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Consignment auctions

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Abstract

This article investigates pollution permit consignment auctions. In this process firms obtain an initial endowment of permits that must be consigned to the auctioneer for sale. In the auction, firms bid for permits, obtain their equilibrium permit allocations, and receive revenue from their consigned permits. It has been proposed that this auction is politically attractive and generates clear price discovery. We provide the first theoretical analysis of this kind of auction. We show, in most cases, the auction does not provide a clear price signal. Our results have policy implications for many permit markets, including the California Cap-and-Trade Program.

Keywords: pollution permit auction; consignment.

JEL Classification: D44; Q52

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1 Introduction

Pollution markets are now a popular policy tool to regulate emissions. In these markets the regulator creates a fixed number of pollution permits that can be traded among firms: the process of permit exchange allows the pollution target to be met at the lowest possible cost. Although these markets are now prevalent in the regulatory landscape, a perpetual and controversial debate exists over how these permits are initially endowed to firms (e.g., Goulder et al., 1999; Cramton and Kerr, 2002; Goulder and Parry, 2008). Two broad approaches have been used: (i) free allocation of permits—also known as 'grandfathering'—and (ii) auctioning of permits. The free allocation of permits—usually based on a firm's historical emissions or output—has been advocated as a politically feasible approach to control pollution: firms generally prefer this process as they obtain rents and potential windfall profits. For auctioned permits, the main justifications include the ability to generate revenue as well as the establishment of a clear price signal that will enhance the functioning of the market. As these schemes have distinct relative merits, attention has focused on designing mechanisms that can incorporate the benefits of both approaches. One such mechanism is the so-called *consignment auction*.

A consignment auction combines aspects of free allocation and auctioning into one mechanism. In the first step, permits are initially endowed to firms based on a free allocation rule (such as endowments based on historical emissions). Firms must then consign their initial permit endowments to the auctioneer, who will sell the permits in a forthcoming auction. In the second step, firms submit their demand schedules and the clearing price is determined; firms pay the clearing price for their equilibrium allocation of permits and obtain revenue from their consigned permits sold at auction. Thus all auction revenue is diverted to the holders of the initial permit endowments. This novel initial allocation process has therefore been regarded as being both politically appealing and successful in generating clear price discovery (i.e., convergence of the auction clearing price towards the Walrasian equilibrium) (Hahn and Noll, 1982; Hahn, 1988; Burtraw et al., 2010, 2016; Burtraw and McCormack, 2017). Although the *prima facie* benefits of consignment auctions appear to be substantial, there is, however, limited theoretical understanding of this process. Importantly, it is currently unclear how a consignment auction influences firms' bidding behavior and the associated equilibrium of the auction.

In this article we formally investigate the multi-unit uniform-price consignment auction and provide firms' bidding strategies as well as the equilibrium clearing price. In our model, we show that each firm has an incentive to submit a demand equal to their initial permit endowment. Firms are therefore neither net buyers nor net sellers within the auction process and their payoffs are independent of the clearing price: the consignment auction does not induce price discovery and the clearing price may be higher than in a standard uniform-price auction. This framework, then, showcases the underlying incentives for firms to bid in the auction as well as identifying the potential irrelevance of the clearing price in firms' equilibrium payoffs.

We develop our framework to first, compare the consignment auction to a standard uniform-price auction and second, to provide the possibility of proportional consignment. We show that prices in a consignment auction are (weakly) higher than the Pareto dominant clearing price of the standard uniform-price auction. Also we generalize our model to include a proportional consignment auction, where only a proportion of the total permits are initially endowed (and then consigned) to the auction. For a proportional consignment auction, we provide a model where, at the limits, our framework converges to either a full consignment auction or a standard uniform-price auction. In the proportional consignment auction, we continue to observe firms' demand schedules being dependent on their initial endowment but now the Pareto dominant clearing price is equal to the reserve price (similar to a standard uniform-price auction).

To investigate permit consignment auctions, we extend the literature on multi-unit uniform-price auctions by allowing firms to obtain auction revenue from their initial endowments. Uniform-price auctions have been extensively investigated (e.g., Wilson, 1979; Back and Zender, 1993; Wang and Zender, 2002; Ausubel et al., 2014). It is well known in the literature of multi-unit uniform-price auctions that bidders have incentives to shade their bids when they have more than one unit demand: so-called demand reduction. As there is a uniform price in the auction, each firm knows that their bids could affect the clearing price they pay for *all* units. Therefore by shading their bids they can reduce the auction clearing price and increase their payoffs. Back and Zender (1993) show, as a result of demand reduction, that an equilibrium clearing price equal to the reserve price could become the Pareto dominant outcome for bidders. This is, in fact, bad news for the auctioneer since their expected revenue is no better than a case where all units are sold via a posted price equal to the reserve price. Although uniform-price auctions have been extended and analyzed in a variety of formats, there has been no analysis of a uniform-price auction with an initial consignment of goods. We denote this as a consignment auction and provide the first theoretical analysis.[1] As such, our framework corresponds to any sale of multi-unit goods, where the auctioneer directs the auction revenue to initially endowed bidders.

