we now present the data that will allow us to estimate the effect of regulation protecting endangered caribou on oil sands auction prices. Our data set combines two different sources of information. The first component is the set of winning auction bids for oil sands development rights on Crown land in Alberta.[15] These rights are sold through first-price, sealed-bid auctions and are land leases for production of the subsurface resource. Auctions are held several times a year. The government posts land available for lease ahead of the auction and bidders submit their bids electronically on the day of the sale. The winner is determined immediately and the information from the sale and the associated lease is posted publicly shortly thereafter.[16]

Because the boundaries of the regulation zones expanded in 2002 and again in 2013, we focus on the 3,870 oil sands leases sold between 2003 and 2012.[17] Figure 2 provides an annual breakdown on sold leases along with the 5-year futures West Texas Intermediate prices per barrel of oil, in 2012 Canadian dollars. The notable increase in lease sales in 2006 through 2008 was due to increased prices and expectations. Oil sands projects last between 20 and 40 years, so expectations about future economic conditions weigh heavily in entry decisions. While much of the mineable area had already been sold by 2003, the remaining sales were

[15] Crown land is land for which any subsurface minerals are collectively owned by the residents of Alberta. Crown land covers approximately 81% of the area of Alberta.

[16] Although these data are publicly available, we obtained them from IHS, Inc.

[17] These zones have expanded a few times since their inception in 1991. The last time there was a zone change was in March 2013, while prior to that, some zone boundaries were changed in 2002. Since the zone boundaries change, firms bidding for currently unregulated land may have expectations about future regulation costs that are capitalized into their bids. Since the zones expand and never contract, this implies our estimates may underestimate the effect of regulation.

for reserves that required *in situ* extraction methods that typically require at least $45 per barrel to make them economically viable. The increase in sales is due to price expectations surpassing this threshold. In 2009 and onwards, sales decrease dramatically. This is due to two main factors. The first is from the global economic recession, which impacted Alberta moderately. The second, more important factor, is due to cost inflation caused by the increase in new projects: during 2006–2012, costs on a per flowing barrel basis as well as operating costs were estimated to at least double, making potential oil sands projects less viable.[18]

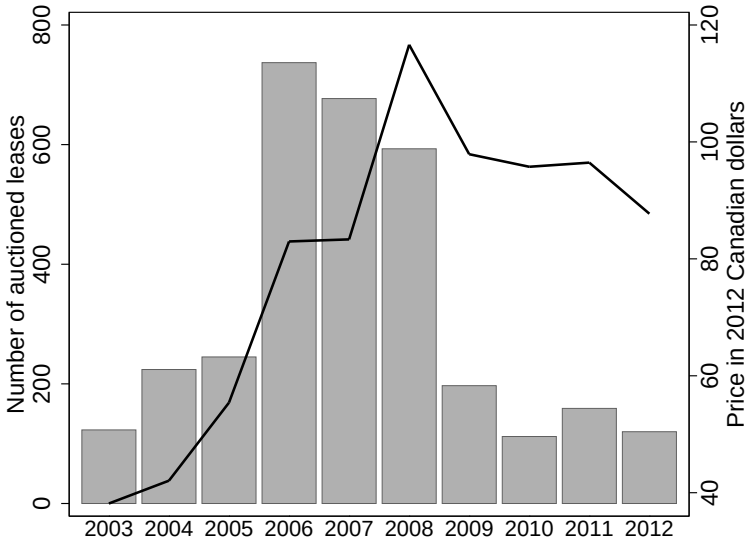


Figure 2: Number of auctioned oil sands leases and West Texas Intermediate 5-year futures prices by year

For each lease, we know the price paid and its geographic boundaries. We also have information on the identity of the owners and their interest share in the lease, as well as the zonal development rights in terms of what formation the producer is extracting from. We omit any observation that gives no information on any of these variables.

[18]See Leach (2013) and Leach (2014) for descriptions on how the price environment and cost inflation have affected the economic viability of oil sands development.

In general, lease prices in our sample are greater for leases covering a larger geographic area. To focus our analysis on the value of land, we use price per hectare as our price measure. To depict the geographic price distribution, Figure 3 plots price per hectare of each land lease on a map of Alberta. As the figure depicts, the oil sands–producing area is in a particular region.

The distribution of price per hectare is positively skewed with a long right tail. In 2012 Canadian dollars, the mean in our sample is just over $800 per hectare, while the median is about $135 per hectare; the minimum price in our sample is over $2 per hectare, while the maximum price is nearly $27,000 per hectare.[19] Because of the skewness of the distribution of price per hectare, we replace this variable for our empirical analysis with the logarithm of price per hectare.

Our second data source is the geographic boundaries of land use regulation zones protecting the endangered caribou that are described in detail in Section 2. There are 31 geographically distinct zones; the median circumference and geographic area of the zones are, respectively, 250 kilometers and just over 1,000 square kilometers. Figure 3 depicts the geographic distribution of the caribou protection zones.

We overlay the auctioned leases on the map of regulation zones to determine whether a given lease falls within a particular caribou zone.[20] We exclude any leases that fall into multiple zones. For each lease, we determine the geographic centroid, in degrees latitude and longitude, to calculate distances to zone boundaries. For a lease lying within a zone, we find directional vectors that are perpendicular to the boundaries of that zone. We then calculate the length of each vector, which is the distance to the boundary, and select the shortest vector as the distance-to-boundary for that lease. For a lease not lying in any zone, we follow a

[19] All dollar figures in this paper are in 2012 Canadian dollars.

[20] In our empirical analyses, we account for the 156 leases in our sample that are intersected by a caribou zone boundary, so that part of the geographic area of the lease lies inside the zone and the remainder lies outside.

