Published: 2013. *Energy Policy*, 62: 788-797.

Market Power in Cap-and-Trade Auctions: A Monte Carlo Approach

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Abstract:

Recent greenhouse gas auctions have resulted in base level prices while remaining significantly concentrated. How do dominant firms receive such a large share of emissions allowances without bidding up the market price? This paper provides a Monte Carlo simulation analysis of a contemporary regional greenhouse gas market in the United States. It introduces a C# simulation software environment, Oligopsony 1.0 that simulates uniform-price emissions auctions in repeated iterations. The results of these simulations indicate that there can be significant non-linearities between profit and market power as exercised through strategic demand reduction. This analysis finds the optimum point of strategic demand reduction that enables firms to exploit these non-linearities. The use of auctions to distribute tradeable pollution rights to firms in heavily concentrated markets can have significant unintended consequences, as it can exacerbate the problems of market power that exist within those markets.

Keywords: *Cap-and-trade; Auctions; Market Power*

JEL Classifications: Q54, D44, L13, C88

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1. Introduction

As the international community looks to market-based mechanisms to address negative externalities such as climate change, the success and efficiency of extant markets can play heavily into design and operation considerations for future market design. Traditionally, transferable property rights (cap-and-trade) markets have utilized centralized allocation of property rights (emissions allowances or permits). That approach, although generally effective, has been shown to lead to inefficiencies such as regulatory capture and political misallocation (Arimura, 2002; Dewees, 2008; Ellerman & Montero, 1998). Emerging cap-and-trade programs have improved upon this by utilizing market-based allocation through auctioning initial property rights. Because the initial allocation can influence both the efficiency and competitiveness of the emissions market, the performance of these auctions is of central importance. And, because the firms that operate within these auctions are the same firms that operate within concentrated deregulated electricity markets, the issue of concentration and the exercise of market power in emissions auctions is of central importance.

The purpose of this paper, therefore, is to evaluate the degree to which the strategic exercise of market power can influence the performance of emissions auctions. Following a brief review of extant literature, this paper introduces a model of a contemporary two-stage auction-based emissions market. A Monte Carlo emissions auction simulation software, Oligopsony 1.0, is then introduced. A set of simulation results is then presented, based upon parameters roughly consistent with a contemporary U.S. market, the Regional Greenhouse Gas Initiative, Inc. (RGGI). Sensitivity analyses and probability density analysis follows.

2. A Brief Background on the Literature

The theory of market power in emissions markets is developed by Hahn (1984) whose analysis of the Los Angeles region emissions market considers the case of a single dominant firm among smaller competing fringe firms. Hahn's analysis suggests that the nature of market power is a product of the initial degree of misallocation, which can transform the dominant firm into either a dominant buyer or seller, who can then reap excessive profits by exploiting the inelastic portions of competitors' demand curves.

This is furthered by the work of Misiolek and Elder (1989) who suggests that those dominant firms have altogether higher valuations in the emissions market because they are willing to pay for increased market share, barriers to entry, and the exclusion of rivals in common product markets (Rogerson, 1984; Salop et al. 1987, 1984, 1983; Williamson, 1968). Moreover, limits on the exercise of market power have been extended as far as the sanction cost for noncompliance (Chavez & Stranlund, 2003; Malik, 2002; Van Egteren & Weber 1996). However, others have suggested that market power, despite its presence in emissions markets, is rather weak (Tietenberg, 2006), and has only minuscule impacts on market prices (Hagem & Westkog, 1998; Liski & Montero, 2005). On the other hand, laboratory experiments have provided robust evidence on market behavior in recent years (Milgrom, 2004). Emissions market experiments have provided evidence that the exercise of market power can be rather extreme (Godby, 2000; Holt, 1989; Muller et al. 2002; Wrake et al. 2008). And Godby (2000) provides even more striking results than Hahn (1984) in terms of the potential for market power to be exercised.

Auctions have been analyzed as an alternative allocation method for addressing the problem of misallocation. The literature lauds auctions for their overall system efficiency improvements (Joskow, Schmalensee & Bailey, 1998; Parry et al. 1999; Ruth et al. 2008; Tietenberg, 2006; Van Dyke, 1991; Wrake et al. 2008), for their strengths in reducing tax distortions, creating market flexibility, creating innovation incentives, and disincentivizing rent seeking (Cramton & Kerr, 2002). And they are lauded for their redistributive strengths; their ability to allow government to offset social costs (Bovenberg & de Mooij, 1994; Bovenberg & Goulder, 1996; Goulder et al. 1999; Parry et al. 1999; Smith et al. 2002; Wrake et al. 2008;).

Just as the Coase Theorem suggests that overall system efficiency is independent of the initial distribution of the property right, Vickrey (1961) argues that the efficiency of auctions, and the revenue they generate, is independent of the format of the auction. However, just as the Coase Theorem is built upon a series of assumptions that are sometimes tenuous in practice, Vickrey (1961) makes two major assumptions. He assumes that all bidders are risk neutral, and that bidder valuations are identically and independently distributed (I.I.D.). These assumptions have been handsomely challenged (Maskin & Riley, 2000; McAfee & McMillan, 1987). Furthermore, bidder valuations are fundamentally impacted by market power, and by the expectation of arbitrage (Garratt & Troger, 2006; Zheng, 2002)-- the 'trade' in cap-and-trade.

The degree of exercisable market power therefore becomes a key issue in the design of property rights auctions, because it directly affects the valuation of market participants. Market power has been consistently revealed in related electricity markets (Kahn et al. 2001; Wolfram, 1998). If the same firms that participate in those markets also participate in emissions markets, the same disproportionate market composition may influence market performance in emissions markets.

3. Why Market Power?: Background and Structure

The Regional Greenhouse Gas Initiative (RGGI) is the first-ever mandatory carbon cap-and-trade program in the United States, and it heavily influences national and international discourse on the development of carbon markets. The success or failure of RGGI, particularly in terms of economic efficiency, is a vital pivot point on the pendulum of future Coasian policy mechanisms. Although there have been previous tradeable property rights markets such as Southern California's Regional Clean Air Incentives Market (RECLAIM), the US Acid Rain Program, and the Virginia NOx Program, RGGI is the first market to target greenhouse gases, which are far more difficult to mitigate or abate.

RGGI also serves as a model for larger programs because of its key institutional feature-- RGGI is the first cap-and-trade program to use a nearly 100 percent auction allocation method. The initial distribution of property rights (allowances/permits) plays heavily into both the efficiency and the equity of the emissions market (Hahn, 1984; Tietenberg, 2006). More importantly, unmitigated market power in the distribution (auction), if exercised, can heavily bias the efficiency of the secondary trading market, making price discovery difficult.

Unlike some other emissions markets, RGGI only covers the electricity sector; transportation, agriculture and other GHG-emitting sectors are not covered entities. As a result, market power is a larger concern because this sector is already heavily concentrated, and its participants are the same natural monopoly firms that operate wholesale power generation.

3.1 Background

RGGI began as the pet project of former New York Republican Governor George Pataki, who invited neighboring state governments to compact with New York in curtailing negative effects of climate change in 2003. Today, ten east coast states are signatories: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey,[1] New York, Rhode Island, and Vermont. Each RGGI state legislature has agreed to the terms of the compact, which are outlined in the RGGI Model Rule, and each state has independently determined a reasonable emissions cap (RGGI, 2008).

RGGI auctions include more than electricity sector firms, however, as banks and hedge funds also participate. Liquidity was a concern from the inception of RGGI, stemming from the significant concentration of market participants. Market developers therefore decided to permit non-covered entities (banks and hedge funds) to participate in RGGI auctions, to serve two main purposes. First, economic theory dictates that greater competition leads to more efficiency, and thus market developers aimed to increase the quantity of market participants beyond the roughly 30 covered entities that would have otherwise participated by fiat. Second, despite the fact that many RGGI participants are protected by rate-of-return regulation, electricity firms in particular have a proclivity for seeking sufficient hedging instruments against economic risk. Participation by banks and hedge funds can facilitate a much more robust derivatives market.

Auctions are held quarterly for two separate vintages of allowances. Current-term vintages constitute the large majority of sales, and forward-term vintages, which are outside the scope of this analysis because they constitute a very small part of the

[1] New Jersey has recently discontinued its participation in RGGI.

market and have since been discontinued altogether. Allowances are fully bankable (can be held for use in future compliance periods), but are not borrowable (which would otherwise enable emissions in the present for allowance purchases in the future).

3.2 Structure

Substantive data on the efficiency and performance of RGGI market auctions are not publicly available. RGGI is structured as a non-profit organization, which has successfully shielded it from public disclosure legislation (Dormady, 2012). Member state governments, who have access to the data, have denied public information requests from numerous sources. In response to significant public inquiry, member governments have deemed all RGGI information 'trade secrets'. Because of this, a qualitative assessment of the efficiency and performance of RGGI auctions cannot be given.