The origin of a permit consignment auction can be found within a discussion by Hahn and Noll (1982), where many of the potential benefits were proposed.[2] First, consignment auctions may facilitate the functioning of the market by requiring all permit holders to consign their permits to the auction; thus, there cannot be any permit 'hoarding' effects. Second, the process can increase transparency and fairness as all initial endowments, and the outcome of the auction, are common knowledge. Indeed, a regulator can take equity considerations into account by adjusting firms' initial permit endowments. Third, by requiring full consignment, there is the potential benefit of early and clear price discovery that can improve the process of the permit market. Importantly, this has been justified as a significant benefit of this process from the outset: "[t]he auction also guarantees that a quick price signal will emerge" (Hahn, 1988, p.47). More recently this argumentation has continued in relation to the recent US Clear Power Plan, where Burtraw et al. (2016, p.51) suggest that "consignment sales ensure that freely allocated allowances enter the market, they help facilitate liquidity and early price discovery". Although there exists many potential benefits of this novel auction format, we show in this article that an auction that consigns all permits may not provide a clear price signal: firms' payoffs are independent

[1]Although no theoretical analysis has been undertaken on consignment auctions, there are a limited number of experiments that test aspects of the consignment auction (Franciosi et al., 1993; Güler et al., 1994; Ledyard and Szakaly-Moore, 1994; Dormady and Healy, 2015). A large literature is also associated with double auctions, yet these auctions are distinct from what we consider here. In a double auction, firms can sell permits within the auction by placing an offer of permits. Normally, their choice to offer permits for sale (and their ask price) is decided by the firm and not a requirement of the regulatory process (as is the case within a consignment auction). A key distinction between a double auction and a consignment auction—and the driving force behind the peculiarities associated with a consignment auction—is that firms in the consignment auction are obligated to consign their initial permit endowment and receive the clearing price per permit.

[2]This has also been referred to as a 'revenue-neutral' or 'zero-revenue' auction.

of the auction clearing price.

The consignment auction is the main permit allocation mechanism within the California (Quebec) Cap-and-Trade Program, which has an annual auction revenue of over $3.8bn (CARB, 2016; Borenstein et al., 2015).[3] Although permits are initially endowed to all Californian utilities, consignment rules differ depending of whether operators are either Investor Owned Utilities (IOUs) or Publicly Owned Utilities (POUs). Investor Owned Utilities have to consign all their endowments whereas Publicly Owned Utilities are allowed to retain a proportion of permits from consignment (they must be transferred into a compliance account). Over time the California auction has developed from a pure consignment auction to a proportional consignment auction, where a proportion of auctioned permits have not been endowed to firms. As we show in this article, moving towards a proportional consignment auction will generate price-discovery characteristics similar to a standard uniform-price auction and the subsequent problems of demand reduction.

The analysis of consignment auctions is related to the growing literature on revenue refunding rules within environmental regulation (e.g., Gersbach and Requate, 2004; Sterner and Isaksson, 2006; Montero, 2008; Aidt, 2010; Cato, 2010; Fischer, 2011; Gersbach and Winkler, 2011). This literature has focused on how the rebate of tax (or auction) revenue to polluting firms can generate first-best incentives to reduce pollution. In particular, the literature on revenue refunding focuses on the *ex post* transfer of the generated revenue, and, as such, the regulator has flexibility in deciding the preferred rebate rule. For example, Gersbach and Requate (2004), find that—in non-competitive product markets—there can exist an optimal tax-rebate system based on output shares. Montero (2008) proposes a new auction mechanism that allows the regulator to determine the number of pollution permits as well as firms' auction revenue rebates. He shows that making the rebate dependent on a firm's environmental damage can incentivize truthful bidding. Montero (2008), however, does not consider a consignment auction. In our article we provide a positive analysis of a consignment auction and show that there are potential pitfalls associated with rebating revenue based on the *ex*

[3] Consignment sales have been a small proportion of the initial endowment process within the US Acid Rain Program (approximately 2.8% of the total annual allocation of permits) (Joskow et al., 1998; Ellerman et al., 2000). Note that the auction system is a double auction, where firms can voluntarily offer permits for sale within the auction; thus, the incentive structures are distinct from a consignment auction (Cason, 1993, 1995).

ante consignment of permits. As we show in this article, the presence of consigned permits has stark consequences for the auction and the resulting secondary market. In particular, a regulator cannot choose initial endowments to incite truthful bidding. Thus a consignment auction—as observed in current regulation—cannot induce truthful bidding and may also provide poor price signal information to the market.

