Carbon Allowance Auction Design:
An Evaluation of the Current Debate*

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Abstract

We describe the debate among economists regarding the most appropriate auction formats for carbon allowance auctions. The two leading candidates are a uniform-price sealed-bid auction and an ascending clock auction. We identify the primary trade-offs between these auction formats and argue that current economic research supports the recommendation of a uniform-price sealed-bid auction for carbon allowance auctions.

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1 Introduction

It is widely believed that the auction of emission permits for CO$_2$ will be a component of future legislation geared towards reducing greenhouse gas emission in the US. Auctions are already being used in the northeast US, as part of the Regional Greenhouse Gas Initiative (RGGI).

There are a variety of different auction formats that could potentially be used for the sale of emission permits. A number of economists have taken sides, some advocating a uniform-price sealed-bid auction and others advocating an ascending clock auction format.$^1$ Loosely speaking in a uniform-price sealed-bid auction, bidders would submit their demand curves for allowances, and all winning bidders would pay the same market-clearing price for the allowances. In an ascending clock auction, the auctioneer would start by calling out a low price and would raise the price incrementally until demand at the announced price no longer exceeds supply. All remaining active bidders would pay the market clearing price.$^2$

Although there are many conceivable auction format choices, the uniform-price sealed-bid and ascending clock auction formats are the leading candidates. In this face-off of ideas, based on our reading of the experimental, theoretical, and empirical literature, we find the arguments in favor of a uniform-price sealed-bid auction more compelling. While both formats would be expected to perform well on a variety of important dimensions, they differ in two key features. On the one hand, a uniform-price sealed-bid auction would be expected to be more robust to collusion; on the other hand, an ascending clock auction offers the potential for better information aggregation, due to the gradual nature of its price formation mechanism. In our view, the existing body of work suggests that the vulnerability to collusion is a more serious issue relative to the potentially superior information aggregation capabilities of the ascending clock format. In particular, the experimental evidence suggests that the potential for improved price discovery with an ascending clock auction may not be realized in practice. For example, Goeree, Offerman, and Sloof (2005) show that demand reduction and preemptive bidding (forms of strategic bidding) may be more of an issue in ascending auctions, potentially meaning the ascending auction is likely

$^1$For example, see Holt et al. (2007, 2008) in support of the uniform-price sealed-bid auction and Cramton and Kerr (2002), Evans & Peck (2007), and Betz et al. (2009) in support of the ascending clock auction.

$^2$We describe these auction formats in greater detail below.
to perform worse both in terms of revenue and efficiency.

The remainder of this paper is organized as follows. In Sections 2 and 3, we provide a framework for thinking about the main types of auctions identified in the literature and used in practice. In Section 4, we provide a list of desirable properties for auction design. In Section 5, we review and offer our assessment of the current debate over auction design for carbon markets. In Section 6, we mention some additional auction design details.

2 Types of Auctions

2.1 Introduction

There are a variety of auction formats used in practice. Some are more appropriate in some cases than others. All require that bidders understand their own willingness to pay for the object being sold; however, they differ in the extent to which “strategic bidding” comes into play.

For example, consider a simple ascending-bid auction for a single object and suppose each bidder has its own privately known willingness to pay for the object, which is unaffected by any information regarding other bidders’ values. Under these assumptions, the optimal strategy for each bidder is to continue bidding for the object until the price reaches the bidder’s value. The bidder need not know anything about the values of rival bidders in order to bid optimally.

In contrast, in a simple sealed-bid auction (high bidder wins and pays its bid) for a single object, a bidder will want to shade its bid below its value. The optimal bid in this case is determined by the trade-off between the probability of winning and the price paid conditional on winning. A higher bid increases the probability of winning, which increases bidder surplus, but also increases the price paid if the bid wins, which decreases bidder surplus. Because the probability of winning depends on how a bidder’s own bid compares with those of rivals, optimal bidding in a sealed-bid

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3In this paper we focus on auction formats relevant for the sale of multiple identical objects, as would be the case in carbon allowance auctions. Alternative auction formats may be more appropriate with differentiated products. For example, in the FCC’s spectrum license auctions, each license has unique characteristics. In that case, the currently used format is a multiple-round ascending-bid auction that allows bidders to submit bids on all the licenses on offer in each round. See Marx (2006) and Brusco, Lopomo, and Marx (2009) for analysis of issues arising in the context of the FCC’s spectrum license auctions.
auction requires not only introspection regarding a bidder’s own value, but also an assessment of rivals’ values and bidding strategies.