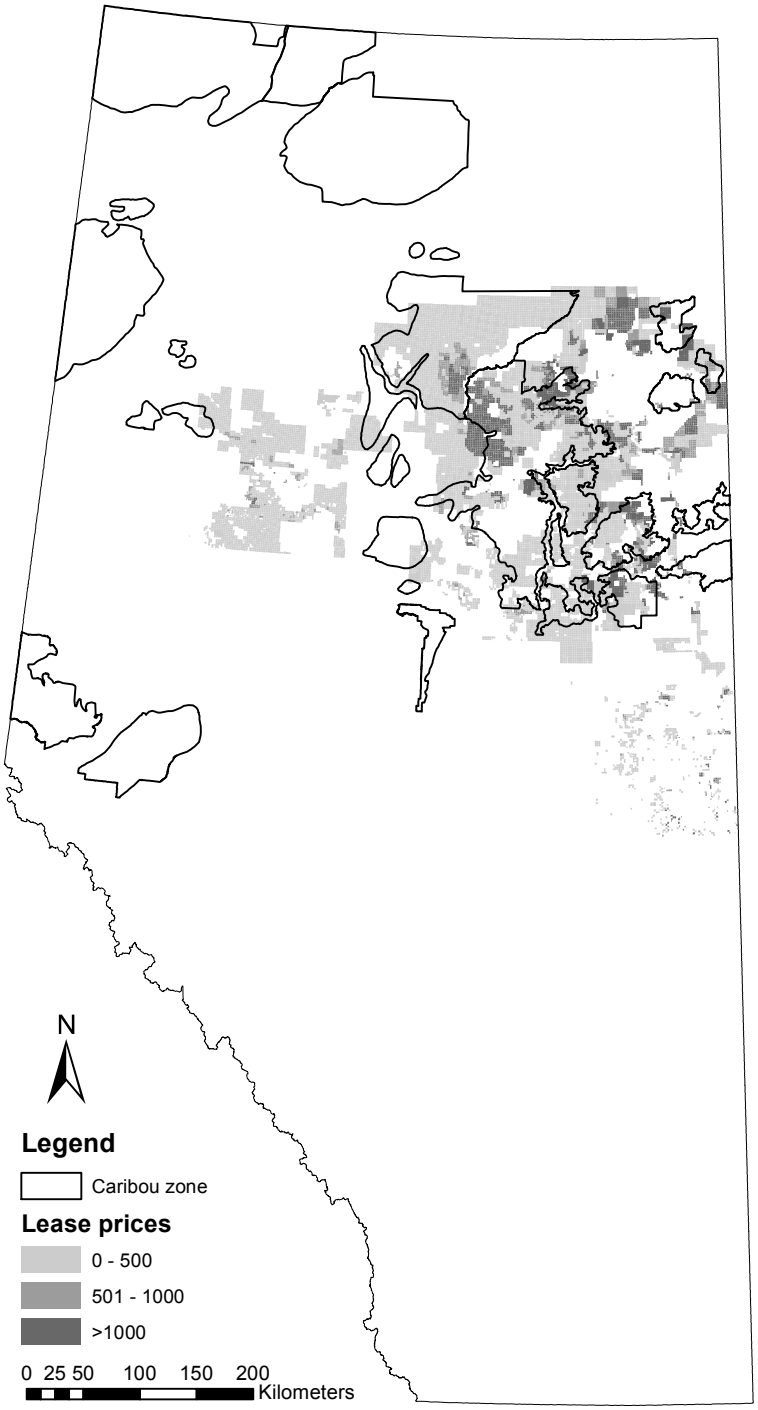


Figure 3: Geographic distribution of price per hectare for oil sands leases and location of caribou protection zones in Alberta

similar approach: we find the directional vectors to all zones within 200 kilometers and select the shortest vector and the associated zone, respectively, as the distance-to-boundary for that lease and the zone group the lease falls into. We exclude a lease if it does not lie inside a zone and is more than 200 kilometers from the nearest zone. Also, for estimation purposes, we exclude any lease whose owner is observed only once in our sample. Altogether, these criteria narrow our sample to 3,089 leases that lie within or near the boundaries of 17 caribou protection zones.

Table 1 reports sample means and standard deviations for leases by zone status, with subsamples determined by narrowing the distance of leases to the nearest zone boundary. Also reported are differences in means for each distance sample and the associated standard error in parentheses. The number of leases on either side of a zone boundary is fairly even. Approximately half of our sample falls within the boundaries of a regulation zone, though the share of leases within a zone increases if we restrict our attention to the subsample of leases that lie within 5 kilometers of a zone boundary, on either side. We will call this subsample the 5-kilometer subsample.

The first row reports statistics for the price per hectare. The first four columns report statistics for the entire sample. The price measure is higher on average for leases within zones in the full sample, and the difference is statistically significant at the 10% level. Considering only the 5-kilometer subsample, leases lying within zone boundaries have a mean price per hectare that is lower than leases outside the zone. Since the mean price per hectare for leases just inside zone boundaries is lower than the mean price per hectare for leases just outside zone boundaries, we interpret this difference as suggestive evidence that the endangered species regulation may impose compliance costs on lease owners.

The second row reports summary statistics for the count of firms with an ownership stake in a given lease. On average, this is close to 1 across all subsamples, implying that most leases are owned by a single firm. If a lease is owned by more than one firm, we will refer

Table 1: Summary statistics for oil sands leases by caribou zone status

	Sample falls within							
	< 200 km of a caribou zone boundary				< 5 km of a caribou zone boundary			
	Inside	Outside	Total	Difference	Inside	Outside	Total	Difference
Price/hectare (2012 CDN $)	865.37	740.52	800.82	124.85*	999.00	1288.67	1096.38	-289.68
	(1994.18)	(1986.28)	(1990.76)	(71.66)	(2628.65)	(2725.04)	(2628.65)	(198.60)
Number of joint owners	1.107	1.100	1.104	0.008	1.104	1.144	1.117	-0.040
	(0.352)	(0.377)	(0.366)	(0.013)	(0.323)	(0.443)	(0.368)	(0.0300)
Special access zone		0.313	0.016					
		(0.174)	(0.126)					
Key wildlife zone	0.063	0.199	0.133	-0.136***	0.108	0.242	0.153	-0.134***
	(0.243)	(0.399)	(0.340)	(0.011)	(0.310)	(0.429)	(0.360)	(0.029)
Depth (m)	803.093	849.525	827.098	-46.431***	815.726	799.875	810.397	15.851***
	(60.506)	(135.182)	(108.402)	(3.728)	(87.758)	(51.644)	(77.845)	(4.870)
Number of firms	68	90	95		54	50	63	
Observations	1492	1597	3089		547	277	824	

Notes: In each four-column panel, the first column reports means, with standard deviations in parentheses, of variables that lie within caribou zone boundaries; the second column reports means, with standard deviations in parentheses, of variables that do not lie within a caribou zone; the third column reports sample means, with standard deviations in parentheses, of the sample total; the fourth column is the difference in means between the first and second columns, with the standard error in parentheses. *, **, and *** denote difference in means different from zero at the 10%, 5%, and 1% significance levels. The final two rows report the number of unique firms in each sample and the total observations in each sample, respectively.

to the owner that interacts with the regulator as the main owner.[21] The total number of firms in the sample is 95, and the number of firms in a given group is reported in the bottom row of the table. In the full sample, 68 of the 95 firms own leases inside zone boundaries, while 90 of the firms own leases outside of the zones. Sixty-three firms own leases in the 5-kilometer subsample; the number of firms operating inside and outside the zones is nearly the same.

The third and fourth rows report summary statistics for binary variables indicating whether the lease falls into other regulatory zones, known as key wildlife and special access zones. Both impose some form of land use guidelines designed to protect wildlife and/or biodiversity that are not endangered.[22] Conversations we had with some of the producers revealed that complying with the regulations protecting endangered caribou is of much greater concern. None of the special access zones fall within caribou zone boundaries, and no leases within 5 kilometers of a caribou zone boundary lie in a special access zone.

A lease is defined not only by its geographic boundaries at surface level, but also boundaries on the depth from which the producer can extract the resource. The final row reports summary statistics for the depth, in meters, of the core sample for that lease.[23] This variable provides information on the costliness of extracting oil sands for that particular lease, since deeper deposits require greater effort to produce to the surface. Consistent with this notion, this variable is negatively related with the price measure: for the full sample, leases inside caribou zone boundaries are on average shallower than leases outside zones, and the mean price per hectare of the former is higher than for the latter. In the 5-kilometer subsample,

[21] As we mentioned above, we excluded from our sample any leases for which we observe the owner only once. This criterion removes 26 unique firms from our sample; this does not affect the distribution of firms across zones.

[22] Key wildlife zones are a combination of key winter habitat for ungulates, mostly moose and deer, and areas with higher habitat potential for biodiversity. Special access zones are designed to maintain the viability of natural habitat and reduce, from all human sources, the excessive mortality of all wildlife in those areas. See Government of Alberta (2013) for more details.

[23] Core samples are made publicly-available by the Government of Alberta; see `http://www.ags.gov.ab.ca/services/mcrf/`.

the pattern remains the same but switches zone status: leases inside zone boundaries are on average deeper and are sold for less.

4 Empirical framework and identification

In this section, we develop an empirical framework for identifying the effect of endangered species regulation on auction prices for oil sands leases. To motivate our empirical approach, we first describe a stylized spatial model of land values and regulation. The model prescribes an empirical specification, which we then describe and use to discuss identification issues.

4.1 A stylized model of land values and regulation

The model described here is adapted from standard one-dimensional models of land values and regulation, such as recently in Turner et al. (2014). A parcel of land is denoted by x, which lies on the real line. The value of owning a parcel, exclusive of any regulatory costs, is described by the function $V(x)$, which is not observed by the researcher. In the context of resource development, $V(x)$ represents the net present value of profits from developing the resource located at x. Given the spatial correlation of natural resource stocks, land values are also spatially correlated. This implies that $V(x)$ is continuous in x, so that $V(x) \approx V(x')$ for x' sufficiently close to x.