Our contribution is thus twofold. First, we add to the theory of auctions by developing a framework where we allow for the consignment of a multi-unit good. This, then, provides auction designers with additional information that can be used when designing efficient and effective auction mechanisms. Second, we advance the literature on permit consignment auctions and environmental regulation refunding. Not only do we provide the first theoretical approach to a consignment auction but our critical analysis advances the discussion on revenue rebating by providing insights into when—and under what circumstances—the use of rebating in environmental regulation is (un)desirable.

The article is organized as follows. In Section 2 we provide the setting for a consignment auction and Section 3 provides the equilibrium of a consignment auction. Section 4 provides a common-value model which is used for comparison of the clearing price with a standard uniform-price auction and a proportional consignment auction. Section 5 discusses extensions to the main model and Section 6 provides some concluding remarks. Proofs are relegated to Appendix A.

2 The model

Consider a cap-and-trade market that consists of a set of firms $I = \{1, 2, \ldots, n\}$. The regulator has a pollution target denoted by $Q \in \mathbb{R}_+$. In order to initially allocate the pollution permits, the regulator adopts a two-step consignment auction. In the first step, the regulator freely allocates all Q permits to firms, where each firm i receives an initial endowment of ω_i permits such that $\sum_{i=1}^{n} \omega_i = Q$.[4] In the

[4]This process—also known as 'grandfathering'—can, for example, be based on an individual firm's level of energy use, historical emissions, or some output-based criterion. Similar results would occur when a regulator separates permit allocation into both a free allocation of permits (that are not consigned) as well as permits used for a consignment auction: the level of auction supply would necessarily decrease and the marginal values for auctioned permits would be adjusted accordingly.

second step, firms participate in a uniform-price auction. The auctioneer generates an auction permit supply by requiring all firms to consign their free allocation to the auction. Thus in this consignment auction firms can bid for the total quantity available in the auction Q and simultaneously receive revenue based on their initial endowment ω that is consigned to the auction. The value of each permit is common but unknown. In particular, suppose the value of each permit for all firms is v, where v is not known to firms.[5] Firms have a similar prior regarding the common value and know that it is distributed according to some distribution function, $F(.)$ on a support $[\underline{v}, \bar{v}]$. Denote $\mathbb{E}(v)$ as firms' expected value of a permit, this can, for example, represent the avoided marginal costs of reducing pollution or an expectation of the future price in the secondary permit market. There is also a reserve price $r > 0$ in the auction and no bids less than the reserve price can be accepted.

The auction is a standard sealed-bid uniform-price auction, where each bidder i submits a non-increasing and left continuous demand function $x_i : [r, \infty) \rightarrow [0, Q]$. Given each firm's demand function, we define the aggregate demand function for all firms as $D(p) = \sum_{i=1}^{n} x_i(p)$, which is also left continuous and non-increasing. Since the total quantity of permits available for sale in the auction is fixed to Q, the auction clearing price is defined as follows,

$$p^* = \max \left\{ p | D(p) \geq Q; p \geq r \right\}. \tag{1}$$

Thus the clearing price is defined at the intersection of the aggregate demand function and quantity Q, where the price is greater or equal to the reserve price. Otherwise, there will be excess supply and the clearing price will be set at the reserve price. If there is any discontinuity in the aggregate demand function at the point of intersection, the clearing price would remain at the point of discontinuity but there will be excess demand. In this particular case the excess demand will be rationed based on the

[5]To reduce pollution, firms modify or adopt new technological processes. When estimating marginal abatement cost curves, a firm's long-run marginal abatement cost curve is increasing but discontinuous—through changes in the cost of alternative (and more expensive) technologies—but within specific technology classes, the marginal cost is constant (e.g., Sweeney et al., 2008; Mckinsey and Company, 2016). Further, for a single auction, the permits issued are negligible relative to the full range of marginal abatement cost curves, as the entire curve usually reflects a much broader compliance period and long-term emissions target. It is intuitive, then, to focus our attention on the adoption of processes from within a specific technology class, where there is sufficiently large capacity to meet the current abatement requirements. In many auctions, such as the California auction, there are even legal (upper bound) restrictions on how many permits a firm can obtain from the auction, which would suggest a firm is unlikely to exhaust all opportunities from a specific technology class.