From publicly-available data, however, one key measure of market concentration can be determined. The Herfindahl-Hirschman Index (HHI) is a measure of market concentration. It is calculated as the sum of each firm's squared market share, or $\left\{HHI = \sum_{i=1}^{N} s_i^2\right\}$ equivalently. It ranges from a value of 10,000 in the case of pure monopoly, and approaches zero in the case of an atomistic market.

Figure 1. Herfindahl-Hirschman Index (HHI) of Past RGGI Auctions

Auction #	Current Vintage		Forward Vintage	
	HHI	Number of Winning Bidders	HHI	Number of Winning Bidders
1	1,061	44	None sold	None Sold
2	1,203	46	None sold	None sold
3	1,122	42	2,020	12
4	1,127	48	2,023	12
5	977	34	1,726	12
6	1,372	40	2,753	8
7	825	40	2,098	9
8	933	42	2,016	10
9	1,038	45	3,474	6
10	1,056	38	4,191	4
11	1,517	34	2,255	6
12	1,122	25	4,884	5
13	884	31	Market discontinued	
14	2,332	38	Market discontinued	
15	2,138	20	Market discontinued	
16	2,046	24	Market discontinued	
17	1,702	22	Market discontinued	

Available at: http://www.rggi.org/market/market_monitor.

The HHI is a key measure of market concentration utilized by the US Department of Justice for oversight of monopolies and trusts for purposes of merger review. Recent guidelines suggest that any market with HHI exceeding 1,000 is moderately concentrated, and any market with HHI exceeding 1,800 is highly concentrated.[2] Figure 1 provides the HHI indices of recent RGGI auctions for both current and forward vintages. Losing bidders are not considered market participants in the calculation. Given that some scholarship suggests that auction design is less relevant than the size of the market (Bernard, et al., 1998), the HHI figures from recent RGGI auctions imply that market concentration can often decline despite declines in the number of market participants. This is important because the HHI is a measure of market inequality. In a market with all firms of equivalent share, the HHI would decrease to H=1/N, where N is the number of firms in the market. Given the background and structure of these contemporary emissions market auctions, it

[2] In August, 2010, the US Department of Justice raised the HHI thresholds of merger guidelines in the wake of financial market reforms, thus making a finding of market concentration more difficult. The current threshold for a moderately competitive market is an HHI above 1,500.

becomes clearer why market power should be evaluated. Auction results show consistently high levels of market concentration while auction prices remain at the lowest possible levels.

4. The Two-Stage Uniform-Price Sealed Bid Auction

4.1 Auction Model

In order to show how market power is exercised in cap-and-trade auctions like the RGGI, it is important to have a model, or system of equations, that characterizes the market. The form of auction used in the RGGI is a uniform-price sealed bid auction. This section provides a mathematical model of the first and second (arbitrage) stage of the RGGI tradeable property rights market. The uniform-price sealed-bid auction is one in which bidders are permitted to submit multiple bids. Unlike alternative auction designs, bidders submit bids of both price and quantity. Quantities are then ordered by bid price, and winning quantities are those quantities that are above the market-clearing price. The market-clearing price is determined when quantity demanded equals the quantity for sale.

Let:

B	≡	an Nx3 matrix containing elements P_n, Q_n, and F_n
		It is rank ordered by price, such that $P_n \geq P_{n+1}$, and $1 \leq n \leq N$.
C	≡	an Nx1 matrix containing elements C_n
n	=	The bid rank identifier.
P_n	=	The bid price associated with n.
F_n	=	The bidder identifier[3] associated with P_n. It is an integer.
Q_n	=	The bid quantity associated with P_n.
C_n	=	The cumulative bid quantity associated with P_n.
Q_T	=	The total quantity (available) to be sold at auction.
$\prod_F$	=	The secondary market profit function associated with bidder 'F.'
P_0	=	The market-clearing (stop out) price.
Q'_F	=	The quantity of allowances awarded to bidder 'F.'
V_F	=	The secondary market resale value of allowances for bidder 'F.'
		V_F is exogenous.
$Q_{F,a}$	=	The quantity of allowances bidder 'F' must surrender for compliance obligations. $Q_{F,a}$ is exogenous.

$$B \equiv \begin{pmatrix} P_1 & Q_1 & F_1 \\ \vdots & \vdots & \vdots \\ P_N & Q_N & F_N \end{pmatrix}; \; P_n = b_{n,1},\; Q_n = b_{n,2}, \text{ and } F_n = b_{n,3}.$$

$$C = \begin{pmatrix} C_1 \\ \vdots \\ C_N \end{pmatrix}; \; C_n = c_{n,1}.$$

$$C_n = \sum_{k=1}^{n} Q_k \tag{1}$$

$$P_0 = P_n \mid \{C_{n-1} \geq Q_T \;\&\; C_{n-2} < Q_T\} \tag{2}$$

[3] This innovation of mine allows us to account for the possibility of multiple bids from a common bidder.

Let n' = n such that $P_n = P_0$. Note: n' is the bid rank identifier associated with the market-clearing price.

Let the profit function[4] for a chosen bidder be:

$$\pi_F = (V_F - P_0) \cdot Q'_F = \Delta P \bullet \Delta Q \quad (3)$$

Profit maximization occurs when either the change in price or the change in quantity is maximized. However, in these markets it is difficult for a monopsonist or oligopsonist to solely determine the market-clearing price P_0. P_0 is influenced by the degree of market power of the monopsonist or oligopsonist. The monopsonist or oligopsonist can seek to maximize its quantity of allowances Q'_F in the auction, or set it strategically.

$$Q'_F = \sum_{k=1}^{n'-1} Q_k \delta_{F_k F}, \quad (4)$$

Where δ is a version of the Kronecker Delta, such that;

$$\delta_{m\,n} = \begin{Bmatrix} 0, & m \neq n \\ 1, & m = n \end{Bmatrix}.$$

Equation 4 sums all of the successful bid quantities Q_n, according to bidder identifier.

4.2 Strategy Under Market Power

The profit-seeking oligopsonist may seek to maximize profit by exercising market power in one of three ways. First, the oligopsonist may seek to use the emissions market to exclude rivals or raise their costs in a common product market (Rogerson, 1984; Salop et al., 1983; 1984; 1987; Williamson, 1968). This would be

[4] A alternative profit function can include an exogenous term to account for those allowances a firm must surrender for compliance. Note that by setting $Q_{F,a}$ exogenous, the model can account for regulated compliance entities as well as banks and hedge funds who may be auction participants. The profit function in this case would be: $\pi_F = (V_F - P_0)(Q'_F - Q_{F,a})$.

equivalent to a strategy of hoarding by buying as many allowances as possible (essentially maximizing Q'_F) and forcing firms in the competitive fringe to face the choice of either reducing output or paying regulatory-enforced sanction costs for non-compliance. A second and related strategy for the oligopsonist is to buy as many allowances as possible and profit from resale arbitrage (Garratt & Troger, 2006; McAfee & McMillan, 1987; Zheng 2002). This second strategy depends crucially upon the rent-indifference point for fringe firms. Oligopsonists can only resell allowances up to the point at which it is less-unprofitable for fringe firms to either pay the sanction cost for non-compliance, or reduce output, or both. Both of these hoarding strategies, although important aspects of market power, are outside of the scope of this analysis because they rely crucially on exogenous factors specific to both the emissions market and the common product market (electricity).

A third strategy, analyzed in this paper, is for the oligopsonist to maximize profit by strategically setting demand parameters (demand reduction) (Ausubel & Cramton, 2002; List & Reiley, 2000; Webber, 1997; Wolfram, 1998). The oligopsonist can act as a Cournot firm and strategically set its bid quantities into the emissions auction to maximize profit. The oligopsonist would, in this case, exercise its influence over the market-clearing price (P_0) to simultaneously push the market-clearing price downward while attempting to minimize its negative influence on its own auction earnings (Q'_F). The exercise of market power through strategic demand reduction requires the balancing of two competing market forces. Bidding for a quantity of allowances too high can have a positive influence on the market-clearing price, thus making it quite costly for the oligopsonist to gain allowances. Bidding for a quantity of allowances too low, or at a price too low, can make it difficult for the oligopsonist to receive sufficient allowances necessary to operate in the adjacent product market and maintain its current market share. The analysis conducted in this paper finds this optimization point for demand reduction under a common set of market parameters, relevant to current cap-and-trade markets. It also includes a set of sensitivity analyses of these results.

5. The Methodology of the Monte Carlo Approach

5.1 Parameters of Analysis

The methodology here expands upon the structure-conduct-performance relationship of traditional Cournot industrial-organization analysis through the use of Monte Carlo repeated simulation. As mentioned in Section 4, the Cournot oligopsonist seeks to maximize an *a priori* profit function, under the assumption that competing firms hold their output fixed. Following from Waterson (1984), the structure of the market (degree of market power and price elasticity of demand for emissions allowances) impacts market performance (the profit-revenue ratio) via market conduct.