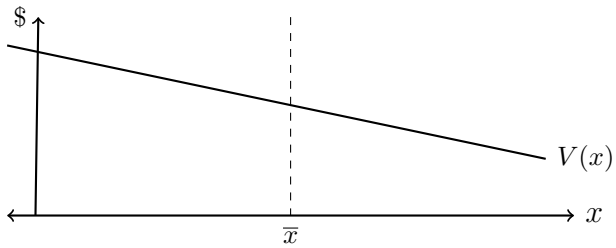
Some parcels are subject to regulation that varies over space. In particular, suppose that the point $\overline{x}$ on the line is the boundary separating regulated and unregulated parcels: any parcel x such that $x \geq \overline{x}$ is subject to regulation, while any $x < \overline{x}$ is unregulated. This zoning approach is typical for land use regulation, and particularly so for endangered species regulation: geographically-defined regulation zones, typically defined by critical habitat designations, restrict development within their boundaries. If parcel $x \geq \overline{x}$, then a cost c is incurred by the owner of the parcel to comply with the regulation. In the context of re-

source development, c represents the net present value of regulatory compliance costs over the lifetime of owning the parcel.

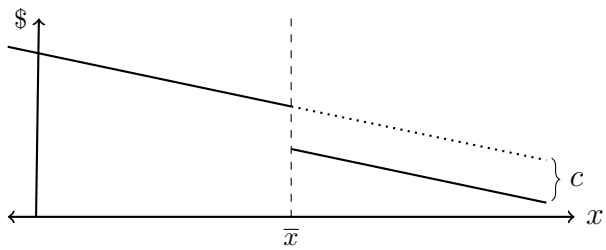
Land markets are competitive, so that the price of a parcel x, which is observed by the researcher and is described by the function $p(x)$, is equal to the value of that parcel net of any regulatory costs. This implies that for any unregulated parcel $x < \overline{x}$, the price of the parcel is equal to $V(x)$. The competitive markets will fully capitalize the cost of regulation into the price of regulated parcels, so that $p(x) = V(x) - c$ for all $x \geq \overline{x}$.

Figure 4 depicts a version of this model. The top panel plots land values exclusive of regulatory costs, which are unobserved by the researcher. For the purposes of illustration, we plot $V(x)$ as linearly decreasing in x. As assumed in the model, the value function $V(x)$ is continuous, even as we move across the regulation boundary, $\overline{x}$. The bottom panel depicts land prices, which the researcher does observe. As depicted, the price of any parcel to the left of $\overline{x}$ is equal to $V(x)$. To the right of $\overline{x}$, the counterfactual price of a parcel in the absence of regulation is depicted by the dotted line and equal to $V(x)$. The capitalization of regulatory costs causes the price of regulated prices to decrease by the amount equal to c; the actual prices of regulated parcels are depicted by the solid line.

To identify the cost of regulation, c, comparing average land prices for regulated and unregulated parcels will not do: identification is confounded by the decreasing land values as one moves from left to right, which yields an overestimate of the cost of regulation. To resolve the identification challenge, one must account for the unobserved and decreasing land values by controlling for the location along the line of each parcel x, along with accounting for which parcels are regulated. This approach to identifying the cost of regulation, which exploits the discontinuity in land prices due to regulation, motivates the use of a standard regression discontinuity framework (see Imbens and Lemieux (2008) and Lee and Lemieux (2010) for surveys).



(a) Land value excluding regulatory costs



(b) Price of land

Figure 4: Land values, prices, and fixed land use regulation

4.2 Empirical specification

The preceding section prescribed using a regression discontinuity (RD) approach that accounts for regulation status and geographic location to identify the effect of land use regulation on land prices. Though the spatial model is one-dimensional, our context of auction prices for oil sands and regulation protecting endangered woodland caribou is two-dimensional, requiring us to augment our RD approach when accounting for the geographic location of a lease. Following Dell (2010), we do so by using a multidimensional RD approach that uses latitude and longitude,[24] along with controlling for the the identity of the nearest zone.

[24]Using latitude and longitude, as opposed to distance-to-boundary, is particularly appealing in the context of natural resources. Several different estimation techniques estimate geology and resource deposits as a function of polynomials in latitude and longitude (see Goovaerts (1997)) and Chiles and Delfiner (2012)). In our context, this implies that longitude and longitude should be useful in controlling for the unobserved value of the resource for a given lease.

In practice, producers have different technologies and cost structures, which will affect how each producer bids and the observed winning auction prices. Additionally, the bids submitted by a given producer that win may change over time, due in part to the firm's own idiosyncrasies as well as how it is affected by the volatile nature of the industry. These concerns suggest we control for any time-varying firm-specific differences across leases.

Additionally, some leases lie on caribou zone boundaries, so that part of the geographic area of the lease is inside the caribou zone and the remainder is outside. Because these leases lie only partly inside caribou zones, they may be treated differently by the regulator, and potentially face compliance costs that are no greater, and possibly lower, than leases that lie entirely inside zone boundaries. Not accounting for these two distinct categories of regulated leases could yield an underestimate of the effect of regulation.

Altogether, this list motivates the following estimation framework for estimating the logarithm of auction price per hectare, p_{izjt}, for lease i near zone z, held by firm j and sold in year t:

$$p_{izjt} = \alpha + \beta_1 \,\text{zone}_i + \beta_2 \,\text{boundary}_i + W_i\Gamma + f(x_i, y_i) + \lambda_z + \lambda_{jt} + \varepsilon_{izjt}. \tag{1}$$

The main variable of interest is zone_i, and is equal to 1 if lease i falls entirely inside the boundary of any caribou zone and is equal to 0 otherwise; it is implicitly a function of latitude and longitude. The variable boundary_i is equal to 1 if lease i lies only partly inside the boundary of a caribou zone and is equal to 0 otherwise. The variable zone_i and boundary_i are distinct: if a lease i lies entirely inside a caribou zone (so that $\text{zone}_i = 1$), then $\text{boundary}_i = 0$; if a lease lies on a caribou zone boundary (so that $\text{boundary}_i = 1$), then it cannot simultaneously lie entirely inside the zone, thus implying $\text{zone}_i = 0$. If both variables are equal to 0, then such a lease lies entirely outside the caribou zones and is therefore unregulated. Since leases for which $\text{zone}_i = 1$ form the majority of regulated leases and –

because their prices may reflect the full effect of regulation – are the variable of interest, we will hereafter refer to them as leases inside caribou zones. Leases lying on caribou zone boundaries, so that $\text{boundary}_i = 1$, are potentially regulated, but since they are exceptions to the group of regulated leases inside caribou zones we will refer to them as 'boundary' leases. Any lease that is neither of these two will be referred to as an unregulated lease.

The parameter β_1, the coefficient for the caribou zone indicator, captures the effect of endangered caribou regulation on auction prices: if the regulation imposes costs on resource development, then we expect $\beta_1 < 0$; if the regulation imposes no costs, then we expect $\beta_1 = 0$. The parameter β_2, the coefficient for the boundary caribou zone indicator, captures the effect of potentially partial regulation: if boundary leases have lower regulatory compliance costs then regulated leases, then we expect $0 \geq \beta_2 > \beta_1$; otherwise we expect there to be no differential effect, so that $\beta_2 = \beta_1$.

The vector W_i contains information specific to the lease, such as the number of joint owners and the depth at which the lease holder is permitted extraction. The variables x_i and y_i denote the latitude and longitude, in degrees, of lease i and the unknown function f controls for smooth functions of geographic location, such as the underlying resource stock and distances to industrial hubs where producers obtain inputs for production.