following proportional rule

$$q_i(p^*) = x_i(p^*) - (D(p^*) - Q)\frac{\Delta x_i(p^*)}{\Delta D(p^*)}, \tag{2}$$

where $\Delta x_i(p^*)$ is the marginal demand of firm i at the clearing price p^* and $\Delta D(p^*)$ is the sum of marginal demands for all firms at the same price. Also $q_i(p^*)$ is the quantity that firm i receives given the clearing price and the submitted demand schedule. Moreover, in the case where firms submit vertical demands, and there is excess demand, the last term in (2) is undefined, and we therefore assume each firm receives its own endowment. Note that if $D(p^*) \leq Q$ then $q_i(p^*) = x_i(p^*)$ and there would be no excess demand. Furthermore, in the case where the aggregate demand and supply completely 'overlap' we have indeterminacy in the equilibrium price. In such a case we use a random rule to specify the clearing price. In particular, the auctioneer chooses the auction clearing price by randomly selecting a price from the feasible interval. Note that, in this instance, both firms and the regulator are indifferent between all prices in the interval.

3 Equilibrium of a consignment auction

Given our outlined model in the previous section, we now characterize the equilibrium of the consignment auction. For an auction clearing price p^*, firm i's payoff for receiving q_i permits at the auction is,

$$\pi_i = (v - p^*)q_i + \omega_i p^*. \tag{3}$$

Equation (3) shows that a firm's payoff depends on their net benefit of purchasing permits as well as the revenue obtained from their consigned permits, $\omega_i p^*$. The objective of firm i is to submit a demand schedule x_i in order to maximize their expected payoff. Formally, firm i solves the following problem

$$\max_{x_i} \quad (\mathbb{E}(v) - p^*(x_i))x_i + \omega_i p^*(x_i), \tag{4}$$

subject to the condition that $x_i + Q_{-i} = Q$, where $Q_{-i} = \sum_{j \in I \setminus \{i\}} x_j$ is the aggregate demand of firms excluding firm i. Given that the common value is unknown, firms use their expectation in the maximization problem. It is also clear from (4) that, within the auction process, if ω_i is larger than firm i's equilibrium permit allocation then firm i is a net seller, and similarly if ω_i is smaller than their equilibrium permit allocation then firm i is a net buyer. Following Wilson (1979) and Kremer and Nyborg (2004), this optimization problem can be adjusted to consider the firm's choice of clearing price p^*. Formally, noting that $x_i = Q - Q_{-i}$ we can rewrite the above maximization problem as follows

$$\max_{p^*} \quad (\mathbb{E}(v) - p^*)(Q - Q_{-i}(p^*)) + \omega_i p^*. \tag{5}$$

In the above maximization problem the aim is to find the clearing price, which maximizes firm i's expected profit given the residual supply and its initial endowment. The residual supply is calculated based on the expectation regarding the sum of demands submitted by $n-1$ other firms at the same clearing price.

Proposition 1. *When firms submit non-increasing weakly convex demand schedules, in the pure-strategy equilibrium of the consignment auction each firm i submits a demand schedule equal to,* $x_i(p) = \omega_i$*, for all feasible prices. Further, the payoff of each firm becomes independent of the auction clearing price.*

Proposition 1 illustrates the peculiarity of a consignment auction. Each firm in equilibrium bids for, and obtains, their own initial endowment ω_i; thus, there exists no net buyers or sellers of permits within the auction process.

One of the major justifications for implementing a consignment auction is to enhance price discovery within a cap-and-trade market and provide transparent and immediate revelation of market information. Yet Proposition 1 suggests that, paradoxically, implementing a consignment auction for the sole purpose of price discovery may actually reduce any signal derived from the clearing price. As each firm's payoff is independent of the clearing price, the equilibrium bids may no longer accurately represent the underlying compliance motives of firms' pollution reduction activities. It follows that in a consignment auction there is no Pareto dominant clearing price.

Consignment auctions have also been justified on other grounds. For example, Hahn and Noll (1982), Burtraw and McCormack (2017), and Burtraw et al. (2016) have stressed the benefits of political acceptability and fairness within such a mechanism. Clearly, firms would prefer to obtain initial endowments and receive rents, yet this comes at a cost of reduced price discovery. This scheme, then, may be relatively easy to implement, but the auction may generate incorrect price signals that distort firms' abatement and technology choices within the cap-and-trade market.

An interesting policy implication is that the regulator's choice of initial endowment to firm i will have a direct impact on individual equilibrium bids. Indeed, providing additional initial endowments will increase firm i's equilibrium bid (and consequently reduce the bids of other firms for a given aggregate emissions cap). Note that although initial endowments may be distributed differently among the firms, the set of clearing prices remains the same; thus, the class of equilibria are invariant to changes in the initial endowments.