Cournot market conduct in emissions market auctions manifests itself as strategic demand reduction. Auctions in general are nothing more than a complex sorting methodology for demand for a fixed quantity of goods. An oligopsonist that commands a significant share of the market would constitute a larger share of aggregate demand, holding all other things equal. Exhausting its budget to bid for every emissions allowance it could afford, would be in most cases, highly unprofitable for the oligopsonistic firm.[5] Such behavior would shift the demand curve

[5] This excludes asymmetric valuations due to the expectation of secondary market resale arbitrage or inter-temporal arbitrage.

upward and increase the market-clearing price for allowances, thus negatively impacting the firm's profit.

The Cournot oligopsonist faces a balancing decision, between strategically reducing its demand for allowances and ensuring sufficient allowance holdings to continue operating in the adjacent production market (e.g., electricity generation). The latter is outside the scope of this analysis, as it varies with exogenous market parameters and a complex legal-regulatory structure. The strategic oligopsonist therefore, seeks a level of conduct (strategic demand reduction in this case) that maximizes profit. This Monte Carlo analysis pinpoints that optimum level of conduct given parameter conditions in the underlying structure of the market.

5.2 The Simulation Environment

The method of analysis provided here offers a third approach to traditional methods of analysis. Traditional game/auction theoretic analysis has many strengths, but it can be limited by simplifying assumptions that inhibit its ability to generate probabilistic findings. Econometric data analysis is often preferable, but is often limited by: a) the availability of data; and b) the inability to alter exogenous structural parameters (e.g., market structure). The simulations provided here, were conducted using Oligopsony 1.0, a Monte Carlo emissions auction simulation environment designed by the author in *C#* in the .NET environment.[6]

Oligopsony 1.0 carries out the operations of the two-stage model, provided in Section 4, in repeated iterations. Although complex in design and fundamental logic, Oligopsony 1.0 must simultaneously carry out several operations. First, it must construct a static bid matrix *B*. Each static bid matrix consists of three columns that

[6] .NET is Microsoft's development environment; its main competitor is Java.

each represent a separate operational class within Oligopsony 1.0. Generating the bid matrix is the most challenging and computation-heavy operation of the software.

The first column is an array of bid prices. All bid prices are drawn from a Gaussian (standard normal) distribution with mean μ and standard deviation σ. The user directly supplies the standard deviation, which is a double variable consisting of an integer and a fraction/decimal to the hundredths place (e.g., dollars and cents). The mean is drawn from a uniform distribution in which the user supplies the minimum and maximum values, also double variables. Oligopsony 1.0 redraws a unique μ for each bid and each bidder. The second column is an array of bid quantities, which are drawn from a uniform distribution with user-supplied min and max values. The third column is an array of bidder numbers F_n matching each unique bid to its bidder. The software permits multiple bids for each bidder, with a maximum of four unique bids per bidder. The logic structure of the software ensures that the entirety of each bidder's bids does not surpass its class' (oligopsonist/fringe) quantity constraint.

Upon completion of the static bid matrix, Oligopsony 1.0 calculates winning and losing bids, market clearing price P_0, quantities awarded to each bidder, and profits for each bidder. Profits in Oligopsony 1.0 are determined from a simple profit function, with a user-supplied exogenous secondary market price V_F, as given by equation 3 in Section 4.1.[7] This process iterates to a user-supplied number of repetitions/auctions, and each value, from each iteration, is stored in the user's system memory. Upon completion of a user-specified number of runs, Oligopsony 1.0 supplies descriptive statistics (mean, min and max) for each of four summary measures; market-clearing price, profit of oligopsonists, profit of fringe firms, and

[7] This proxy profit calculation carries a modest approximation of actual firm-level profits under standard rate-of-return regulation in markets with cost pass-thru.

fringe loss (the quantity of emissions allowances that firms in the competitive fringe bid for but did not receive).

6. Monte Carlo Simulation Results

The analysis here functionalizes parameters consistent with modern auction-based emissions markets (RGGI) in large samples via Monte Carlo simulation to operationalize market conduct through strategic demand reduction. Whereas a traditional Cournot oligopsonist seeks to optimize quantity given an assumed static response behavior among firms in the competitive fringe, this analysis allows both oligopsonists and firms in the competitive fringe to draw both price and quantity parameters from parametric distributions *ex ante*, as detailed in Section 4.2. Firms in the competitive fringe are not static in this analysis. Results of the Monte Carlo analysis are first provided for a main case, and then provided for two sensitivity cases.

6.1 Main Case Monte Carlo Results

The main case attempts to approximate input parameters of contemporary auction-based emissions markets as closely as possible. In this case, the simulation is set for a total of 50 bidders, where the number of oligopsonists is set from 1 to 3. The total quantity of allowances for sale is 50,000; consistent with the quantity sold in most quarterly RGGI auctions. The quantity constraint on competitive fringe firms is drawn from a uniform distribution ~U (*1, 2500*), where the quantity sum of each fringe bidder's bids in any static auction cannot exceed 2,500 allowances. Both oligopsonist and fringe firms' bid prices are drawn from a Gaussian distribution ~N

(μ, σ^2), where μ is drawn from ~U ($*1.00,* $*2.00*), and where σ is set at $0.25. And, for calculation of profit, the exogenous secondary market price V_F is set at $2.00.

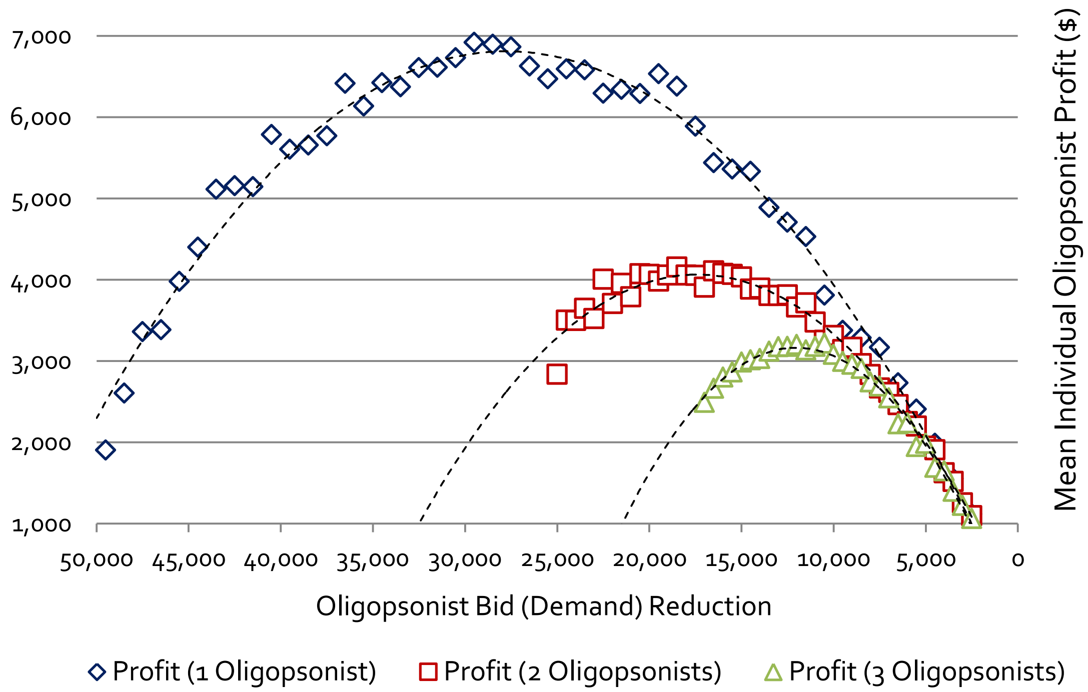

Figure 1. Oligopsonist Profit Under Demand Reduction

Figure 1 provides the main results of this analysis. Oligopsonist profit is plotted as a function of market conduct. Market conduct is set incrementally across the x-axis, and represents a single fixed quantity bid by the oligopsonist(s).[8] Each data point represents the expected value, or average individual oligopsonist profit, for 2,000 Monte Carlo auction runs.[9] The horizontal axis represents a fixed parameter of quantity, which is the bid specified by the oligopsonist(s) in each simulation. The far left data point represents a monopsonist's bid for all 50,000 allowances. Three plots are presented in Figure 1; monopsony, duopsony, and triopsony. Clearly there exists

[8] The x-axis of Figure 1 can be read from left to right as a decrease in the oligopsonists' bid, or equivalently, as an increase in demand reduction.
[9] Consider the duopsony case as a clarifying example. There are 46 data points plotted in Figure 1 for the duopsony case profit curve, at a quantity interval of 500 emissions allowances that ranges from 2,500 to 25,000. Each of the 46 data points represents the average profit of 2,000 auctions. As such, the duopsony curve in Figure 1 was plotted from 92,000 individual auction simulations.

a non-linearity between profit and the exercise of market power through strategic demand reduction.

