J. Kenneth Jung
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July 4, 2025

Dear Hiring Committee,

I write to apply for the Assistant Professor position at the Department of Resource Economics and Environmental Sociology at the University of Alberta. As a practitioner of industrial organization tools applied to questions in resource economics during my PhD candidacy at Yale University, I am excited at the prospect of advancing my research agenda at an interdisciplinary department like REES. I further hope to meaningfully contribute to the broader academic community at the University of Alberta and foster interdepartmental collaboration.

My research demonstrates how methods from industrial organization can illuminate environmental policy questions involving strategic interactions. My job market paper examines timber auctions designed to control the mountain pine beetle outbreak using structural methods to model the behavior of logging firms and measure policy counterfactuals. Similarly, my work on fishery buybacks identifies novel channels through which license retirement programs affect market outcomes, employing structural modeling to evaluate alternative policy designs. This approach allows me to address fundamental resource management challenges while making methodological insights relevant to both social and physical scientists.

In a similar vein, my teaching philosophy emphasizes inclusive, responsive pedagogy that removes barriers to student success. As a Teaching Fellow across environmental economics, econometrics, and other courses, I have redesigned course structures to improve accessibility—transforming office hours, creating peer learning environments, and developing clear materials with real-world examples. I work individually with students facing diverse challenges while building supportive learning communities through collaborative discussions and structured peer interaction.

As an active participant of both the Department of Economics and the School of the Environment at Yale University, I believe that my interdisciplinary orientation aligns with your department's mission. I describe my background and philosophy toward research and pedagogy in further detail in the enclosed materials. I am excited for the potential opportunity to contribute to the University of Alberta's research community and inclusive education mission.

Thank you for your consideration.

Sincerely,

Ken Jung

J. Kenneth Jung

Ph.D. Candidate in Economics

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Research Interests

Primary Fields: Industrial Organization, Environmental and Resource Economics

Education

Yale University, New Haven, CT

Ph.D., Economics 2025 (expected)
M.Phil., Economics 2022
M.A., Economics 2021

University of Chicago, Chicago, IL

B.A., Economics 2017

Dissertation

Title: Essays in Industrial Organization and Resource Economics

Comprehensive Examinations

Oral: Industrial Organization, Political Economy
Written: Microeconomics, Macroeconomics

Research

Job Market Paper

"Moral Hazard in Resource Extraction: Evidence from the Mountain Pine Beetle Outbreak"

Work in Progress

"Additionality and Leakage in Equilibrium" *with Andrew Vogt*
"Aircraft Leakage under Cap and Trade" *with Meichen Chen and Miho Hong*

Teaching Experience

Yale College

Teaching Assistant Spring 2025
Introduction to Data Science and Econometrics (Prof. John Eric Humphries)

Teaching Assistant Fall 2023–Spring 2024
The Senior Essay (Prof. Rebecca Toseland)

Teaching Assistant Spring 2023
Intermediate Econometrics (Prof. Edward Vytlacil)

Teaching Assistant Fall 2022
Environmental Economics (Prof. Robert Mendelsohn)

Teaching Assistant Spring 2022
Industrial Organization (Prof. Philip Haile)

Teaching Assistant Fall 2021
Intermediate Microeconomics (Prof. Evangelia Chalioti)

Research Experience

Research Assistant Summer 2023
Yale University (Prof. Nicholas Ryan)

Research Assistant 2017–2019
Massachusetts Institute of Technology (Prof. Amy Finkelstein)

Presentations

Conference and Seminar Presentations:

London School of Economics and Political Science, Environment Camp 2025
University of Colorado at Boulder, Environmental and Resource Economics Workshop 2023

Professional Service

Referee Service: American Economic Review

Additional Information

Languages: English (native), Korean (intermediate), French (beginner)

References

Prof. Katja Seim
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Moral Hazard in Resource Extraction: Evidence from the Mountain Pine Beetle Outbreak [Job Market Paper]

Abstract. Natural resource owners often design and auction the rights to extraction contracts not only to raise revenue, but also to achieve other resource management goals of interest. I study the tradeoff between revenue and the timing of extraction in the context of the mountain pine beetle outbreak, a climate-induced shock that increased the urgency of timely harvests in infested forests and eventually killed about half of British Columbia's merchantable timber supply. I show that the use of a negligible fixed price for the harvest of low-grade timber succeeded in ensuring the salvage of beetle-killed trees, but also made it profitable for loggers to delay the harvest of attacked forests. This delay ran counter to the province's goals by allowing pupating beetles to mature, posing an externality by threatening to neighboring forests. A regression discontinuity for payment formats in timber auctions reveals that harvests in tracts that charge low-grade logs at the fixed price are 3.6 months more delayed. To measure the effects of counterfactual pricing schemes, I estimate a dynamic resource extraction model and show how the timing of harvests depends on tract characteristics, including the severity of beetle attack. I use the model to quantify the delay reduction and revenue loss from counterfactual pricing and term length policies. I show that the province's contract designs were frequently interior of the optimal frontier between revenue and delay, indicating substantial gains to alternative pricing policies targeted toward beetle-infested tracts.