4 Consignment versus a standard uniform-price auction

To illicit a meaningful comparison of a consignment auction, it is worthwhile providing details of a standard multi-unit uniform-price auction. Standard uniform-price auctions have been frequently used to allocate pollution permits, such as in the European Union Emissions Trading Scheme (EU-ETS) and the early auctions of the US Regional Greenhouse Gas Initiative (RGGI). The standard uniform-price auction can be viewed as a special case of a consignment auction, where firms receive no initial endowments, $\omega_i = 0$ for all $i \in I$ in (3). It is well known from Back and Zender (1993) that in a standard multi-unit auction there exists a set of symmetric pure-strategy subgame-perfect equilibria with clearing prices $p^* \in [r, v]$, where each firm receives $\frac{Q}{n}$ permits.

Since the payoffs are decreasing in the clearing price, and the allocation of permits is independent of the clearing price, it follows that the Pareto dominant clearing price for firms is $p^* = r$. That is, all firms increase their payoffs when their bids result in the lowest possible auction price. To highlight the potential differences between a consignment and standard uniform-price auction, we consider the impact on the clearing price. Noting that there is no Pareto dominant clearing price given the set of equilibria of a consignment auction, the following proposition is obtained.

Proposition 2. *When firms have common but unknown values, the equilibrium auction clearing price in the consignment auction is (weakly) higher than the Pareto dominant clearing price in a standard uniform-price auction.*

Proposition 2 shows that we expect to observe prices in a consignment auction that are higher than a standard uniform-price auction. Although both auction formats appear not to provide accurate price discovery—the clearing price is likely to be the reserve price (standard uniform-price auction) or somewhere above the reserve price (consignment auction)—the consignment auction may be less well suited in signaling the true costs of compliance. For a standard uniform-price auction, the regulator, over time, can adjust the reserve price to something that they perceive as the correct clearing price. Yet under a consignment auction, the range of potential clearing prices is much larger and provides a greater level of inherent uncertainty over the clearing price: although the regulator can select the reserve price, the clearing price is determined spuriously as there exists no Pareto superior clearing price. A main reason for using a consignment auction is that the revenue from permit sales are directed to firms, which results in a politically viable mechanism. Yet our results show that obtaining a politically viable mechanism comes at a direct trade-off of increased clearing prices, and, ultimately, unclear price discovery.

4.1 A proportional consignment auction

Up to this point we have assumed that the regulator endows all permits to firms, $\sum_{i=1}^{n} \omega_i = Q$. In this subsection we relax this assumption by allowing only a proportion of the total permits to be endowed to firms and the remainder are traditionally auctioned. Formally, let the regulator initially allocate ω_i of permits to each firm i with $\sum_{i=1}^{n} \omega_i < Q$. Define $\tilde{Q}$ as the residual permits that are auctioned (but not consigned) so that $\tilde{Q} = Q - \sum_{i=1}^{n} \omega_i$. Note that the regulator will auction both consigned and non-consigned permit in the same single auction. We then have the following proposition.

Proposition 3. *There exists a class of linear equilibria with the following demand schedule for each firm i with endowment ω_i,*

$$x_i(p) = \omega_i + \frac{\tilde{Q}}{n} + \frac{(p^* - p)\tilde{Q}}{(\mathbb{E}(v) - p^*)n(n-1)}, \tag{6}$$

where the clearing price is $p^* \in [r, \mathbb{E}(v)]$ and for any equilibrium clearing price p^* firm i receives $q_i(p^*) = \omega_i + \frac{\tilde{Q}}{n}$.