Each case is fitted with a simple second-degree polynomial trend line, each of which has extremely significant fit (R^2>0.95). A first-order condition can be derived from the fitted function to provide the optimum point of strategic demand reduction for each case (e.g., monopsony). For the monopsony case, the first derivative of the fitted function is $\pi'(q_F)_{monopoly} = 0.50624 - 0.00001824x$, which, when set equal to zero yields a value of ≈ 27,750 allowances. This value can also be approximated by visual inspection of Figure 1. The most profitable strategic bid for a monopsonist in a uniform-price sealed-bid auction for emissions allowances with equivalent parameters, therefore, is not to purchase the entirety of the market, but rather to reduce demand by approximately 45 percent [1-(27,750 ÷ 50,000)] of the total quantity of allowances sold. The equivalent values for duopsony and triopsony are ≈ 17,350 and 12,650 allowances, respectively.

An oligopsonist's ability to influence the market-clearing price is a key determinant of its ability to successfully exercise market power. As the structure of the market changes (e.g., monopsony) the strength of an oligopsonistic firm's influence on price can change. This analysis also provides insight into this aspect of market power. Figure 2 provides the relationship between auction-clearing price and strategic demand reduction. The data points in Figure 2 provide the expected value, or average auction-clearing price for the same 2,000 Monte Carlo auction runs. In Figure 2, a linear trend line function is fitted to the data points for exposition, and each fitted function has similarly significant fit (R^2>0.95).

By evaluating the slopes (in a manner similar to elasticities) of these linear functions, a very close approximation of the relationship between demand reduction and auction-clearing price can be determined. These slopes represent the impact on auction-clearing price of a foregone unit of demand. A 5,000 allowance demand reduction (10 percent) by a single oligopsonist, under equivalent parameters, yields a 2.4 cent reduction in mean auction-clearing price. The equivalent values for duopsony and triopsony are 4.36 cents and 6.35 cents, respectively.

This indicates that firms that exercise a significant portion of demand for emissions allowances can parlay that market influence into significant reductions in auction-clearing price, and thereby successfully suppress the value of tradeable allowances in a cap-and-trade market. Furthermore, matching the optimum profit calculations from above with the price influences determined here, allows us to determine a price-suppression indifference point. Another interpretation of the optimal profit point is the point at which it is no longer profitable for an oligopsonist to suppress the price and forego an additional emissions allowance.

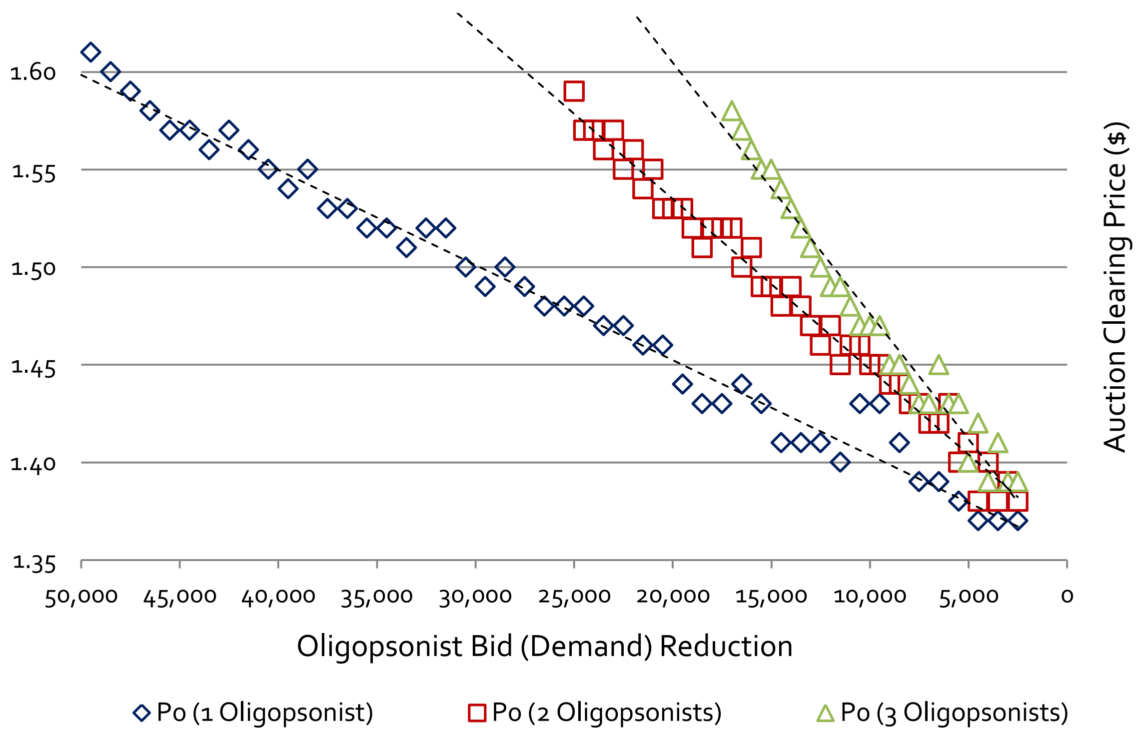

Figure 2. Market Clearing Price Under Demand Reduction

An interesting side effect of the influence of market power in emissions auctions is the effect on the profit of firms in the competitive fringe. This Monte Carlo analysis also provides insights into these effects of market power as well. The results provided in Figure 3 show the relationship between demand reduction as exercised by the oligopsonist(s) and the expected profit of firms in the competitive fringe. It shows that a kind of price-leadership effect occurs.

Although oligopsonistic firms exercise a significant portion of the market, smaller firms in the competitive fringe piggyback on the price suppression of the oligopsonist(s). As the market conduct of the oligopsonist(s) moves toward the optimum point of demand reduction, the expected value of profit among fringe firms grows almost exponentially. In markets like the RGGI, fringe firms that are small or independent electricity generators or participating municipalities can actually profit significantly by the exercise of demand reduction by dominant firms.

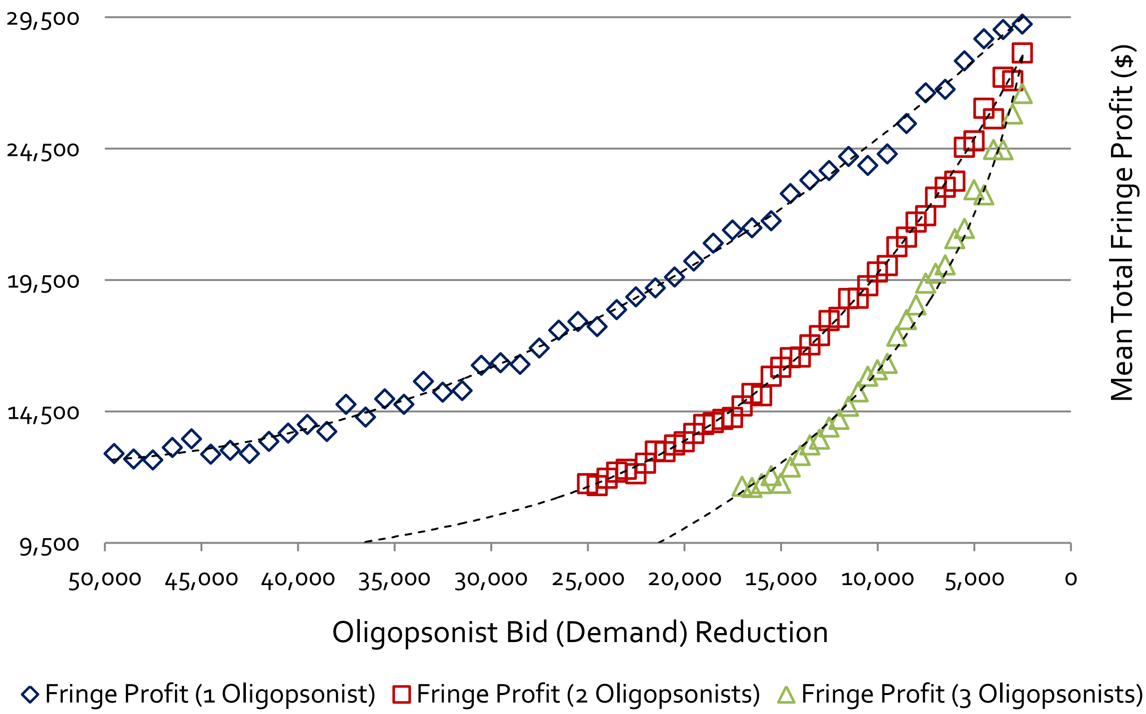

Figure 3. Mean Total Fringe Profit Under Demand Reduction

6.2 Sensitivity Analyses

The robustness of these findings was also subjected to sensitivity analyses of changes in market structure. In electricity-only cap-and-trade markets like the RGGI, the quantity of firms participating in the market is relatively fixed, as market participants are generally covered power generating firms. Fluctuations in the number of bidders are affected by participation rates among covered firms in quarterly auctions as well as participation by non-covered entities such as banks and other speculative participants.