The parameters λ_z are fixed effects that account for the zone to which lease i is near, and control for differences in lease prices across zone regions. The owner-year fixed effects, λ_{jt}, control for time-varying owner-specific differences in winning auction bids and account for, among other things, differences in production technologies and the timing of when firms obtain leases.

An issue is how to estimate equation (1) in the presence of the unknown function f, which controls for smooth functions of latitude and longitude. Here we again follow Dell (2010) and specify f as a series of polynomials in latitude and longitude. While it is unclear what degree polynomial to employ, particularly given the overfitting that may occur with

too high a degree, our main specifications will employ a quadratic polynomial in latitude and longitude.[25] To test the robustness of our results, we will also re-estimate equation (1) using polynomials both of lower and higher degree.

4.3 Identification and interpretation

Given the specification described in equation (1), our strategy to identify the effect of endangered caribou regulation on auction prices attributes, after controlling for lease-specific differences, geographic location, and firm-specific time-varying heterogeneity, any difference in the prices of leases lying within a caribou zone's boundary to leases lying outside the boundary to be caused by the regulation. Further, if the auctions are competitive, then the model in Section 4.1 suggests we may be able to interpret our estimates as the expected net present value cost of complying with the regulation.

The identification of the effect of regulation requires that factors affecting auction prices other than regulation to vary continuously at caribou zone boundaries. To determine whether this assumption is valid for the covariates in our data set, we can examine the summary statistics and the difference in means reported in Table 1. For the lease-specific controls listed therein, most of the variables have little difference across zone boundaries in the 5-kilometer subsample. Two sets of variables do stand out, however. The first is the key wildlife zones, which predominantly lie outside the caribou zones. The second is the vertical depth the lease holder can extract from. We can evaluate the validity of our estimation results by examining the extent to which the estimated effect of depth on auction prices is economically and statistically significant. Second, we will evaluate the robustness of our estimation results by restricting our subsample to lie solely within or outside key wildlife zones and re-estimate equation (1).

[25] If latitude and longitude are denoted by x and y, then the quadratic in latitude and longitude is $x^2 + y^2 + xy + x + y$.

The identification of the effect of endangered caribou regulation on lease prices also relies on the assumption that unobservables affecting lease prices do not change discontinuously across caribou zone boundaries. The following subsections raise such potential identification issues, and provide a discussion on how to interpret the effect of regulation.

4.3.1 Location of regulation boundaries

Our identification strategy relies on the assumption that the caribou zone boundaries are drawn independently of the quality of the underlying oil sands resource. If the regulator had drawn boundaries so that higher-value resources were excluded from caribou zones, then our identification strategy is invalid: comparing leases just outside the zone to those just inside would mistakenly attribute a difference in prices to the effect of regulation, whereas part or all of the difference in prices may be due to variation in the unobservable resource quality of the leases.

We have no reason to suspect that the caribou zone boundaries were manipulated in such a way. The zones represent the historical ranges that individual caribou herds inhabit. Range boundaries were drawn by ecologists decades prior to the initial implementation of this endangered species regulation (Dzus (2001)). The reason the caribou herds have historically lived in those ranges is that they require old-growth boreal forests to survive (Environment Canada (2012)), and such boreal forest covers much of the northern half of Alberta. Caribou herds exist not only in Alberta but also across much of northern Canada (Environment Canada (2012)). That oil sands deposits overlap parts of caribou ranges in Alberta is coincidence.

A potential issue with our approach is due to the expectations of bidders in the face of changing regulation. Since the caribou protection zones have expanded, but never contracted, over time, bidders seeking to obtain currently unregulated parcels may have an expectation that the land parcels they are interested in will be regulated sometime in the

future. Knowing this, bidders will calculate the expected costs of future regulation and capitalize these expected costs into their bids. If there is an expectation that zones will expand, we may be underestimating the true cost of the endangered caribou regulation.

4.3.2 Selection

A lease won by a bidder is chosen because the bidder believes it can profit from developing the resource the lease entitles it to. In this way, bidders choose where to locate and can therefore choose whether to bid for leases within caribou zones or avoid them entirely. Such ability to manipulate the assignment to treatment leads to bias in most RD applications. However, in our application, choosing whether to lease land in the caribou protection zones does not lead to bias because bidders are fully able to compensate themselves, by decreasing their auction bids, for bearing the cost of regulation within caribou zones. Whether winning a land lease inside or outside caribou zone boundaries, bidders will in equilibrium pay the value of that land lease. It is on this economic behavior that we rely to identify the effect of the regulation on auction prices.

It may be the case that certain firms are better able – in the least-cost sense – to comply with regulations and so are more likely to obtain leases in the caribou zones. This may pose problems for the competitiveness of auctions in the zones, which we discuss below. But assuming auctions remain competitive, we are able to control for producer identity, and thus our identification strategy is robust to this issue.

Finally, even if auctions are competitive and our identification strategy is valid, we will be identifying the cost of regulation only for those parcels of land for which the profits of producing oil sands exceeds the cost of regulation. Having consulted with industry actors, we do not believe that firms' entry decisions are affected by the costs that arise from complying with the regulation.[26]

[26] One employee of a large producer told us that although it costs millions of dollars to comply with

4.3.3 Competitiveness of auctions and the winner's curse

Although we do observe the winning auction bid, we do not observe, nor does any other entity but the regulator, any other bids nor the number of bidders. The government claims that the auctions are competitive (Government of Alberta (2009)) and there exists no evidence suggesting otherwise. Watkins (1975) and Watkins and Kirby (1981) found that Alberta's oil and gas auctions are competitive; the industry has only grown since that time.

Even if there is less competition in the caribou zones because of uncertainty of costs and/or avoidance of costs of compliance by producers, this will not invalidate our identification strategy. If this is the case, then it may be that bidders vying for leases in the zones can, due to a lack of competition, submit bids less than the value of the leases in zones and still win. Since it is the regulation that causes the decline in competition leading to lower auction prices within caribou zone boundaries, our approach still identifies the effect of the regulation on auction prices.

Even if auctions are competitive, there may still be reasons to believe auction prices may not perfectly reflect the cost of regulation. Auctions for mineral rights are often modeled under the common values informational paradigm, where the object has the same value, to a first approximation, for all bidders (see Capen et al. (1971) for the seminal article). This phenomenon leads to the so-called winner's curse, where the auction winner pays more for the object than its actual worth.

Common values and the winner's curse could affect the interpretation of our estimates of the effect of endangered caribou regulation. Like the value of developing the resource, the costs of complying with the regulation are common values for bidders bidding for parcels within zone boundaries. If bidders are subject to the winner's curse, then the winner of a

the regulation, they were still able to earn a sizeable rate of return on their investment. We took this as anecdotal evidence that firms were able to reduce their auction bids by the compliance cost of the regulation and, given that first-price sealed-bid auctions extract all economic rents, were earning the market rate of return on capital.

parcel within a caribou zone will underestimate the cost of regulation and overestimate the value of the parcel. As a result, our estimates of the effect of endangered caribou regulation on the winning auction bid may form a lower bound on the true cost of the regulation. However, if bidders are rational, then they will anticipate the winner's curse and decrease their bids accordingly (Cox and Isaac (1984)); Hendricks et al. (2003) found evidence supporting this prediction. This implies that the winning bid for a parcel within a caribou zone should reflect the true cost of regulation.

5 Results

In this section, we report results from estimating equation (1) under different specifications. We then report estimation results from various robustness checks.

5.1 Baseline estimation results

Table 2 reports coefficient estimates from various specifications of equation (1). Column (1) reports coefficient estimates from a regression where we account for whether a given lease lies entirely within a caribou zone or on its boundary. The coefficient estimate for leases lying inside a caribou zone, in the first row, is equal to 0.0308. The coefficient estimate for leases lying on caribou zone boundaries, in the second row, is equal to 0.2330. Without additional controls in the regression, these coefficient estimates, being positive, reflect the fact that leases lying inside caribou zones or on their boundaries have higher prices on average than leases that are unregulated.