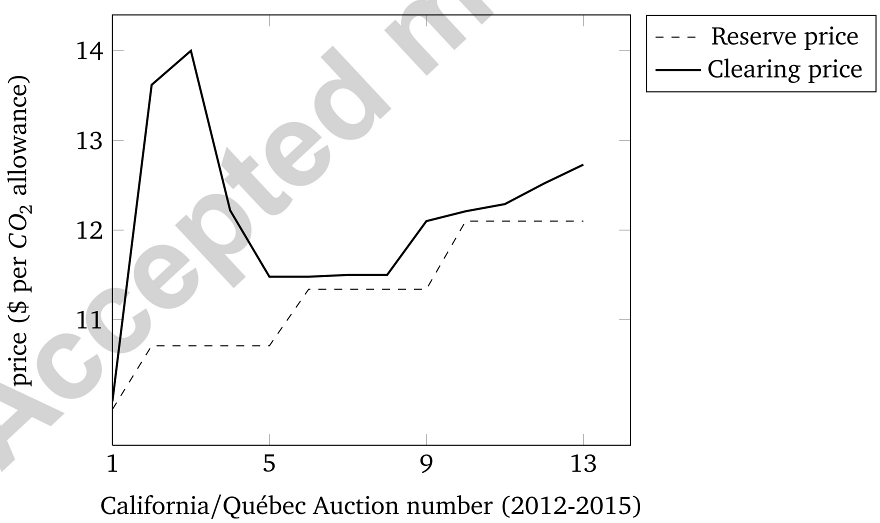
Proposition 3 presents a class of linear equilibria in which any price below $\mathbb{E}(v)$ characterizes an equilibrium with each firm i receiving a quantity equal to its initial endowment ω_i plus a share of the non-consigned permit quantity $\frac{\tilde{Q}}{n}$. The major implication of this result is that a proportional consignment auction provides an incentive for demand reduction. To observe this, note that a firm's non-consigned equilibrium permit allocation $\frac{\tilde{Q}}{n}$ is obtained regardless of the clearing price level: payoffs are therefore decreasing in the clearing price. Firms then have an incentive to systematically bid below their true valuations to obtain a lower clearing price for their permit allocation. As a result, a clearing price equal to the reserve price r is Pareto dominant for all firms. Therefore, similar to a standard uniform-price auction, we have undesirable equilibria and the demand reduction problem.

The proportional consignment framework is general enough to incorporate both a pure consignment auction $\sum_{i=1}^{n} \omega_i = Q$, a standard uniform-price auction $\sum_{i=1}^{n} \omega_i = 0$, and any degree of consignment in between. It follows that our result continues to hold when firms have the choice not to consign all their initial allocation. In fact, a risk-neutral firm is indifferent between consigning any unit into the auction and holding the permit because, in equilibrium, they will receive the consigned unit with certainty. This contrasts with the literature on revenue refunding, which shows that the share of auctioned permits is an important parameter (Gersbach and Winkler, 2011).

As the same set of clearing prices is expected from both a proportional consignment auction and a standard uniform-price auction, this raises a number of questions regarding the main justifications for using such an approach. Recall that one main justification of a consignment auction is that it will facilitate price discovery (Hahn, 1988). Yet what we have shown is that a proportional consignment auction has the same price discovery characteristics as a standard—and arguably simpler—uniform-price auction: demand reduction is still present. Thus the only substantive justification for using a proportional consignment auction—relative to a uniform-price auction—is to provide rents to regulated firms in order to generate a politically appealing mechanism. Of course, there may also exist simpler and alternative *ex post* rebate schemes that could be used to distribute auction revenue (see, for example, Montero, 2008).

The results in Proposition 1 and 3 have some implications for the California Cap-and-Trade Program.[6] The California auction commenced with full consignment of permits then progressed towards partial consignment. This non-consigned proportion was initially very small—less than 20%—and then raised to more than half of the total permits. Figure 1 shows the clearing and reserve price for the California (and Québec) consignment auctions. As can be observed, the clearing price was initially very volatile and sometimes much larger than the reserve price.[7] However, once the proportion of non-consigned permits increased, the clearing price—as predicted—becomes very close to the reserve price, which is potential evidence of the existence of a demand reduction equilibrium.

Figure 1: Auction clearing prices



Source: Adapted from: http://www.arb.ca.gov/cc/capandtrade/auction/results_summarypdf

[6] In Khezr and MacKenzie (2016) we also analyze the inclusion of a cost containment permit reserve into the auction process. This is modeled in a similar fashion to the cost containment permit reserve implemented within in the California Cap-and-Trade Program. It is found that bidding behavior is not altered by the existence of an allowance reserve.

[7] Note that there were 8 California auctions before a joint auction process included Québec. Further note that for both schemes, there appears to be 'learning' for the first number of auctions, then we observe more stability in the clearing prices.

5 Discussion

In this section we discuss the implications of our results when the model assumptions are modified. In particular, we discuss the strength of our main result when one changes the assumption of the basic model to private values and the case where firms' endowments are private information.

In our basic model, we assume firms have a common but unknown marginal value for permits. This fits well with the interpretation of the permit value being indicative of firms' perceptions of the permit price on the future secondary market: firms may bid for permits with a expectation of the permit price on the secondary market. Given many of the information sources available to firms about the future secondary market are common (e.g. government data on expected future energy use, the implementation of new or revised regulations, and so on), this is a plausible assumption. However, our main result (Proposition 1), is much stronger as it continues to hold even if we allow for firms to have private values for permits. In particular, it is possible to show that when firms have private values for permits, there exists a Bayesian-Nash equilibrium in which the quantity allocated to each firm is equal to their initial endowment. We provide the formal proof in Appendix B. As a consequence our main result continues to hold when we interpret firms as having different priors or expectations regarding the permit values.