This analysis is not limited to electricity-only cap-and-trade markets, however, as the simulations could apply to a number of auction-based markets or other cap-and-trade markets moving toward auction-based allocation. The question that remains, therefore, is to what degree are these findings robust to changes in the number of bidders? To evaluate this, a robustness check was conducted by varying the number of fringe bidders by ±50 percent (25 and 75 bidders). All other market parameters were retained.

The results in Figures 4 and 5 provide the relationship between oligopsonist profit and strategic demand reduction. The 75 bidder case in many ways carries the same properties as the 50 bidder case. The same non-linearities exist and the optimal points do not change much, as the oligopsonist demand structure does not change much; however, the level of profit potential decreases by nearly 30 percent across the board. As the market expands, the exercise of market power becomes less profitable as demand-side competition leaves the oligopsonist with a smaller share of the overall supply of allowances. Recall that each data point represents the mean profit from 2,000 auction simulations, and as the size of the market increases, the same demand reduction optimization strategy remains. However, the mean profit from that strategy shifts downward, as shown by comparison between Figures 1 and 4.

The 25 bidder case provides an interesting peculiarity. Although the level of oligopsonist profit increases (shifts upward) in the expected direction, the strategic demand reduction optimization point is influenced by the supply point. The expected value of oligopsonist profit begins to shift upward as significant demand reductions occur toward the right hand side of Figure 5. This is due to the fact that with few bidders and large demand reductions by the oligopsonist, demand from both the oligopsonist and the fringe is insufficient to match the overall supply of allowances for sale, and residual supply exists. In uniform-price auctions in which residual supply exists, the auction clearing price converges to zero.[10] As the auction clearing price converges to zero, the profit peaks.[11] And, as a result the second-degree polynomial trend line traces the outcome with less precision.

[10] Often in uniform-price auctions, a reserve price can act as a constraint on auction clearing prices that would otherwise converge to zero. In recent RGGI auctions, for example, the auction clearing price has converged to the reserve price.

[11] Because the profit function utilized here (equation 3 in section 4.1) is a basic one, there is no direct mapping between auction clearing prices and secondary market prices, as the secondary market price is exogenous by simplification. The residual supply effect shown in Figure 5 would be smaller in magnitude in markets in which changes in the secondary market reflect changes in the primary allocation auction. The same profit function shape would results, but it would be lower or higher about the horizontal axis.

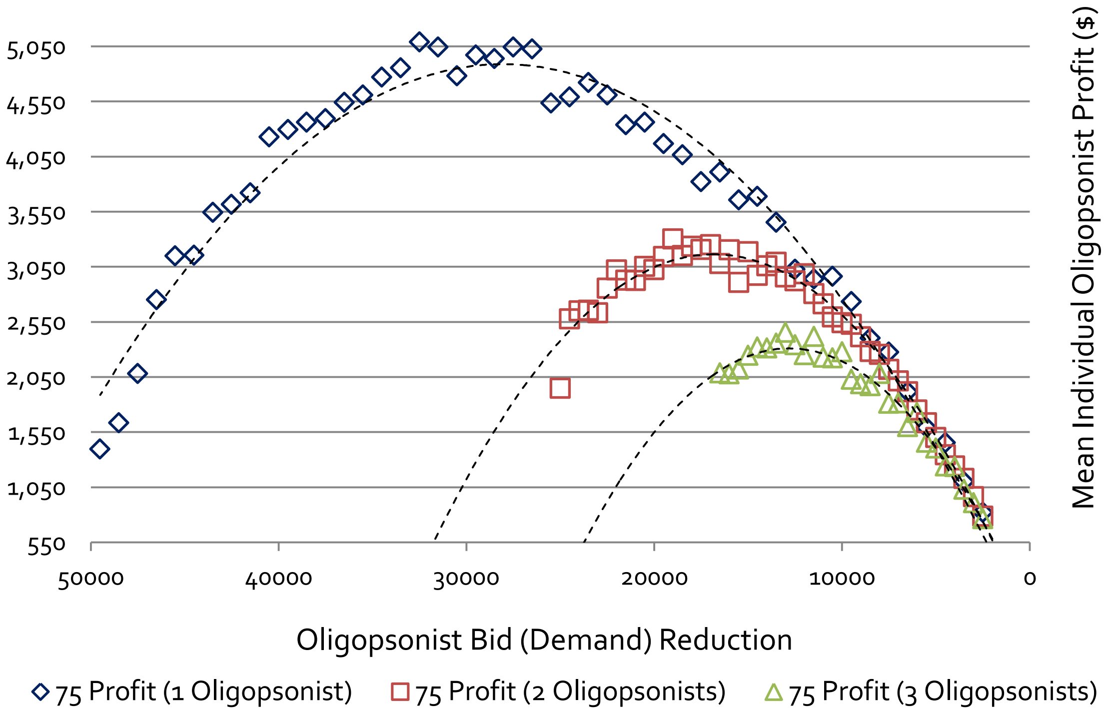

Figure 4. Oligopsonist Profit Under Demand Reduction (75 Bidders)

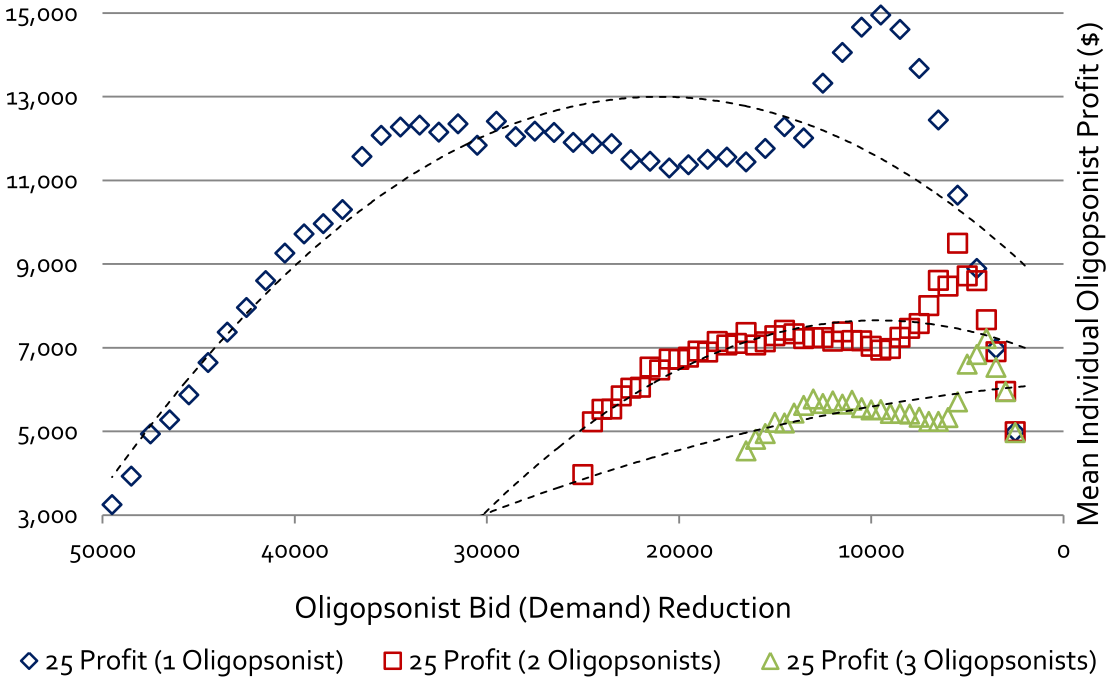

Figure 5. Oligopsonist Profit Under Demand Reduction (25 Bidders)