The second and third columns contain the main components of the multidimensional RD approach. Column (2) adds the quadratic polynomial in latitude and longitude. Relative to the estimates for the caribou zone and boundary coefficients in the first column, the estimates in the second column have the opposite sign, indicating that lying inside or on

the boundary of caribou zones imposes a negative effect on the auction price for such leases. Column (3) adds the zone fixed effects that are necessary to compare leases within the same zone region; doing so does not change the caribou zone coefficient estimate much, though the boundary caribou zone coefficient estimate changes sign.

Table 2: Estimates of the effect of regulation protecting endangered caribou on oil sands auction prices

	(1)	(2)	(3)	(4)	(5)
Caribou zone	0.0308	-0.1489	-0.1520	-0.2497**	-0.2732***
	(0.1478)	(0.1129)	(0.0922)	(0.1048)	(0.0926)
Boundary of caribou zone	0.2330	-0.1873	0.1411	-0.0525	-0.0717
	(0.3684)	(0.2780)	(0.2153)	(0.1121)	(0.1128)
Number of joint owners					-0.1484
					(0.2523)
Special access zone					0.3542
					(0.4138)
Key wildlife zone					-0.1320**
					(0.0590)
Log(depth)					-0.2668
					(2.4832)
Quad. poly. in lat/lon	N	Y	Y	Y	Y
Zone fixed effects	N	N	Y	Y	Y
Owner-Year fixed effects	N	N	N	Y	Y
R^2	0.0007	0.0987	0.1589	0.5549	0.5556
Observations	3089	3089	3089	3089	3089

Notes: The dependant variable is the logarithm of price per hectare at the lease level. Robust standard errors, adjusted for clustering by zone, in parentheses. *, **, and *** denote estimates different from zero at the 10%, 5%, and 1% significance levels.

Columns (4) through (5) progressively add several important controls. In column (4), owner-year fixed effects are added as controls alongside the caribou zone and boundary indicator variables, the polynomial in latitude and longitude, and zone fixed effects. The caribou zone coefficient estimate nearly doubles in magnitude. The boundary caribou zone coefficient estimate becomes negative and, consistent with the prediction that boundary leases are

less regulated than leases inside caribou zones, smaller in magnitude than the caribou zone coefficient estimate. These changes in coefficient estimates arise because, without owner-year fixed effects, we account for neither the identity of the lease holder nor the year of sale. The owner-year fixed effects control not only for the volatility in this industry, but also for how winning bids differ across firms and how winning bids, for a given firm, change over time. As the reported R^2 shows, the inclusion of owner-year fixed effects explains a large amount of the variation in lease prices relative to the other controls.

Column (5) adds the key wildlife and special access zone indicator variables as well as the depth variable, the coefficient estimates of which are also reported. The key wildlife zone variable, which indicates whether a lease lies within a biodiversity protection zone, is negative and statistically significant, and implies that complying with biodiversity protection regulation, like complying with the caribou protection regulation, is associated with lower auction prices. The final row reports the coefficient estimate for the logarithm of depth. The sign of the estimate indicates that leases for lower depths have lower auction prices per hectare, consistent with the notion that deeper deposits are more costly to extract. The estimate implies that a 1% increase in the depth of extraction decreases the auction price by about one-quarter of a percent. Additionally, based on the identification discussion at the outset of Section 4.3, the depth variable stuck out as potentially discontinuous across the caribou zone boundary. The lack of statistical significance is suggestive that, conditional on the fixed effects and other covariates, there is no statistical difference in lease depths across the caribou zone boundaries.

To put the caribou zone and boundary zone coefficient estimates from column (5) into perspective, the zone coefficient estimate -0.2732 represents approximately 15% of one standard deviation in the logarithm of price per hectare. This estimate implies that lying inside caribou zone boundaries decreases a lease's per hectare auction price by approximately 24%. At the median and mean prices per hectare in our sample, this amounts to a change of \$32

and \$192, respectively. The boundary zone coefficient estimate -0.0717 indicates that lying partly within a caribou zone decreases the lease's per hectare auction price by about 7% on average. At median and mean prices per hectare in our sample, this amounts to a change of \$9 and \$56, respectively.

In unreported results, we tested for heterogeneity in the effect of regulation by interacting several variables of interest with the zone indicator variables and found little evidence of treatment heterogeneity in the effect of regulation. In particular, we find no evidence that the number of owners has an impact on the effect of regulation. We also tested whether firms which are more experienced in the sense of owning more leases pay less for a lease than firms that own fewer leases. To do so, for each owner and each lease they own, we counted up the number of leases that that owner purchased prior to the purchase of that lease as a measure of prior experience. From interacting this measure of experience with the caribou zone indicator variables, we find no evidence that more experienced owners pay less for leases. Finally, we also tested whether the effect of regulation varies over the business cycle. To do so, we interacted the regulation indicator variables with a quadratic time trend and the West Texas Intermediate price for a barrel of oil, in 2012 Canadian dollars. We found that the magnitude of the effect of the caribou zones decreased when the price of oil was high and increased when the price of oil was low. We do not take this as evidence that there is a differential effect, but that the cost of complying with the regulation stays relatively the same over the business and/or oil price cycle. To see why, note that our dependent variable is the logarithm of price per hectare, which lends an interpretation of the effect of regulation as a percentage. When the price of oil is low, then the effect is a given percentage. When the price of oil goes up, the value of the leases increases, causing auction prices to increase, but the cost of complying with the regulation remains the same; these two factors implying a smaller, in absolute value, percentage effect of the regulation when the price of oil is high than when it is low.

5.2 Sensitivity analysis

In this section, we evaluate the robustness of our baseline estimates by re-estimating equation (1) under different subsamples and specifications. First, we evaluate our regression discontinuity approach by investigating whether our estimates change as we restrict our sample to leases that are nearer to regulation boundaries. Second, we evaluate the robustness of our estimates under different choices of polynomial in latitude and longitude. Last, we consider how our estimates change when using restricted subsamples based on concerns from analyzing summary statistics reported in Table 1.

5.2.1 Distance to caribou zone boundaries

Our first robustness check is to estimate equation (1) with progressively smaller samples based on distance to the nearest caribou zone boundary. Our goal in doing so is to examine the validity of our RD specification, from which we should obtain estimates on the effect of caribou protection that are stable, for a given specification, across subsamples that are closer in proximity around zone boundaries. Our estimates from this robustness check are reported in Table 3. Given the structure of Table 3, this means that a given coefficient estimate is directly comparable to the same-column estimate in Table 2 as well as the in same column, but across panels, in Table 3. In panel A, we narrow our sample to those observations within 30 kilometers of a zone boundary; we choose 30 kilometers because the majority of observations inside caribou zones lie no more than 30 kilometers from the zone boundary. In panels B and C, we narrow the sample to those leases within 15 kilometers and 5 kilometers of a caribou zone boundary, respectively.

In column (1), we control only for whether a lease lies inside or on the boundary of any caribou zone. Although zones are associated with higher prices per hectare in the full sample, this relationship disappears as we narrow the distance bands around zone boundaries. In particular, for all samples in Table 3, the caribou zone coefficient estimate is always

negative, while the boundary zone coefficient is becomes lower in value the shorter is the distance subsample. We take this as an indication that controlling for geographic location in proximity to caribou zone boundaries – which we are partly doing by narrowing the distance bands that define the subsamples – is necessary for identifying the effect of the regulation protecting endangered caribou on auction prices.

Column (2) adds the RD polynomial. The caribou zone and boundary caribou zone coefficient estimates have all decreased in value relative to the same-sample estimates in column (1). Since the coefficient estimates in column (1) decrease in value as we partly control for geographic location by narrowing the distance sample, it is no surprise that the estimates in column (2), which provide greater controls for geographic location, are all lower in value relative to the same-panel estimates in column (1).