Statement on Inclusion

My teaching philosophy emphasizes meeting students where they are, both academically and personally. I have worked extensively with students facing various challenges, from those struggling with mental health issues—whom I helped connect with campus resources—to students encountering coding difficulties, with whom I spent hours troubleshooting scripts line by line. When developing teaching materials for environmental economics, I prioritized accessibility by creating clear explanations of concepts ranging from competitive equilibria to environmental justice, supplemented with real-world examples and recent research applications. All materials were made available as PDFs online to ensure broad accessibility. This approach reflects my belief that academic excellence and inclusivity are not competing goals but rather mutually reinforcing elements of effective education. In my future role, I will continue to prioritize accessible pedagogy, proactive student support, and the creation of learning environments where all students can thrive regardless of their starting point or background.

My approach to fostering equity and belonging in teaching centers on creating inclusive learning environments that recognize and respond to students' diverse backgrounds and needs. Through my experience as a Teaching Fellow across environmental economics, econometrics, and other courses, I have learned that effective teaching requires moving beyond one-size-fits-all approaches. For example, when redesigning the structure of the Senior Essay course for those seeking to write a bachelor's thesis in economics, I changed the traditional appointment-based office hours into accessible walk-in sessions after observing that the existing system was underutilized. This simple change dramatically increased attendance and created a more welcoming space where students could drop in to work individually or seek help as needed. I also established regular roundtable meetings where students could present their work formally or discuss progress informally, providing structure while maintaining flexibility. These innovations emerged from listening to student needs through surveys and direct feedback, demonstrating my commitment to responsive pedagogy that adapts to serve all learners effectively.

Similarly, in approaching research I believe that breaking down artificial barriers is essential for fostering collaborative relationships across academic communities and advancing work that holds meaning to broader audiences. For example, at my home institution I noticed a somewhat artificial separation between the Department of Economics and the economics group at the Yale School of the Environment (YSE) in spite of their shared research interests. During my time as a PhD candidate, I actively participated in the environmental economics seminars at YSE and befriended many in the community. These efforts led to many fruitful discussions about research with students and faculty, presentation of my own research at the YSE Forest School, as well as coauthorship with an environmental economics PhD student. This experience taught me the importance of creating bridges between communities and the value of cross-disciplinary collaboration. I also co-founded Industrial Organization Tea, a forum for economics PhD students to share their work in a supportive and collegial setting. Just as in my coordination of roundtable meetings for the Senior Essay, my organization of IO Tea shaped my understanding of how intentional community-building efforts can cultivate belonging across diverse academic spaces.

Research Statement

My research agenda applies industrial organization (IO) methods to pressing questions in environmental and resource economics. This intersection proves particularly fruitful because many environmental policy questions inherently involve strategic interactions between firms, government agencies, and other stakeholders—precisely the types of complex market dynamics that industrial organization is designed to analyze. My work demonstrates how tools traditionally used to study competition and market structure can shed light on critical environmental policy questions that require understanding both the underlying resource dynamics and the strategic behavior of economic agents.

My job market paper exemplifies this approach by examining how climate change-driven environmental shocks create urgent policy design challenges. I study the mountain pine beetle outbreak that threatened western North American forests, focusing on how policymakers designed timber auctions to encourage rapid harvesting while maximizing revenue. The key insight is that effective policy design required understanding how logging firms' harvesting decisions depend on resource quality, how they form beliefs about beetle spread patterns, and how they compete with each other for harvesting rights. By modeling these strategic interactions through structural methods, I am able to measure the full effects of different auction designs. Similarly, my coauthored work on additionality in fishery buybacks addresses the question of additionality in environmental economics: how can policymakers determine whether paying someone to change their behavior actually did so? We identify a novel channel where buyback programs increase the value of remaining licenses by reducing competition, and find preliminary evidence of this mechanism in Texas shrimp fisheries. Our ongoing work involves modeling shrimping behavior as a function of buyback opportunities and market conditions to answer whether gradual versus immediate fund disbursement would improve program effectiveness. This, again, is a policy counterfactual that requires structural modeling techniques central to industrial organization.

I am attaching my job market paper draft, which is currently incomplete and contains just reduced form results so far. The project is progressing rapidly, as I am currently computing policy counterfactuals using estimates from my structural model. These counterfactual simulations are time-consuming to run and test, with the first round of results having just finished recently. I am happy to append the next set of results to the paper in the coming week or two upon request.