Therefore, an important between ascending-bid auctions and sealed-bid auctions in simple one-object environments is that in the ascending-bid case, bidders need only consider their own values, whereas in the sealed-bid case, bidders must consider both their values and their estimates of rivals’ values and bidding strategies. Intuitively, this difference stems from whether the price paid by the auction winner is decided by the winner’s own bid or by the bids of others. In an ascending-bid auction, the winner is the bidder that is still active when all others have ceased bidding. Therefore, the amount paid by the winner is determined by the point at which the last among its opponents has exited the bidding, which in equilibrium is equal to that opponent’s value. Thus, the amount paid by the winner is determined by some other bidder’s value. On the contrary, in a sealed-bid auction, the winner’s own bid determines the amount it pays if it wins.

The simple structure of optimal bidding strategies in the ascending-bid format may account for the popularity of that format. However, once one moves to an environment with multiple objects for sale, strategic bidding can become important even in ascending-bid formats. In multi-unit auctions, bidders with demand for multiple units must consider whether one of their bids might affect the price they pay for objects won as a result of other bids. In general, bidders with demand for multiple units have an incentive to bid strategically, understating their demand, in case one of their bids turns out to be the one that determines the price they must pay for units won. This type of strategic bidding is referred to in the literature as “demand reduction.”

Because of incentives for demand reduction, in multi-unit auctions strategic bidding is an issue for both ascending-bid and sealed-bid formats.

2.2 Categorization

The different auction formats relevant for carbon allowances are those appropriate for the sale of multiple identical objects. The standard auction formats for this case can be categorized according to two key characteristics: (i) whether the bidding is

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dynamic or sealed-bid, and (ii) whether winning bidders pay their bid prices (discriminatory pricing), or whether all winning bidders pay the same price (uniform pricing).\textsuperscript{6}

<table>
<thead>
<tr>
<th>Pricing</th>
<th>Bidding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discriminatory</td>
<td>Descending clock</td>
</tr>
<tr>
<td></td>
<td>Discriminatory sealed-bid</td>
</tr>
<tr>
<td>Uniform</td>
<td>Ascending clock</td>
</tr>
<tr>
<td></td>
<td>Uniform-price sealed-bid</td>
</tr>
</tbody>
</table>

Table 1: Categorization of Multi-Unit Auction Formats

We now provide a more detailed description of each of the four auction formats shown in Table 1. We begin with the two sealed-bid auction formats.

### 2.3 Discriminatory sealed-bid

In a discriminatory sealed-bid auction, bidders simultaneously submit bids, with each bidder potentially submitting multiple bids.\textsuperscript{7} Each bid specifies a price and a quantity. Bids are ranked and the market clearing price is set at the level that makes the total demand equal to the available supply. Bids at or above the market clearing price are winners. Winning bidders receive the quantity bid and pay the prices they bid. Thus, different bidders will pay different amounts for the units they win.

With pay-as-bid pricing, each bidder has an incentive to bid as close as possible to the clearing price. Cramton and Stoft (2007, p.33) comment: “Indeed, the pay-as-bid auction may be renamed ‘Guess the clearing price.’ The pay-as-bid auction rewards those that can best guess the clearing price. ... Typically, this favors larger companies that can spend more on forecasting.”