Column (3) adds the second component of the RD specification, which are the zone fixed effects. In nearly every panel, the coefficient estimates are lower in absolute value than the estimates in column (2) in the same panel, indicating that not controlling for zone boundaries leads us to overestimate the effect of the regulation.

Column (4) adds the owner-year fixed effects, which decrease the value of each panel's coefficient estimate relative to the column (3) estimate. As was the case in column (3) of Table 2, the inclusion of owner-year fixed effects explains a large amount of the variation in lease prices.

Finally, column (5) adds the lease-specific controls, which do not change the coefficient estimates much relative to the same-panel estimates in column (4).

Column (5) is our preferred specification and is therefore worth a closer examination across the different subsamples. Using the full sample, in Table 2, the coefficient estimate for leases lying inside caribou zones is statistically significant and implies that the regulation decreases lease prices per hectare by 24%. For the 30-kilometer and 15-kilometer subsamples in panels A and B, respectively, the zone coefficient estimate is not statistically significant

Table 3: Estimates of the effect of regulation protecting endangered caribou on oil sands auction prices using subsamples based on distance to caribou zone boundaries

	(1)	(2)	(3)	(4)	(5)
Panel A. Sample falls within less than 30 km of a zone boundary ($n = 1847$)					
Caribou zone	-0.3447**	-0.4078	-0.2776	-0.2623	-0.2795
	(0.1506)	(0.2746)	(0.2340)	(0.1933)	(0.1915)
Boundary of caribou zone	0.0232	-0.2395	0.0417	-0.1098	-0.1320
	(0.2935)	(0.1952)	(0.1494)	(0.1310)	(0.1299)
R^2	0.0080	0.1231	0.2044	0.6043	0.6068
Panel B. Sample falls within less than 15 km of a zone boundary ($n = 1447$)					
Caribou zone	-0.3201*	-0.4191	-0.2237	-0.2713	-0.2858
	(0.1793)	(0.3197)	(0.2502)	(0.1901)	(0.1824)
Boundary of caribou zone	0.0021	-0.1829	0.1454	-0.0729	-0.0955
	(0.2606)	(0.2422)	(0.1853)	(0.1577)	(0.1533)
R^2	0.0066	0.1385	0.2276	0.6338	0.6384
Panel C. Sample falls within less than 5 km of a zone boundary ($n = 824$)					
Caribou zone	-0.5350**	-0.6462**	-0.3560	-0.3991**	-0.3664**
	(0.2018)	(0.2734)	(0.2051)	(0.1570)	(0.1388)
Boundary of caribou zone	-0.0920	-0.3277	0.0106	-0.1730	-0.1523
	(0.2213)	(0.2463)	(0.1687)	(0.1803)	(0.1759)
R^2	0.0157	0.1776	0.2419	0.6834	0.6928
Quad. poly. in lat/lon	N	Y	Y	Y	Y
Zone fixed effects	N	N	Y	Y	Y
Owner-Year fixed effects	N	N	N	Y	Y
Lease-specific controls	N	N	N	N	Y

Notes: The dependant variable is the logarithm of price per hectare at the lease level. The set of lease-specific controls include the number of joint owners, key wildlife zone and special access zone indicators, and the logarithm of depth. Robust standard errors, adjusted for clustering by zone, in parentheses. *, **, and *** denote estimates different from zero at the 10%, 5%, and 1% significance levels.

at conventional levels (though have unreported p-values of 0.16 and 0.13, respectively), and produce similar effects compared to the estimate in panel A. In particular, the caribou zone coefficient estimate in the 15-kilometer subsample implies that regulation decreases the average price per hectare by 25%.

Panel C of column (5) reports the estimate for the 5-kilometer subsample. The coefficient estimate for the caribou zone indicator is similar in magnitude to the estimates using larger subsamples and is statistically significant at the 5% level. The coefficient estimate implies that leases lying entirely within caribou zone boundaries, all else being equal, have auction prices per hectare that are 30% lower than unregulated leases. The coefficient estimates for leases lying on caribou zone boundaries, -0.1523, implies that such leases have auction prices per hectare that are 14% lower on average. The fact that the estimated effect of caribou protection regulation implied by the coefficient estimates in column (5) of Tables 2 and Table 3 are relatively stable across the different subsamples suggests that our empirical approach is valid.

5.2.2 Polynomials in latitude and longitude

Our second robustness check is to evaluate the semiparametric specification in equation (1). To estimate this equation, we have opted to use a series of polynomials in latitude and longitude. Our choice to use a quadratic polynomial is arbitrary, so in this section we will test the sensitivity of our estimates by re-estimating equation (1) with both lower- and higher-degree polynomials in latitude and longitude.

Because owners purchase leases in proximity to one another, the inclusion of owner-year fixed effects leads to collinearity problems with higher-degree polynomials in latitude and longitude. In particular, we cannot usefully employ a quartic or higher degree polynomial, as many of the terms become collinear and their coefficients are not estimable. Even with a cubic polynomial, the inclusion of owner-year fixed effects forces us to drop one of the ten

Table 4: Alternative functional forms for polynomial in latitude and longitude

Sample within:	< 200 km	< 30 km	< 15 km	< 5 km
	(1)	(2)	(3)	(4)
Panel A. Linear polynomial in latitude and longitude				
Caribou zone	-0.2060*	-0.2954	-0.2798	-0.3855**
	(0.1040)	(0.1890)	(0.1853)	(0.1490)
Boundary of caribou zone	-0.0434	-0.1487	-0.1036	-0.1544
	(0.1072)	(0.1237)	(0.1506)	(0.2036)
R^2	0.5539	0.6054	0.6360	0.6863
Panel B. Cubic polynomial in latitude and longitude				
Caribou zone	-0.2930***	-0.1731	-0.2275	-0.3778***
	(0.0915)	(0.2324)	(0.1947)	(0.1250)
Boundary of caribou zone	-0.0719	0.0096	-0.0204	-0.1671
	(0.0943)	(0.1748)	(0.1757)	(0.1776)
R^2	0.5562	0.6069	0.6393	0.6932
Panel C. Ordinary least squares				
Caribou zone	-0.2602**	-0.3542*	-0.3250*	-0.4227**
	(0.0930)	(0.1978)	(0.1646)	(0.1440)
Boundary of caribou zone	-0.0740	-0.1737	-0.1193	-0.1748
	(0.1007)	(0.1251)	(0.1442)	(0.2012)
R^2	0.5527	0.6023	0.6332	0.6858
Zone fixed effects	Y	Y	Y	Y
Owner-year fixed effects	Y	Y	Y	Y
Lease-specific controls	Y	Y	Y	Y
Observations	3089	1847	1447	824

Notes: The dependant variable is the logarithm of price per hectare at the lease level. The set of lease-specific controls include the number of joint owners, key wildlife zone and special access zone indicators, and the logarithm of depth. Robust standard errors, adjusted for clustering by zone, in parentheses. *, **, and *** denote estimates different from zero at the 10%, 5%, and 1% significance levels.

terms due to collinearity.

Table 4 reports estimation results that re-estimate our baseline regressions under different degrees of polynomials in latitude and longitude. Each panel specifies the degree of polynomials used; we consider a linear polynomial in panel A, a cubic in panel B, and a specification that omits latitude and longitude in panel C. The columns indicate the sample in terms of distance of an observation to the nearest zone boundary. Each cell reports estimates of caribou zone or boundary indicator variables, controlling for the specified polynomial in latitude and longitude, the lease-specific controls, and the zone and owner-year fixed effects. The estimates in column (1) are directly comparable to the estimates in column (5) of Table 2. The estimates in columns (2) through (4) are, conditional on the subsample, directly comparable to the estimates in column (5) of Table 3.