Moral Hazard in Resource Auctions: Evidence from the Mountain Pine Beetle Outbreak

Kenneth Jung*

June 30, 2025

Abstract

Natural resource owners frequently design and auction the rights to extraction contracts in order to raise revenuewhile achieving resource management objectives. I study the tradeoff between revenue and the timing of extraction in the context of the mountain pine beetle outbreak, a large climate-induced shock that increased the urgency of timely harvests in infested forests. I show that the use of quality-adjusted pricing in British Columbia timber auctions made it profitable for firms to salvage value from beetle-killed trees, but also provided incentives to delay the harvest of decaying trees. This delay ran counter to the province's goals by allowing pupating beetles to mature, posing a threat to the health of neighboring forests. I use a regression discontinuity for bidding formats to show that harvests in auctioned tracts that implement quality-adjusted pricing are 3.6 months more delayed than tracts that do not. To measure the effects of counterfactual pricing schemes, I estimate a dynamic resource extraction model in which the timing of harvests depends on lumber prices and tract characteristics, including the severity of beetle attack. I demonstrate that the province's contract designs were frequently interior of the optimal frontier between revenue and delay, indicating substantial gains to alternative pricing policies targeted toward beetle-infested tracts.

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1 Introduction

Natural resource owners often aim to advance a range of conservation, management, and revenue goals when designing extraction contracts with firms. In many settings, the timing of extraction is a key factor in achieving such objectives. This consideration grows in importance and complexity when the resource evolves dynamically, as is common in biological resources that undergo growth or decay; moreover, shorter delays in extraction are particularly crucial when earlier action can prevent losses due to fires or disease.

I study contract design and extraction behavior in a setting where both characteristics are present: timber auctions for forests affected by the 1999-2015 mountain pine beetle outbreak in British Columbia. The scale of the outbreak, which killed approximately half of the merchantable conifers in the province, forced the government to pursue multiple objectives. First, the government sought to increase the harvest of dead trees in order to salvage logs that were rapidly losing their economic value. Second, as the owner of virtually all of forested land in the province, the government aimed to prevent the further spread of the beetle to nearby areas. For timber harvesting rights that were sold by auction, each these objectives could be met by policy levers that came with potential effects on the other objectives. Most straightforwardly, auctions with shorter term lengths, which reduce harvesting delays by giving the winner less time to complete extraction activities, would earn lower revenues if bidders place value on the option to harvest later. Similarly, designating an auction as lump sum, which demands payment from the winner upfront, lowers delay times compared to scaled auctions, which charge the winner's bid per unit of wood extracted over the course of harvesting; however, in this case the lump sum format was also complementary to the salvage objective because it eliminated payments for the logging of trees of lower quality, making them more valuable to firms.

An interesting peculiarity of scaled timber auctions as implemented by British Columbia relates to the incentives it sets up to salvage dead trees. This feature is that harvest payments in scaled auctions are in fact adjusted for quality, such that a fixed price of C$0.25 per cubic meter instead of the winner's bid is charged to logs deemed to be of lower grade at the time of harvest. The low-grade price, also known as the price for "reject sawlogs", is widely acknowledged by both industry observers and the government to be more than low enough to ensure that logging dead trees is profitable. Indeed, its small size has been justified on the grounds that scaled auction participants will increase their bids, which apply only to high-grade logs, in order to compete on the surplus they anticipate deriving from reject sawlogs. However, the rapid onset of checking and other defects in beetle-attacked trees raises the possibility that their subsequent loss in value is offset by the reduction in harvesting payments if they qualify as reject sawlogs. This hypothesis

Figure 1: Time Series of Provincial Timber Prices and Auction Bids

../temp/ts.pdf

is supported by Figure 1, which graphs average monthly log prices in British Columbia by quality ("sawlog" versus "pulpwood") over time together with average bids in timber auctions. Since pulpwood logs are typically eligible for the low-grade price which is two orders of magnitude smaller than most scaled bids, it is striking that they retain a value in the open market that is about half of that of sawlogs on average. Thus, the winner of the auction may find it profitable to delay harvests in forests with such trees, allowing them to degrade and working against the goal of extracting quickly to prevent the spread of the beetle.

In order to assess the total effect of auction format on logging delays, I exploit a threshold rule used to designate auctions as scaled or lump sum. Since lump sum auctions were intended to reduce the cost of measuring harvests in tracts of lesser value, they were assigned to all tracts in which the estimated share of beetle-killed conifers by volume exceeded 35 percent. For tracts with a lower share, most auctions were sold as lump sum.

I apply a fuzzy regression discontinuity design to recover the effect of auction format on the time between the announcement of the winning firm and the commencement of logging. I find that the lump sum auctions are 3.6 months less delayed than scaled auctions at the threshold, a result that is robust to the inclusion of controls for term lengths and other variables. Interestingly, there is no statistically significant effect on auction revenues at the same threshold. These estimates thus indicate that lump sum auctions appreciably reduce harvesting delays at no measurable cost to the province, but their size bundles together both of the anticipated effects of auction format on delays described above. In other words, the regression discontinuity does not separately identify timing distortions caused by per unit payments in scaled auctions from those caused by the small size of the reject sawlog price in scaled auctions.