Another possible interpretation of our model is a case where the initial endowment of other firms are not known to individual firms. As clear in the proof of Proposition 1, the only information which firm i uses in its maximization problem regarding the endowments, is the sum of other firms' endowments. Therefore, even if one assumes that the initial endowments are firms' private information, the result in Proposition 1 would continue to hold.

Thus, even in a more general framework, there exists a Bayesian-Nash equilibrium in which firms demand their own endowment. Consequently, one can still question the effectiveness of a clear price signal in a consignment auction.

6 Conclusion

This article investigates permit consignment auctions. A consignment auction is similar to a standard uniform-price auction but with one key distinction: the pollution permits are initially endowed to firms and are required to be consigned to the auction supply prior to an auction. A consignment auction, therefore, provides each firm with a source of revenue from the sale of permits. Many potential advantages have been advocated. First, the process forces permits onto the market, which should discourage hoarding of permits and improve market exchange. Second, providing firms with the generated revenue is an important way to ensure the cap-and-trade market is politically acceptable. Third, using an auction may generate an immediate price signal, which can be used by the secondary market to cost effectively exchange permits: a classic advantage of using a permit auction.

In this article we consider firms' bidding strategies as well as the equilibrium clearing price within a consignment auction. Surprisingly we show that, in equilibrium, each firm may obtain exactly the same amount of permits as their initial endowment. This has major policy implications. As a result of firms' bidding strategies, firms' payoffs are independent of the clearing price. Thus the clearing price no longer reflects the true opportunity cost of holding a permit. As such, one would predict that the clearing prices in a consignment auction may be relatively higher than standard uniform-price auctions. We develop the model to include proportional consignment.

Given our findings that a clear price signal may not be guaranteed, it is important to reassess the use of such an auction. For example, this mechanism is the major allocation mechanism for permits within the California Cap-and-trade Program. Thus it is important to consider if other forms of auction revenue rebating, such as rebating proposed by Montero (2008), can be used to satisfy the objectives of the regulator while simultaneously providing immediate and clear price discovery.

Appendix A

Proof of Proposition 1. Differentiate (5) with respect to p^* to find the first-order condition for all firms. For each firm $i \in I$ we have

$$(Q - Q_{-i}(p^*)) + (\mathbb{E}(v) - p^*)Q'_{-i}(p^*) - \omega_i = 0, \tag{7}$$

or

$$x_i(p^*) + (\mathbb{E}(v) - p^*)Q'_{-i}(p^*) - \omega_i = 0. \tag{8}$$

The sum of endowments for all firms is $\sum_{i=1}^{n} \omega_i = Q$ and also $\sum_{i=1}^{n}(Q - Q_{-i}(p^*)) = Q$. Then the sum of first-order conditions for all firms yields

$$Q + (\mathbb{E}(v) - p^*)(n-1)\sum_{i=1}^{n} x_i^{'}(p^*) - Q = 0. \tag{9}$$

Therefore, we have

$$(\mathbb{E}(v) - p^*)(n-1)\sum_{i=1}^{n} x_i^{'}(p^*) = 0. \tag{10}$$

For this condition to be satisfied there are two possibilities. First, if $\mathbb{E}(v) = p^*$ then according to each firm i's first-order condition we have $x_i(p^*) = \omega_i$. Second, if $\sum_{i=1}^{n} x_i^{'}(p^*) = 0$, then since demand schedules are non-increasing it must be the case that $x_1'(p^*) = ... = x_n'(p^*) = 0$, to guarantee the equality. Again from each firm i's first-order condition we have $x_i(p^*) = \omega_i$. Given the equilibrium demand schedule for each firm i at the clearing price, each firm receives a quantity equal to their initial endowment $q_i(p^*) = \omega_i$. Given the equilibrium quantity and using (5), each firm i's payoff is equal to $v\omega_i$ and thus independent of the clearing price. □

Proof of Proposition 2. As we mentioned, according to Back and Zender (1993), the set of equilibria for a uniform-price auction with a reserve price r is $p^* \in [r, v]$. Thus in our setting with common but unknown marginal value, the interval is transformed to $p^* \in [r, \mathbb{E}(v)]$. Also the quantity each buyer receives is unchanged given any equilibrium price. Therefore, the Pareto dominant clearing price for buyers is r. However, as we showed in Proposition 1, for the consignment auction equilibrium any clearing price above the reserve price is equally likely and would not affect buyers' payoffs. Also according to rules of the auction, buyers are not allowed to submit bids lower than the reserve price. Thus the set of possible clearing prices in the consignment auction is any price greater than or equal to the reserve price. □