Column (1) reports estimates of the effect of caribou zone regulation using different polynomials of latitude and longitude for the entire sample. In Table 2, the corresponding estimate is -0.2732, which is similar to all of the coefficient estimates reported in column (1) of Table 4. Similarly, the baseline coefficient estimate for boundary leases reported in Table 2 is -0.0717, and is virtually the same for all polynomial specifications in column (1). Columns (2) and (3) report estimates from the 30- and 15-kilometer subsamples. The corresponding estimates using the quadratic polynomial, reported in Table 3, are -0.2795 and -0.2858; the linear polynomial estimates are similar to these estimates, while the cubic specification estimates are lower in value, potentially due to overfitting of the data. The OLS estimates in both subsamples are larger in magnitude than the corresponding quadratic specification estimates. These patterns are similar for the coefficient estimates for leases lying on caribou zone boundaries.

For the 5-kilometer subsample, the estimate reported in Table 3 is -0.3664 and is statistically significant at the 5% level. The estimates in panel A and panel B of Table 4 are virtually the same relative to the estimates from the quadratic specification. The OLS esti-

mate of -0.4227, like most of the OLS estimates using any of the subsamples, overestimate the effect of the regulation compared to the specifications that control for the geographic location of a lease. The 5-kilometer estimate for boundary leases in Table 3 is -0.1523 and the estimates using different polynomial specifications in column (4) are virtually the same.

Overall, we take the similarity of estimates in Table 4 compared to our baseline estimation results and the results in Table 3 as suggestive that our RD approach for estimating the effect of caribou zone status is valid.

5.2.3 The effect of endangered caribou regulation in other protection zones

For our final robustness check, we consider how our estimates change using restricted subsamples based on our controls. The identification of the effect of the caribou protection regulation requires that factors affecting oil sands auction prices other than regulation to vary continuously at the zone boundaries. In Section 4.3, we discussed how the means for leases lying in key wildlife zones, which protect biodiversity, differed across caribou zone boundaries. To test the robustness of our estimation results, we re-estimated equation (1) for subsamples of leases lying solely inside or outside the key wildlife zones. Table 5 reports estimation results for this robustness check for the 5-kilometer subsample.

We report coefficient estimates for the caribou zone and boundary zone indicators on the subsample of leases that lie outside of the key wildlife zones and the subsample of leases lying inside the key wildlife zones. About 84% of the 5-kilometer subsample of leases lie outside key wildlife zones, and the coefficient estimates in column (1) of Table 4 are nearly the same as those in column (5), panel C, of Table 3. The estimates for leases lying within key wildlife zones are virtually the same as our previous estimates, even though the number of observations producing this result is quite small. Altogether, we take the estimates reported in Table 5 as evidence in favour of the validity of our empirical approach.

Table 5: Estimates of the effect of regulation protecting endangered caribou from subsamples restricted by key wildlife zone status

	Sample restricted to:	
	Outside key wildlife zones	Inside key wildlife zones
	(1)	(2)
Caribou zone	-0.3500	-0.3792
	(0.2003)	(0.6945)
Boundary of caribou zone	-0.1086	-0.2170
	(0.2021)	(0.6617)
Zone fixed effects	Y	Y
Owner-year fixed effects	Y	Y
Lease-specific controls	Y	Y
R^2	0.7136	0.7824
Observations	698	126

Notes: The dependant variable is the logarithm of price per hectare at the lease level. The set of lease-specific controls include the number of joint owners, the special access zone indicator, and the logarithm of depth. Robust standard errors, adjusted for clustering by zone, in parentheses. *, **, and *** denote estimates different from zero at the 10%, 5%, and 1% significance levels.

6 Discussion

Our results indicate that zoning regulation protecting endangered caribou imposes a significantly negative effect on the auction prices for oil sands leases. In this section, we attempt to put our estimates into context by calculating the total costs of the existing regulation and the costs from a counterfactual scenario where the regulation is applied everywhere. Note that because our identification strategy relies on the price of auctioned leases, our present value total cost estimates are for leases sold during the period of our sample. Since these leases are for oil sands projects that last at least 20 years, the net present value costs we calculate may be incurred past 2030. Also, because our sample includes only leases sold during 2003-2012, our total cost calculations exclude any costs that may be incurred during this time period for leases sold before 2003. Thus, our total cost calculation of the regulation is focused on the net present value of costs incurred for leases sold during 2003-2012.

Though it is outside the scope of this paper to calculate benefits and provide a cost-benefit analysis, we contrast our cost estimates with observed caribou population outcomes described in Section 2. The total cost estimates and how they contrast with observed population outcomes are important for two reasons. First, unlike most scenarios where regulation affects firms, the costs are borne entirely by the government, which uses the auction (and royalty) revenues to fund local public goods. Second, it is difficult to judge the magnitude of the cost estimates without putting them into the context of the goal of the regulation.

Based on our baseline coefficient estimates of caribou zone status in column (5) of Table 2, the estimated effect of the regulation is to decrease the price per hectare of oil sands leases lying inside or partly within zone boundaries by 24% and 7%, respectively. At the mean price per hectare in our sample, these effects amount to approximately $192 and $56, respectively, per hectare. To obtain the total effect of the regulations on auction revenues, we use our estimate of the effect of regulation to calculate total revenues under the counterfactual

scenario where there is no regulation, i.e., $\text{zone}_i = 0$ and $\text{boundary}_i = 0$ for each lease i.[27] The difference between the counterfactual total revenues and the actual total revenues is the foregone total revenues during this time period. In 2012 Canadian dollars, the total foregone auction revenues during 2003-2012, based on our estimates, is about \$577 million.

If our identification approach is valid and auctions are competitive, then the model from Section 4.1 suggests we can use our estimates to calculate the total net present value costs of the regulation. However, the total foregone auction revenues do not represent the true total net present value cost, but rather the total net present value cost discounted by royalties and taxes. Alberta is similar to many resource-producing jurisdictions that apply a royalty on profits, and firms must also pay corporate taxes. The cost of complying with environmental regulation is deductible from royalty payments and corporate taxes, so the net present value of the abatement cost is discounted by these rates. To see this, suppose that the net present value of net revenues from developing an oil sands lease is R, and the cost of complying with the caribou regulation is c. The sum of royalty and corporate taxes is α, so a firm's net present value profits for an oil sands lease in a regulation zone are equal to $(R - c)(1 - \alpha)$. In a competitive first-price, sealed-bid auction, the winning bid is equal to this amount. Our identification approach compares leases where a firm has had to incur such costs to another otherwise identical lease where the firm has not, so the price difference is $c(1-\alpha)$. Although auction revenues may have decreased by this amount for each lease, identifying the true cost of regulation means accounting for the magnitude of royalties and corporate taxes.[28]

Based on the Alberta Royalty Framework, the minimum royalty rate applied to oil sands leases is 25%, while the maximum rate is 40%. The provincial and federal corporate taxes

[27] In other words, for a given lease i and an observed price per hectare p_i, we calculate the counterfactual price per hectare if there is no regulation, denoted here by $\widetilde{p}_i$, as $\widetilde{p}_i = p_i/(1 - 0.24)$ if $\text{zone}_i = 1$, $\widetilde{p}_i = p_i/(1 - 0.07)$ if $\text{boundary}_i = 1$, and $\widetilde{p}_i = p_i$ if both $\text{zone}_i = 0$ and $\text{boundary}_i = 0$.

[28] We also abstract from selection issues, though considering conversations with industry, discussed in Section 4.3.2, we do not believe entry to be greatly affected by the regulations. However, should entry have been deterred, our total cost estimates would represent a lower bound.