To disentangle these mechanisms from each other, I use bid and harvest data to estimate an auction model in which bidders account for the expected value of the dynamic extraction problem that follows in the event that they win. In the dynamic part of the model, the winning firm decides how much, if any, of the remaining timber to extract each month until the end of the contract term. In addition to the remaining time and stock of trees, the relevant states that enter this decision are a market index based on macroeconomic variables, the idiosyncratic cost of logging that month, and the quality of the representative tree in the forest. I leverage reports that quantify beetle-caused damage just prior to the auction to construct the last state, so that tree quality evolves stochastically but is only observed by the econometrician during the initial period. In both auction formats, the winning firm trades off the profit of selling higher-grade trees by harvesting earlier against the opportunity cost of foregoing potentially more favorable future market conditions. However, only in the scaled auction does the firm reduce harvesting payments by selling more logs of lower quality, thus capturing the channel by which the low price of reject sawlogs may lead to delay. At the stage of the auction, bidders thus form valuations on both their private costs and the expected value of the dynamic program.

These results relate to empirical work that studies the effects of contract design on the timing of resource extraction, almost all of which study oil drilling (Herrnstadt, Kellogg, and Lewis 2023; Anderson, Kellogg, and Salant 2018). Of these, the most closely related is Bhattacharya, Ordin, and Roberts (2022), who study the effects of auction formats and contingent payments on the likelihood of extraction activity. I contribute to the findings of these papers in several ways. First, I study a setting in which the resource changes in value over time for reasons separate from fluctuations in its demand, a feature that is present in any resource that features dynamics through some kind of growth or decay process. My methods and results are thus more widely applicable to agricultural or aquacultural resources, bringing the real options literature closer to classic theories of extraction dating back to Faustmann (1849). Second, in the context of the beetle outbreak, early extraction confers benefits to non-participants by preventing the destruction of additional resources. This feature is unique to this study but applicable to biological resources in which the mitigation of fire or blight is a policy objective[1]. In valuing the loss in social welfare stemming from tree mortality in particular, I also draw from Druckenmiller (2020), who uses a phenological model of bark beetle survival as an instrument.

This paper also relates to a couple strands of literature on empirical auctions. For example, outside of the timing of extraction, moral hazard is of concern for other reasons in common value resource auctions, power procurement, and construction procurement (Nguyen 2023; Ryan 2020; Bajari and Lewis 2014). In addition to the innovations I mentioned above, I explore contract dimensions such as quality-adjusted prices that only apply to resources or services that are heterogeneous in composition. This also makes my work closer in spirit to that of Paarsch (1993), who studied the effect of scaled and lump sum payment formats on timber recovery. Further, a number of papers study the differences between auction formats in terms of the information structure (Haile, Hong, and Shum 2006), attitudes toward risk (Vasserman and Bolotnyy 2023; Athey and Levin 2001), or the composition of bidders (Athey, Levin, and Seira 2011; Krasnokutskaya and Seim 2011). In contrast, I emphasize extraction delays across formats as the outcome of interest, but draw from the same set of methodological tools to study equilibrium bids (Guerre, Perrigne, and Vuong 2000; Athey and Haile 2005).

2 Empirical Setting

2.1 The Mountain Pine Beetle Outbreak in British Columbia

The mountain pine beetle is a wood-boring insect that attacks many species of pine trees in western North America. The outbreak of 1996-2022 saw the population of the beetle reach epidemic proportions and expand in geographic range throughout United States and Canadian forests. By 2017, the cumulative loss in Canadian pine trees that could have been sold was 752 million cubic meters, accounting for 58% of the commercial stock; in British Columbia, the province that regularly accounts for the largest share of Canada's lumber supply, about half of all commercial lodgepole pines have been attacked across 18 million hectares, or 30% of the province's total forested area. The beetle's

[1] Hsiao (2024) studies deforestation for palm oil, in which extraction instead harms social welfare through the release of carbon. However, the focus of that paper is on international coordination rather than contract design for individual resource stocks.

spread to epidemic levels is widely thought to be a consequence of global warming due to successive mild and short winters that took place during the outbreak, allowing a larger share of pupating beetles to survive. The unprecedented scale of the outbreak is thus an extreme example of the risks to biological resources that climate change is considered to exacerbate. Indeed, the increased severity of fires and flooding in Canadian forests is often attributed to beetle-caused tree mortality.

The government of British Columbia, which owns 95% of the forested land in the province, attempted to implement a wide range of policies in response to the outbreak. As these policies pertained specifically to the extraction of forest resources, they largely took the form of increasing quotas on the amount of timber that could be harvested in areas most affected by the beetle. This was done in service of two broad objectives, those of "sanitation" and "salvage," which were intended to respectively control the spread of the beetle and recover attacked trees that were losing value. For example, quota increases between 2001 and 2004 were targeted toward areas lying at the frontier of the outbreak with the purpose of protecting neighboring forests; further, even as containing the outbreak after 2004 proved futile in those same areas, their quotas continued to increase in order to sustain the salvage effort. Indeed, the lump sum payment format that is a focus of this paper did not see widespread use until the quota increase of 2010, and aided in enabling the quota increase by lowering the administrative cost of having to grade and measure logs under the scaled format.