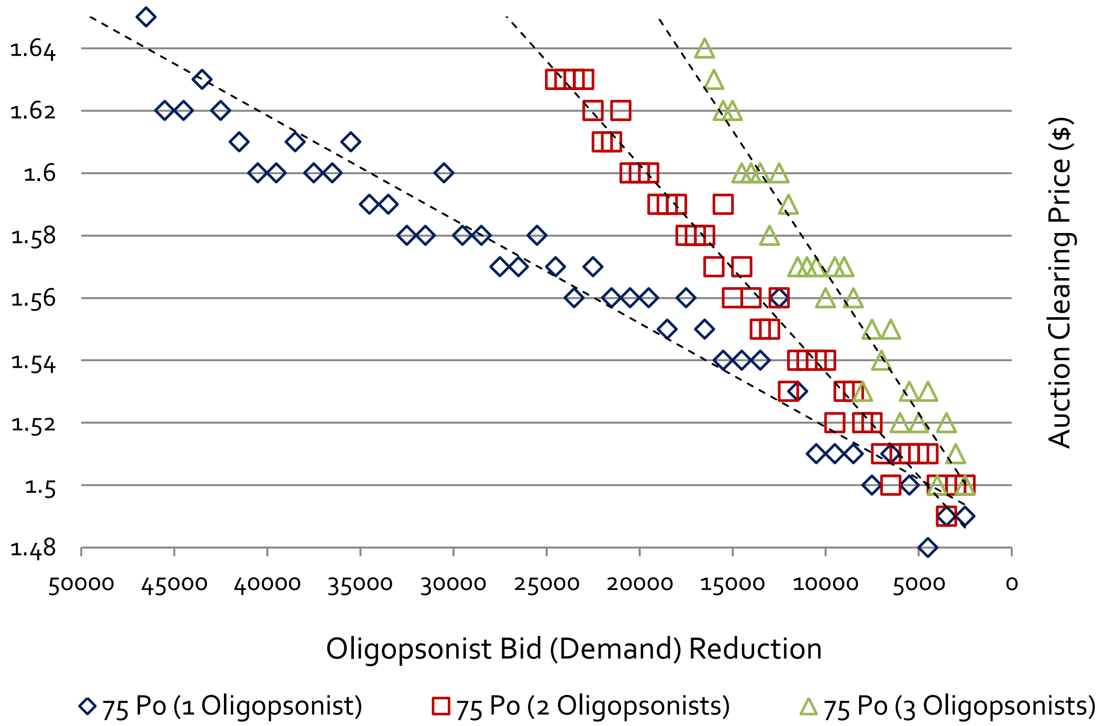

Figure 6. Market Clearing Price Under Demand Reduction (75 Bidders)

The profitability of this residual supply effect is driven quite strongly by the price responsiveness of the auction to changes in strategic demand reduction by the oligopsonist. Figures 6 and 7 present the results of the sensitivity simulations for auction clearing price. Figure 7 clearly shows how quickly the mean clearing price can dip downward as strategic demand reduction by the oligopsonist begins to increase the likelihood of residual supply. Put another way, the mean auction clearing price becomes significantly more responsive to strategic demand reduction as that reduction encroaches upon the point at which residual supply is more likely.

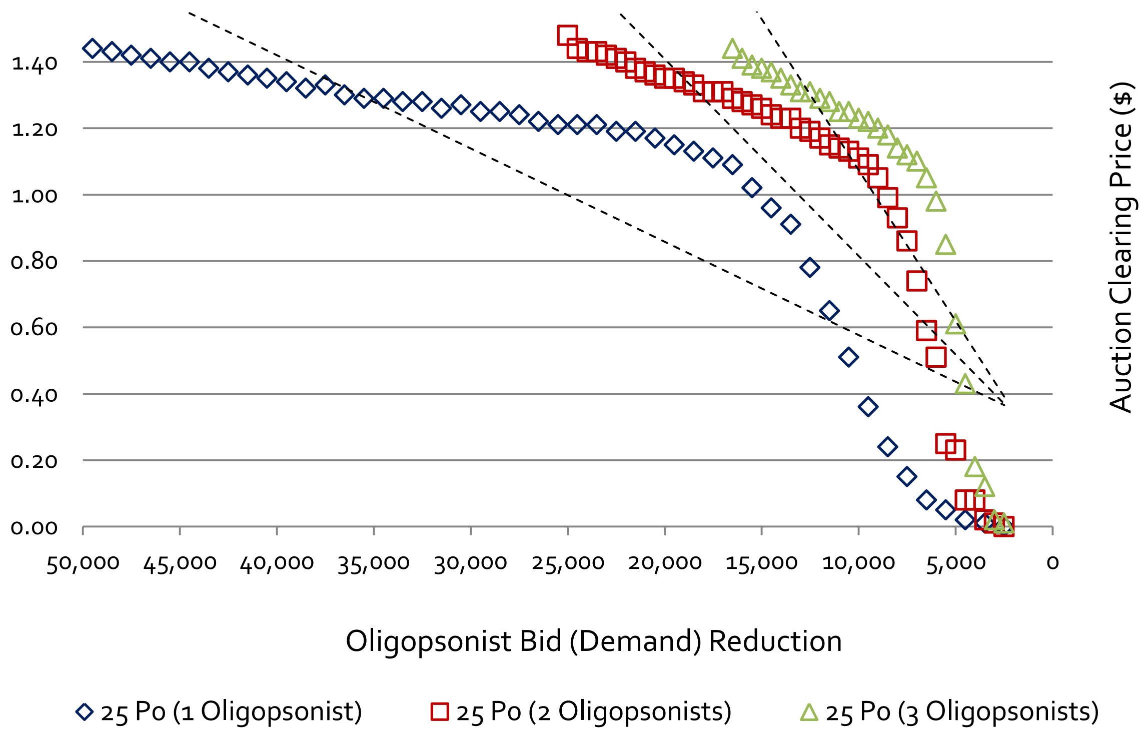

Figure 7. Market Clearing Price Under Demand Reduction (25 Bidders)

A comparison of these effects across each of the three cases reveals the degree to which the impact of market power on auction clearing price is affected by changes in the overall structure of the market. Table 2 provides this. The responsiveness of auction clearing price to strategic demand reduction is measured as the slope, or elasticity, of the fitted linear relationship between them.[12]

Table 2. Auction Price Responsiveness to Demand Reduction

	25 Bidders	*50 Bidders*	*75 Bidders*
1 Oligopsonist	14.06₵	2.44₵	1.67₵
2 Oligopsonists	29.68₵	4.36₵	3.33₵
3 Oligopsonists	45.51₵	6.35₵	4.53₵

Slopes reflect a 10 percent (5,000 allowance) change in oligopsonist strategic demand reduction.

[12] The significance of the linear fit was good (R^2>0.95) for the 50 and 75 bidder cases. For the 25 bidder case the fit was less robust (R^2>0.74) due to the price impact of residual supply.

As mentioned above, in the simulations with 50 total bidders, a 10 percent (5,000 allowance) demand reduction by a monopsonist, under equivalent parameters, yields a 2.44 cent reduction in mean auction-clearing price. The equivalent values for duopsony and triopsony are 4.36 cents and 6.35 cents, respectively. In the 75 bidder simulations, a 10 percent demand reduction by a monopsonist yields a 1.67 cent reduction in mean auction clearing price. And, in the 25 bidder simulations, a 10 percent demand reduction by a monopsonist yields a 14.06 cent reduction in mean auction clearing price. Remaining cases are presented in Table 2.

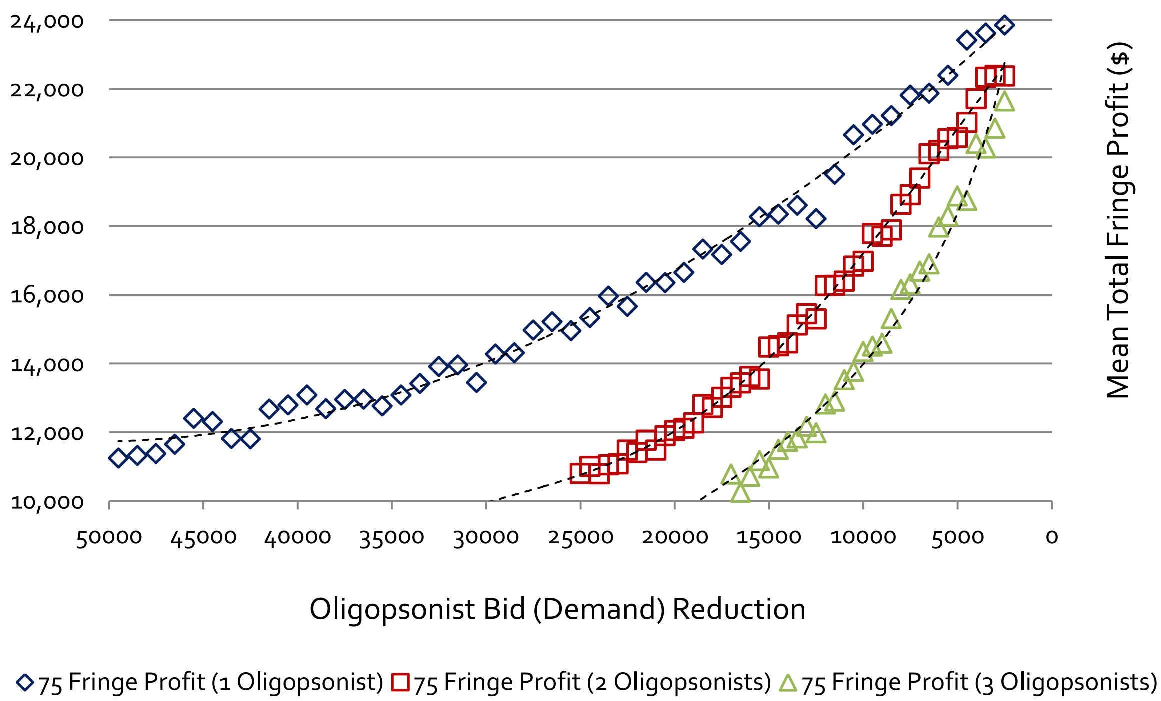

Figure 8. Mean Total Fringe Profit Under Demand Reduction (75 Bidders)

The mean total of fringe profit also reveals the same profit impacts for firms in the competitive fringe in both sensitivity cases. The profit of fringe firms is directly impacted by clearing price reductions as a result of strategic demand reduction by the oligopsonist(s). The same sort of price leadership effect occurs. The rate of change of mean total fringe profit increases as the size of the market decreases. This rate of change becomes dramatic as the probability of residual supply becomes more likely. This is shown in Figure 9 by the upswing in the mean total fringe profit curve.