Proof of Proposition 3. We are looking for the linear equilibria with the following linear demand function,

$$x_i(p) = \alpha_i + \beta p. \tag{11}$$

Substituting the above demand function in (5) and differentiating results in the first-order condition for firm i, that is,

$$x_i(p^*) + (\mathbb{E}(v) - p^*)(n-1)\beta - \omega_i = 0, \tag{12}$$

where $x_i(p^*)$ is the demand submitted by firm i at the clearing price since in equilibrium it is equal to the residual demand left for firm i. Then the sum of the first-order conditions for all firms becomes,

$$Q - \sum_{i=1}^{n} \omega_i + (\mathbb{E}(v) - p^*)n(n-1)\beta = 0, \tag{13}$$

which can be simplified to

$$(\mathbb{E}(v) - p^*)n(n-1)\beta = -\tilde{Q}. \tag{14}$$

Rearranging for β, we have

$$\beta = -\frac{\tilde{Q}}{(\mathbb{E}(v) - p^*)n(n-1)}. \tag{15}$$

We are looking for an expression for demand schedules. Since the demand function is also satisfied at the clearing price p^*, in the first-order condition, we can substitute $x_i(p^*)$ with $x_i(p^*) = \alpha_i + \beta p^*$ and substitute β from (15) to find an expression for α_i. After some manipulation we have,

$$\alpha_i = \omega_i + \frac{\tilde{Q}}{n} + \frac{p^*\tilde{Q}}{(\mathbb{E}(v) - p^*)n(n-1)}. \tag{16}$$

Using α_i and β gives the following demand function for each firm i

$$x_i(p) = \omega_i + \frac{\tilde{Q}}{n} + \frac{(p^* - p)\tilde{Q}}{(\mathbb{E}(v) - p^*)n(n-1)}. \tag{17}$$

Also at a price equal to p^* we have,

$$q_i(p^*) = x_i(p^*) = \omega_i + \frac{\tilde{Q}}{n}. \tag{18}$$

□

Appendix B

Our model can be generalized to allow for firms to have private values by extending the model outline in Section 2. Let firm i have a constant marginal value v_i for permits. The values are private information of each firm but it is commonly known that they are distributed according to some distribution function, $F(.)$ on a support $[\underline{v}, \bar{v}]$.

The maximization problem is

$$\max_{p^*} \quad (v_i - p^*)(Q - Q_{-i}(p^*)) + \omega_i p^*. \tag{19}$$

Similar to Proposition 1, We can show that when firms submit non-increasing weakly convex demand schedules, there now exists a Bayesian-Nash equilibrium in which the quantity allocated to each firm is equal to their initial endowment, $q_i(p^*) = \omega_i$, for all $i \in I$. Further, the payoff of each firm becomes independent of the auction clearing price.

To do this note that demand schedules submitted by other firms are not known to a given firm i, we can rewrite (19) in terms of expectation as follows.

$$\max_{p^*} \quad \mathop{\mathbb{E}}_{v,\omega}\Big[(v_i - p^*)(Q - Q_{-i}(p^*)) + \omega_i p^*\Big]. \tag{20}$$

Differentiating with respect to p^*, we have

$$\mathbb{E}_{v,\omega}\left[(Q - Q_{-i}(p^*)) + (v_i - p^*)Q'_{-i}(p^*) - \omega_i\right] = 0, \tag{21}$$

or

$$\mathbb{E}_{v,\omega}\left[x_i(p^*) + (v_i - p^*)Q'_{-i}(p^*) - \omega_i\right] = 0. \tag{22}$$

The sum of endowments for all firms is $\sum_{i=1}^{n} \omega_i = Q$ and also $\sum_{i=1}^{n}(Q - Q_{-i}(p^*)) = Q$. Then the sum of first-order conditions for all firms yields

$$\sum_{i=1}^{n} \mathbb{E}_{v,\omega}\left[(v_i - p^*)Q'_{-i}(p^*)\right] = 0. \tag{23}$$

We can rewrite this term as follows,

$$\sum_{i=1}^{n} \mathbb{E}_{v,\omega}\left[(v_i - p^*)\sum_{j\neq i}^{n} x_i^{'}(p^*)\right] = 0. \tag{24}$$

One solution to above first-order condition is $x_i = \omega_i$ for every i. This is because each firm would have $x_i^{'}(p^*) = 0$ and the above condition is satisfied. Therefore, a Bayesian Nash equilibrium is that each firm submits a demand schedule equal to its initial endowment. Given the equilibrium demand schedule for each firm i, each firm receives a quantity equal to their initial endowment $q_i(p^*) = \omega_i$ and all clearing prices above the reserve price can be the equilibrium clearing price. Also it is easy to check that each firm i's payoff is equal to $v_i\omega_i$ and thus independent of the clearing price.

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