I study the institution of British Columbia Timber Sales (BCTS), the agency that sells approximately 20% of the annual timber harvest by first-price sealed-bid auction. Since BCTS auction outcomes are used to price all other timber in British Columbia, tracts sold by auction are selected to have provincially representative characteristics, making them an attractive sample of harvests to study. Moreover, the sanitation and salvage objectives were present in auctioned tracts, but it appears unclear how effective BCTS was in achieving them. For example, numerous auction advertisements prior to 2006 request that the winning firm cuts down beetle-infested pines prior to July, when the beetles were expected to emerge from the bark and take flight[2]; however, nowhere in the accompanying documents to the posting are any rewards or penalties for compliance mentioned. Similarly, scaled auctions—in which the winning firm pays their bid per unit of logs harvested—contain waste fees for trees left standing, but their efficacy in enforcing salvage has been questioned on the grounds that waste is difficult to measure and assess[3].

[2]An example from Timber Sales License A78645: "The objective of this timber sale is to remove the current Mountain Pine Beetle infestation prior to the 2006 flight. The licensee will be expected to make a reasonable effort to dispose of as much infested lodgepole pine by July 15, 2006 as is possible."

[3]Notably, waste assessment requires surveyors to make a distinction between "avoidable waste" and "unavoidable waste". The latter category, which refers to trees that were physically inaccessible or unsafe

I thus focus on three features of BCTS auctions: term lengths, lump sum payments, and the low-grade price described in the previous section. Despite the fact that these contract dimensions were not necessarily employed for the explicit purposes of sanitation or salvage, they set up incentives that were quite consequential for those goals. For example, despite the exhortations to log beetle-infested trees quickly in the auction postings mentioned above, it is unclear to what extent term lengths were actually shortened in all but the most extreme cases. More prominently, the low-grade price of $0.25 per cubic meter dates back to the 1980s, but was still the subject of a 2011 trade dispute in which the United States accused British Columbia of using the outbreak to systematically misgrade logs. This allegation, which was dismissed in the London Court of International Arbitration ruling in favor of Canada, is distinct from the mechanism I study in which loggers may delay extraction in order to take advantage of the low-grade price. Nevertheless, statements made by the Canadian defense indirectly support this hypothesis in two ways. First, they acknowledged that firms derive value from the price of low-grade logs and incorporate this source of surplus into their bids[4]. Second, the defense cited research showing that "checking"—the main defect that determines how a log is graded—can increase in severity within a matter of months[5]. Finally, the government recognized the need to reduce the share of beetle-attacked logs that was billed under the low-grade price, prompting a redesign of the entire grading system in 2006.This suggests that the province was concerned about the low-grade price failing to reflect the commercial value of dead logs, and perhaps that the returns to delaying harvests were larger during the earlier years of the outbreak.

3 Data

The primary dataset consists of 1,350 scaled auctions and 1,195 lump sum auctions that BCTS held between 2007 and 2022. This sample is restricted to timber tracts lying with the interior region of British Columbia, which was much more heavily impacted by the mountain pine beetle than the coast. Auction variables include all winning and losing bids—together with the identities of the bidders—as well as the reserve price. There variables are complemented with tract characteristics such as area, net merchantable wood

to log, is not billed.

[4]"When assessing what price to bid for the Grade 1 and 2 [timber] of the stand...bidders will incorporate any value of the Grade 4 timber in that stand that exceeds the $0.25 price for that Grade 4." Rejoinder by Canada (2012).

[5]"Researchers have distinguished early Red Stage from late Red Stage and have found moderate drying and little checking at the early stage and more substantial drying and increased likelihood of checking at the late stage." Rejoinder by Canada (2012)

volume, tree mortality rates, and beetle attack rates that are taken from pre-auction estimates. Finally, I observe the date at which harvesting operations begin and end, so I construct the harvesting delay relative to the auction date as well as the harvest duration.

Table 1: Summary Statistics

	Scaled		*Lump Sum*	
	Mean	Std.Dev.	Mean	Std.Dev.
Reserve Price ($/m^3 or $)	26.76	13.10	366,711.47	392,570.79
Winning Bid ($/m^3 or $)	43.45	24.34	635,344.31	783,341.30
Predicted Volume (m^3)	27,214	18,487	30,393	24,357
Area (hectares)	86.34	75.51	141.11	127.53
Term (months)	18.96	5.76	19.32	5.88
Predicted Live Share	0.66	0.26	0.35	0.23
Predicted Green Attack Share	0.01	0.03	0.03	0.04
Predicted Red Attack Share	0.01	0.06	0.04	0.09
Predicted Grey Attack Share	0.06	0.10	0.46	0.26
Delay to Harvest (days)	208.06	204.09	240.69	242.44
Harvest Duration (days)	226.28	324.03	295.27	440.23
Observations	1350		1195	

Summary statistics broken down by auction format are displayed in Table 1. Definitionally, reserve prices and bids are not directly comparable across auction formats: the average scaled bid is $43 per cubic meter, whereas the average lump sum bid is $635,344. However, scaled and lump sum auctions are clearly not balanced in terms of charateristics that share comparable units either: the share of trees estimated to be live in lump sum auctions (35%) is much smaller than in scaled auction (66%). This was to be expected, since the policies discussed earlier targeted lump sum bidding toward tracts of lower value. On the other hand, lump sum tracts are substantially larger in area and contain a higher total volume of wood than scaled tracts.