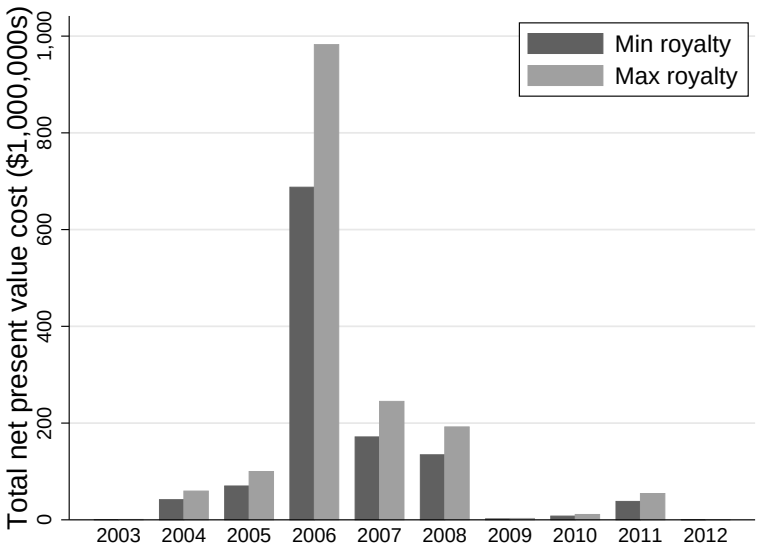


Figure 5: Total net present value cost of regulation for leases under different royalty rates for leases sold during 2003–2012

during this time period are, at their lowest, 10% and 15%, respectively. Figure 5 plots the annual total net present value cost, based on our estimates, for leases sold during 2003-2012 across the minimum and maximum royalty rates. In 2012 Canadian dollars, the minimum and maximum total net present value costs of the existing regulation for leases sold during this period are $1.15 billion and $1.65 billion, respectively. To put these numbers into perspective, these amounts represent approximately more than 25% of oil sands auction and royalty revenue generated in Alberta in 2012, approximately 3% of all oil sands revenue generated between 2003 and 2012, and about 2% of total nonrenewable resource revenue generated between 2003 and 2012.[29]

We also consider a counterfactual scenario where the regulation is expanded across the province for our sample period, i.e. $\text{zone}_i = 1$ for each lease i. To obtain the total cost estimates for this counterfactual, we compare the total auction revenues when there is no regulation to the counterfactual total auction revenues if regulation is expanded, and then

[29]For royalties revenue data, see `http://www.energy.alberta.ca/About_Us/2564.asp`.

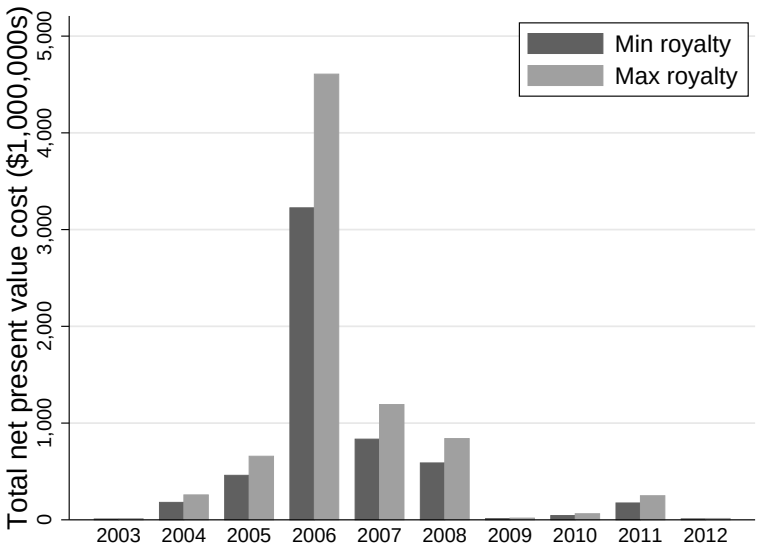


Figure 6: Total net present value cost of counterfactual expanded regulation under different royalty rates for leases sold during 2003–2012

account for the royalty and tax rates described above. We plot the annual total cost estimates in Figure 6 for the minimum and maximum royalty rates. We find that the costs incurred from leases sold during this period would increase dramatically relative to the existing cost of the regulation: the expanded regulatory policy would cost, $5.54 billion at a minimum and, at a maximum, $7.91 billion.[30]

That endangered species regulation inhibiting resource development imposes significant aggregate costs is perhaps not altogether surprising. What is surprising, in contrast to the total cost estimates, is how the caribou are faring under this regulation. The wildlife protection zones are meant to protect endangered caribou from further population declines, yet as Hervieux et al. (2013) document and as Figure 1 depicts, these populations are in continued decline, and some herds are at serious risk of extirpation.

Naturally, one may ask why the government would undertake this approach, given its costs and the observed outcomes. Though one may speculate as to motivations, we can offer

[30]If regulation were fully expanded during this time, this might induce a greater likelihood of non-entry for certain leases, though this would obviously depend on the option value of developing the lease.

some facts that are suggestive. First, the provincial government is legally bound, by its own *Wildlife Act*, to protect species at risk using this type of approach. Second, if the provincial government fails to substantively protect at-risk species, then the federal government is mandated under the *Species at Risk Act* to step in and preempt provincial authority. In 2013, compelled by a federal court ruling in 2012, the federal government did just that for the caribou.

Finally, various commissions formed by the provincial government – see Dzus (2001) and ASRD and ACA (2010) – have provided numerous recommendations on how to improve regulations to curb population declines. Nearly all recommendations have been accepted, except for the recommendation that a temporary moratorium be imposed on the sale of oil sands leases within critical habitat areas. This suggests that the regulator believes the value of resource development may be too high to impose the remaining regulatory option of a moratorium. An alternative approach, suggested by the literature on 'efficient conservation,' prescribes choosing certain caribou herds over others on the basis of the quality of the resource they reside on (see Ando et al. (1998) for an overview, and Schneider et al. (2010) and Schneider et al. (2012) for the case of oil sands and caribou in particular). However, such a flexible regulatory approach is not permissible under current at-risk species legislation in Alberta, or anywhere else in North America.

7 Conclusion

In this paper, we estimate the effect of endangered species protection on auction prices for the right to develop natural resources. Our identification is based, in part, on the assumption that bidders for natural resource rights will capitalize the net present value cost of environmental regulation into their bids. The remainder of our identification strategy exploits the sharp and discontinuous change in endangered species protection across regulation

boundaries by using a spatial regression discontinuity approach to estimate the effect of the regulation on auction prices.

Our application focuses on the sale of leases to produce oil sands in the Canadian province of Alberta between 2003 and 2012, some of which are subject to land-use regulations that aim to protect endangered woodland caribou. We find that the regulation decreases lease prices per hectare by approximately 24% on average, which at the sample mean implies a decrease of $192 per hectare in 2012 Canadian dollars. Aggregating over our sample and accounting for the resource royalty structure, we find that the total net present value cost of the regulation for oil sands leases sold during 2003-2012 is at least $1.15 billion in 2012 Canadian dollars. This cost represents 2% of total nonrenewable resource revenues in Alberta over this time period. In spite of these considerable costs, the populations of the endangered caribou remain in steep decline.

In light of strained resources aimed at protecting endangered species and the growing complexity of doing so, a long literature has argued that society should select, on the basis of efficiency, which at-risk species to protect (see, among others, Ando et al. (1998)). Such efficient conservation requires credible measures of costs and benefits in protecting individual endangered species. This paper has shown that the cost component of species protection can be identified and estimated from land prices for resource development. Further, our cost estimates of Alberta's caribou protection regulation and its demonstrated lack of effectiveness suggest that evaluating the costs and benefits of protecting individual subgroups of a given species may be required to save the species from extirpation and/or extinction. Since extinction rates are predicted to only increase in the future (De Vos et al. (2015)), policies that rely on credibly measured costs and benefits will be even more critical to efficiently protect wildlife.

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