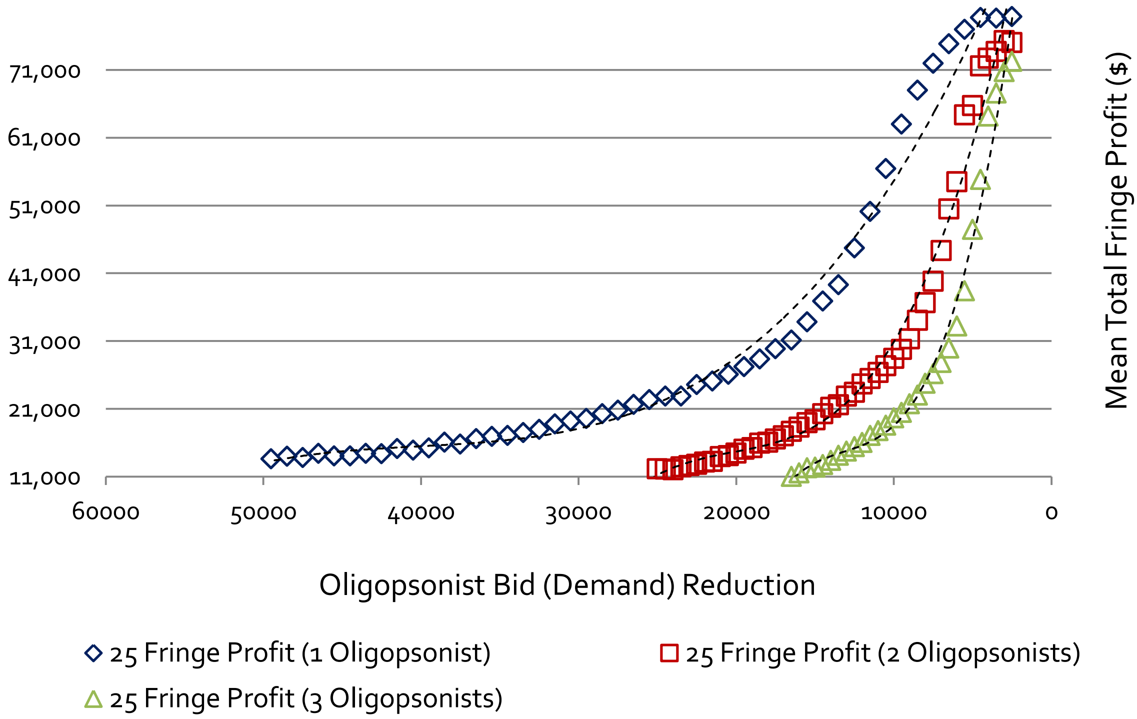

Figure 9. Mean Total Fringe Profit Under Demand Reduction (25 Bidders)

6.3 Kernel Density Analysis

An illustrative method for evaluating the probabilistic nature of events in a Monte Carlo study is the use of density analysis. Because the data points in the previous section each represent the expected value, or mean, of 2,000 Monte Carlo runs, they provide a strong summary of the events that occurred throughout those thousands of auctions. Summary measures, however, do not provide further detail into the range of events that populated those summary measures.

Kernel density plots,[13] as provided below, give probabilistic detail to the results of the main case Monte Carlo analysis at the respective optimum oligopsonist profit points. These figures show the density, or likelihood, in a manner similar to a histogram, of the events that populated the summary measures. The probability of auction outcomes in these simulations is not uniformly distributed, and the distribution of those outcomes changes as the structure of the market and the conduct of market participants changes.

[13] Kernel density plots in Section 6.3 each use a Gaussian kernel function.

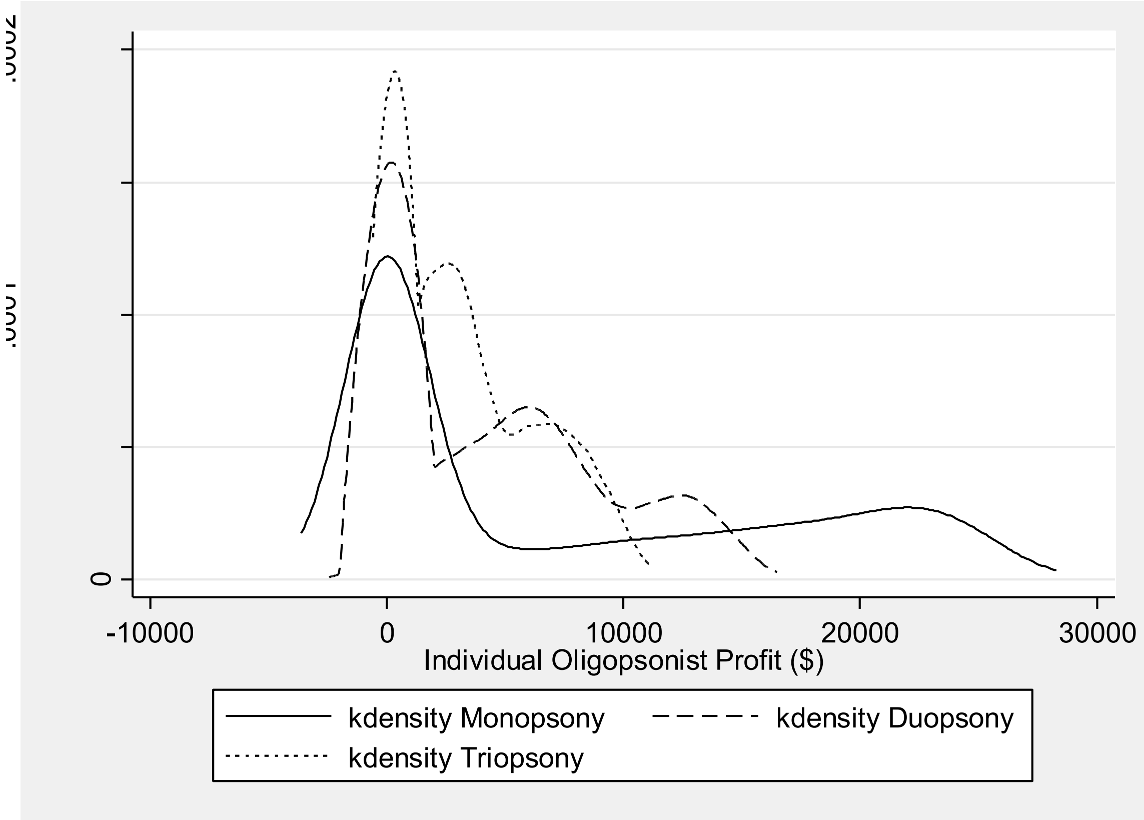

Figure 10. Kernel Density Plot of Individual Oligopsonist Profit

Figure 10 provides kernel density plots of the main case results at the respective optimum profit points for each of the three oligopsony scenarios. The spike in the distributions about the zero profit point reflects the likelihood of oligopsonist(s)' bids encroaching upon or falling below the auction-clearing price. Bids falling below the clearing price return zero commodities (e.g., emissions allowances) to the bidder, and thus zero profit. The right-skewed tails of the distributions indicate the strong likelihood of actual oligopsonist profit far exceeding the mean profit points reported in section 6.1. The spike in the tail of the monopsonist profit density function, for example, indicates that out of 2,000 auctions, the monopsonist actually yielded profits exceeding $20,000 frequently.