The green, red, and grey attack variables refer to the share of the total volume that was estimated to have been in the respective stage of attack by the mountain pine beetle. Green attack refers to the early stage within about one year of beetle attack in which a tree's needles still retain their green color. This is followed by red attack, in which the tree loses its red needles, until none are left during the grey attack stage. The distinction between these stages is useful for quantifying the expected development of defects in attacked wood over time, as the following section will show. Presently, it is clear that all three stages of beetle attack are more severe in lump sum auctions, though grey attack is by far the most pervasive in both formats. This reflects the fact that the beetle outbreak was already beginning to subside by the start of the sample period in 2008, so that most affected tracts had been exposed to the beetle multiple years in the past.

4 Descriptive Evidence

I proceed to demonstrate how the value of beetle-attacked trees are captured in auction bids and harvesting behavior through a series of descriptive exercises. First, I regress winning and average bids on tract characteristics separately for the scaled and lump sum samples. I report the coefficient estimates in Table 2. Since the tracts may differ in terms of unobservables that also affect bids, these estimates are not directly interpretable as causal relationships between tract characteristics and bidder valuations; moreover, comparisons of effects between scaled and lump sum auctions are limited by the fact that bidding formats are not randomly assigned. Nevertheless, I argue that the patterns shown here align strongly with the institutional features of this setting as well as as the known development of defects that come with the stages of beetle attack.

Several results are intuitive. First, winning and average bids in both formats increase in the quantity and quality of trees, as shown by the positive coefficients on volume and the live share. Second, the green attack share tends to decrease with bids across specifications. This is unsurprising because green attack is deemed to be of lower quality than a healthy unattacked tree but higher in quality than a dead tree. The green attack coefficient is thus measurably separate from the live share, which has its own independent variable. Finally, the grey attack share seems to have a large positive relationship with scaled bids, but becomes smaller and statistically weaker in lump sum bids; indeed, the size of the coefficient is similar to that of the green attack share. I interpret this as evidence that bidders compete for the surplus that the \$0.25/m^3 provides for beetle-killed logs. This happens to be consistent with industry reports that pines in the grey attack phase tend to fall consistently within the low-grade category, but retain much of their value over a “shelf life" extending multiple years. I show robustness of this set of results, including in a pooled sample with a full interaction of regressors with a lump sum indicator, in the appendix.

Next, I use data on harvest outcomes in order to show that delay causes appreciable decay within the term length of timber contracts, and is therefore empirically relevant to this setting. To do this, I use payment data from the Harvest Billing System, which records the amount of wood harvested from each scaled auction tract at a monthly frequency. These harvest volumes are aggregated by species and grade, meaning that the share of lodgepole pine—the preferred species of the mountain pine beetle—that was billed at the

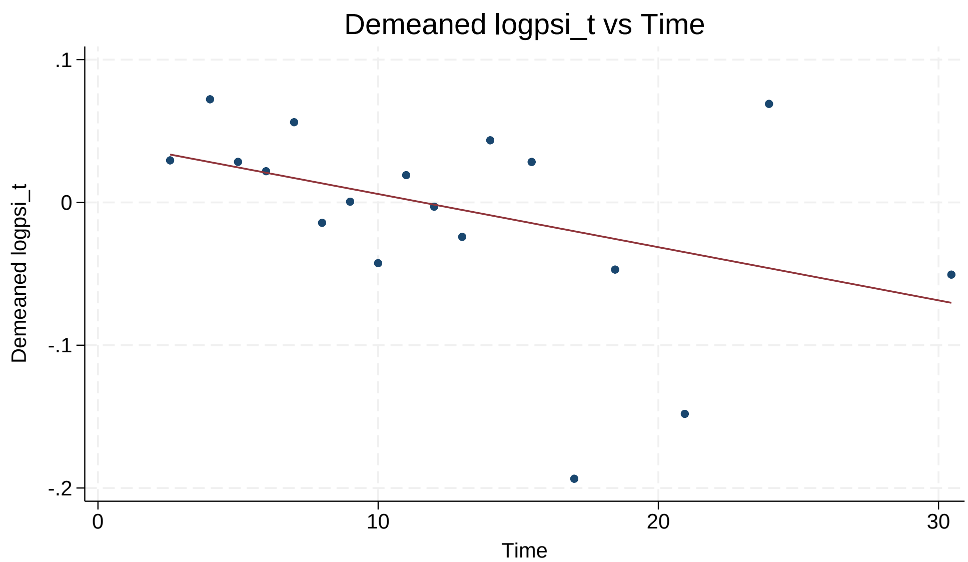
Table 2: Regression of bids on auction characteristics

	(1) Log Winning Bid	(2) Log Winning Bid	(3) Log Average Bid	(4) Log Average Bid
Log Volume	0.21^{***}	0.77^{***}	0.21^{***}	1.67^{***}
	(0.05)	(0.06)	(0.05)	(0.06)
Live Share	0.27^{***}	0.56^{***}	0.26^{***}	0.61^{***}
	(0.06)	(0.16)	(0.06)	(0.15)
Green Attack Share	-1.33^{**}	-1.44^{***}	-1.06^{*}	-1.54^{***}
	(0.49)	(0.41)	(0.46)	(0.40)
Red Attack Share	0.71^{*}	0.22	0.52	0.27
	(0.34)	(0.28)	(0.33)	(0.27)
Grey Attack Share	1.10^{***}	0.31^{*}	1.00^{***}	0.31^{*}
	(0.29)	(0.13)	(0.28)	(0.13)
Term	-0.07^{*}	0.01	-0.07^{*}	0.02
	(0.03)	(0.04)	(0.03)	(0.04)
Log Area	-0.14^{**}	-0.75^{***}	-0.15^{**}	-0.67^{***}
	(0.05)	(0.06)	(0.05)	(0.06)
Sample	Scaled	Lump Sum	Scaled	Lump Sum
N	1350	1195	1350	1195

Note. Standard errors in parentheses. All specifications include region-year as well as calendar month fixed effects. Lump sum bids are divided by total volumes in order to improve the comparability of units and effects.

low-grade, reject sawlog price of \$0.25/m^3 is known each month. If delay causes decay, then the share of pines graded as reject sawlog should increase over time. In Figure 2, I show that this is true by graphing a binned scatterplot of the log share of high-grade (not reject) pine sawlogs over time, where measurements from the same tract are demeaned in order to make units comparable across tracts. The plot shows a strong and statistically significant slope of -0.021, which translates directly into a decay rate that will be used for estimation of the full model.

Figure 2: Log High-Grade Share of Monthly Pine Harvest



4.1 Regression Discontinuity Analysis of Extraction Delays

I now show how I exploit the threshold rule used to assign auction formats to recover the effect of scaled and lump sum payments on harvesting delays. In the years following its inception in 2004, scaled contracts were used almost exclusively by BCTS as well as the Ministry of Forests more broadly. However, this changed as salvage became a higher priority over sanitation for the province, leading to the systematic introduction of lump sum auctions in the summer of 2010 throughout the British Columbia interior. From that point thereafter, any tract in which over 35% of the coniferous net merchantable volume was assessed as red or grey attack—which is also referred to as "beetle kill"—had to be sold lump sum. Format assignment thus changes discontinuously at the 35% threshold, motivating the use of a regression discontinuity design with imperfect compliance ("fuzzy" RDD). The imperfect compliance is due to the fact that tracts with a beetle kill share under 35% were still sometimes assigned lump sum. This assignment rule can be visualized in

Figure 3, which makes clear that the majority (86%) of auctions to the left of the threshold were scaled.

Figure 3: Auction format versus beetle kill shares

../temp/first.pdf

In the baseline specification without any controls and a bandwidth selection procedure following Cattaneo et al. (2024), I find a local average treatment effect of the lump sum format on the log number of delay days to be -0.91. In terms of absolute units, this is equivalent to a 3.6 month reduction in harvest delay days under the lump sum format. I show the raw binned scatterplot of delay by auction type in Figure 4. Crucially, the effect is comparable in magnitude even after accounting for the term length of the contract in various ways. Further, the point estimate grows in statistical significance with the inclusion of a rich set of covariates.

Figure 4: Binned scatterplot of delays across beetle kill shares

../temp/logdt1_fuzzy.pdf

5 Empirical Model

In order to attribute the extent to which moral hazard drove the increase in delay associated with scaled auctions, I set up a model of harvesting and bidding in timber auctions to be estimated on harvest and auction data. Estimation follows a full-solution method in the spirit of Rust (1987) in which the joint likelihood of observing a sequence of actions given a set of structural parameters is computed from the solved policy functions implied at those parameters. Bid data from the auctions further allow me to discipline the mapping between parameters and value functions at the time of the first period of harvest, much like how Kalouptsidi (2014) pins down value functions using data on ship prices. The empirical model consists of a bidding stage in the auction followed by a dynamic harvesting problem for the auction winner. I describe these stages in reverse order.

5.1 Dynamic Extraction

Time is discrete and finite, with periods $t = 1, 2, \ldots T$ representing the month since the auction up to the term length T of the contract. The logging firm that won the auction enters an *inactive* phase in the first period, during which it has not yet harvested. If the inactive firm chooses to harvest, they pay a sunk cost κ that same period and harvest the entire tract under the contemporaneous state.