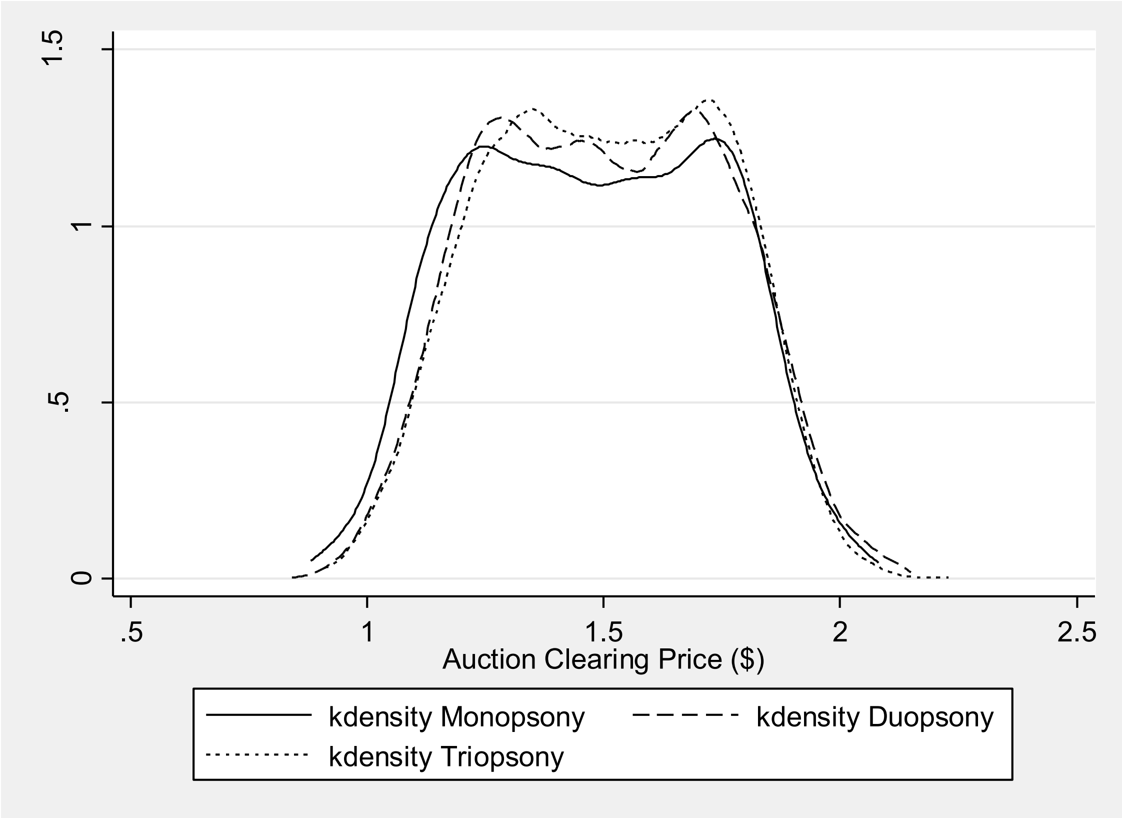

Figure 11. Kernel Density Plot of Auction Clearing Price

The density plots provided in Figure 11 show the probabilistic range of auction clearing prices at the respective optimum points. Recall that throughout these Monte Carlo simulations, constraints on the distribution of bid prices for both bidder types are equivalent. And, recall that Oligopsony 1.0 draws a unique mean bid price for each bidder's unique bid, and allows for the possibility of multiple bids from the same bidder in each auction. As a result, the density plots provided in Figure 11 are similar in shape to a platykurtic normal distribution or a tall uniform distribution. Thus, they indicate that auction clearing prices slightly above and below $1.50 are nearly equally likely.

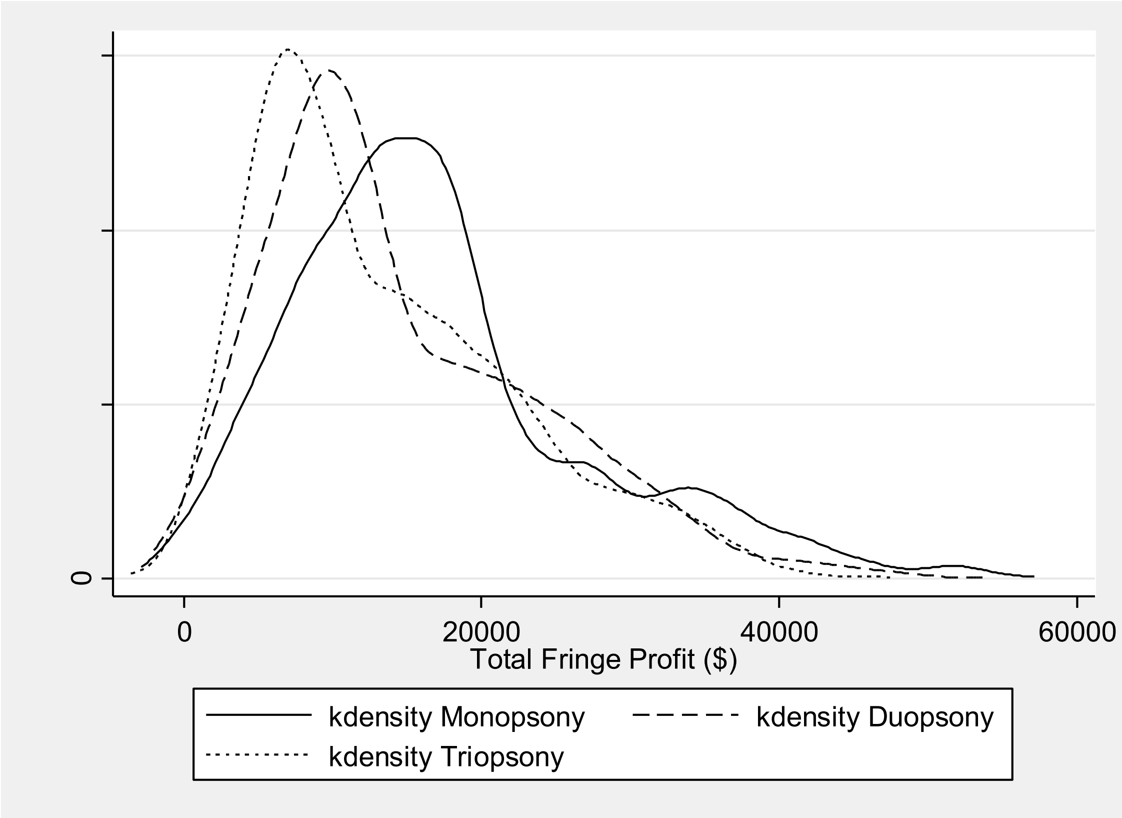

Figure 12. Kernel Density Plot of Total Fringe Profit

The figure also shows the weak likelihood of auction clearing prices rising above the secondary market price. The small likelihood of those events produces the few cases of negative profit shown in Figure 10. The probabilistic distribution of total profit for firms in the competitive fringe also indicates events of high fringe profit at a higher rate for the monopsony scenario than other scenarios. The right-skewed tails of the distributions indicate that the likelihood of increasing total fringe profit occurs beyond the mean point, but at a declining rate.

7. Implications and Conclusions

This paper has evaluated the extent to which one aspect of market failure, market power, can impact the range of possible outcomes in a Coasian transferable property rights market with auction-based allocation. It has applied a parameter set roughly equivalent to a current operating cap-and-trade program in the United States, and has evaluated the range of possible outcomes under three market power scenarios (monopsony, duopsony, and triopsony), with a set of sensitivity analyses evaluating robustness to changes in market size.

The analysis has shown that structural tradeoffs exist between positive demand-side influences on price and negative influences on profit from bids that yield firms insufficient quantities of goods (e.g., emissions allowances). Because non-linearities exist between these tradeoffs, optimal bidding strategies of strategic demand reduction were determined. As well, because the analysis was conducted using Monte Carlo simulation, the probabilistic distribution of these results was also provided.

Consistent with the structure-conduct-performance paradigm in traditional industrial organization theory, this analysis has shown that market conduct, as exercised through strategic demand reduction, can lead to performance changes in the auction market. Moreover, it has determined the specific marginal rate of influence, or slope, of changes in market conduct on expected auction clearing price for each individual scenario.

The influence of market power was also considered from the standpoint of firms in the competitive fringe, who participate in the market with weaker price influence. The results suggest that the exercise of strategic demand reduction by dominant firms is not entirely injurious to fringe firms, as a sort of price-leadership effect can occur. That is, as strategic demand reductions by oligopsonistic firms suppress market prices, fringe firms also benefit from that price suppression as they acquire goods (e.g., emissions allowances) at a lower cost.

As national and international discourse on climate change mitigation looks to market and auction-based solutions for further policy implementation, it is important for consideration to be given to the nature of market structure and the impact it will have on efficiency and performance. If participants in emissions markets are to be the same natural monopoly firms that operate within electricity markets, then the design and operation of emissions markets should reflect the same degree of deference to considerations of strategic behavior and market concentration.

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