Firms derive value from the expectation of the flow profit of harvesting discounted at a rate ρ. For flow profits π, marginal revenues r depend on sawlog prices p and the average quality of the remaining stock of trees, which can be interpreted as the share of a tree's volume that can be sawn into boards. Tree quality is measured by ψ for trees attacked by the beetle, which account for a share x of all trees in the tract. On the cost side, I assume that the cost function c has constant returns in harvest quantity q. This cost is also a function of tract-specific cost shifters w which may include characteristics such as the size or slope of the tract. Importantly, the winner's bid b_i and the low-grade price are also cost shifters in the scaled auction. Scaled payments are then the inner product of these prices with the shares of high-grade and low-grade trees, meaning that these payments are also a function of ψ and x. Finally, costs depend on a shock ε that is unobserved to the econometrician. I assume that this shock is linear in harvest quantity.

Putting these components together, the flow profits for harvesting a quantity of wood q in tract i and time t is given by

$$\pi(q_{it}, p_{it}, \psi_{it}, \varepsilon_{it}; b_i, x_i, w_i) = r(p_{it}, \psi_{it}; x_i)q_{it} - c(q_{it}, \psi_{it}; b_i, x_i, w_i) - \varepsilon_{it}q_{it} \tag{1}$$

As the subscripts indicate, b_i, x_i, and w_i are taken to be time-invariant, whereas all other variables are not. In particular, the state variables include the time period t, timber prices p_{it}, beetle-attacked tree quality ψ_{it}, and the cost shock ε_{it}. I assume that p_{it} follows the first-order Markov process $\Gamma_p(\cdot|p_{it-1}))$, while $\varepsilon_{it} \sim F_\varepsilon$ is independently and identically distributed across i and t. Finally, I assume that ψ_{it} evolves deterministically according to an exponential decay process $\psi_{it} = \psi_{i0}\exp(-\delta t)$ for some decay rate $\delta > 0$.

Suppressing the tract subscript i as well as the time-invariant characteristics x_i, w_{it}, I denote the observable state variables with ω, so that the value function of a firm V_t is

$$\begin{aligned} V_t(\omega_t, \varepsilon_t; b_i) = \max\left\{\rho\mathbb{E}_{\omega_{t+1},\varepsilon_{t+1}}[V_{t+1}(\omega_{t+1}, \varepsilon_{t+1}; b_i) \mid \omega_t],\ V_t^a(\omega_t, \varepsilon_t; b_i) - \kappa\right\} \\ - b_i \cdot \mathbb{1}\{t = 1, \text{lumpsum}\} \end{aligned} \tag{2}$$

In the max operator in the expression for V, the firm chooses between the option value of continuing to remain inactive with the value of starting the harvest less the sunk cost κ. The final term of the second equation contains the winning bid b_i, which is paid in the first period for lump sum auctions.

5.2 Bidding in Auctionsfl

The auction stage of the model cosnsists of a bidding game among N exogenous (*for now*) players. I assume a private values information structure in which bid heterogeneity is driven by the sunk cost of planning the harvest $\nu_{ij} \sim F_\nu$, which is independently and identically distributed across both auctions i and bidders j. This sunk cost is incurred by the auction winner at time $t = 1$ and is known with certainty at the time of bidding. Further, I assume that the first period's cost shock, ε_1, is unknown to bidders at the time of the auction. The value of winning an auction is therefore $u_{ij} = u(b_{ij}, \nu_{ij}; \omega_{i1}, x_i, w_i)$, where

$$u(b_{ij}, \nu_{ij}; \omega_{i1}, x_i, w_i) = \mathbb{E}[V_t(\omega_{i1}, \varepsilon_1; b_{ij}, x_i, w_i)] - \nu_{ij} \tag{3}$$

It is clear that valuations decrease one-for-one in both the sunk cost ν and the lump sum bid b_{ij}. In scaled auctions, the bid enters the valuation nonlinearly. In the appendix, I show that u is decreasing in b_{ij} in the scaled auction as well.

I henceforth suppress the time subscript on ω_{i1}, which is constant across auctions at the time of bidding. Equilibrium bidding must therefore solve the problem

$$\max_b u(b, \nu_{ij}; \omega_i, x_i, w_i) \cdot G(b; n_i, \omega_i, x_i, w_i)$$

where G is the probability of the bid winning the auction with n_i entrants. The first order necessary condition is

$$-\frac{u(b, \nu_{ij}; \omega_i, x_i, w_i)}{\frac{\partial u(b, \nu_{ij}; \omega_i, x_i, w_i)}{\partial b}} = \frac{G(b; n_i, \omega_i, x_i, w_i)}{g(b; n_i, \omega_i, x_i, w_i)} \tag{4}$$

Since valuations are strictly decreasing in both ν and b, it is straightforward to show the existence of a unique equilibrium bidding strategy β that is symmetric and monotonically decreasing in ν.