### 2.4 Uniform-price sealed-bid

In a uniform-price sealed-bid auction, bidders again simultaneously submit bids, with each bidder potentially submitting multiple bids. As in the discriminatory

\textsuperscript{6}The categorization dates back to Vickrey (1961). See also Bartolini and Cottarelli (1997).

sealed-bid format, each bid consists of a price and a quantity, and bids are ranked by price. The market clearing price is determined by setting total demand equal to available supply. Each bidder receives the quantity bid at prices at or above the market clearing price, and all bidders pay the (same) market clearing price.8

Absent market power, uniform-price auctions yield competitive equilibria, which are efficient: the outcome maximizes social welfare. Real markets may not achieve the ideal of perfect competition, but there is a substantial body of both theoretical and empirical work showing that the convergence to full efficiency is rapid as markets become more competitive.9

Theoretical comparisons of revenue for the uniform-price and discriminatory auctions are ambiguous. Their relative performance depends on the particulars of the auction setting.10 However, there is empirical evidence that differences are typically small and often insignificant.11

### 2.5 Ascending clock

In contrast to the two sealed-bid auction formats just described, the ascending clock auction involves dynamic bidding.

In an ascending clock auction, the auctioneer announces the current price and bidders indicate the quantity they would be willing to purchase at that price. If the quantity demanded exceeds supply, the price is increased. The process starts with a low price and continues until the total of all quantities demanded at the current price is equal to the quantity supplied. This is a dynamic auction format, with the bidding taking place in rounds. Ultimately every winning bidder pays the same per-unit price.

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8Related literature includes Wilson (1979) and Back and Zender (1993).
10As reported in Wolfram (1998, p.704), “Simon (1994) and Nyborg and Sundaresan (1996) focus on differences between discriminatory and uniform-price auctions generated by informational asymmetries across bidders. (For instance, theory suggests that the winner’s curse will restrain bidding more in discriminatory auctions than in uniform-price auctions.)”
11See Hortaçsu (2002) for empirical results based on Turkish treasury security auctions.
2.6 Descending clock

Our final auction format is one that involves dynamic bidding, but which allows for discriminatory pricing. In the descending clock format, the auctioneer begins with a high price and then progressively lowers it until a bidder “stops the clock.” Units are progressively awarded to individual bidders, which can buy any fraction of the remaining quantity at the current price. The price continues to fall until all available units are sold.

3 Examples of auctions in practice

3.1 Introduction

In this section we provide a number of examples of auctions being used in practice. As an overview, we can return to the matrix presented in Table 1 and give examples associated with each category.

<table>
<thead>
<tr>
<th>Pricing</th>
<th>Dynamic Bidding</th>
<th>Sealed Bidding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discriminatory</td>
<td>- Dutch Tulips</td>
<td>- US Treasury (pre-1992)</td>
</tr>
<tr>
<td></td>
<td>- Sydney Fish Market</td>
<td>- Mexico Treasury (pre-1990)</td>
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<tr>
<td></td>
<td></td>
<td>- US Sulfur Dioxide</td>
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<tr>
<td>Uniform</td>
<td>Virginia NOx</td>
<td>- US Treasury (post-1992)</td>
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<tr>
<td></td>
<td></td>
<td>- Mexico Treasury (post-1990)</td>
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<tr>
<td></td>
<td></td>
<td>- RGGI Carbon Dioxide</td>
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<td></td>
<td></td>
<td>- US Electricity</td>
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</tbody>
</table>

In what follows, we provide additional discussion of the examples in Table 2.

12Another example of a dynamic discriminatory auction, which as far as we know remains theoretical and is not used in practice is the Ausubel “clinching” mechanism, which was proposed in Ausubel (2004). In that paper, Ausubel describes the ascending-bid “clinching mechanism” as follows (p.1452): “The auctioneer announces a price and bidders respond with quantities. Items are awarded at the current price whenever they are ‘clinched,’ and the price is incremented until the market clears. With private values, this (dynamic) auction yields the same outcome as the (sealed-bid) Vickrey auction, but has advantages of simplicity and privacy preservation.” Because this is not a format with which there is real-world experience, we will not comment on it further.
3.2 Government treasury security auctions

Governments sell trillions of dollars worth of securities every year. There is a debate among economists as to the optimal auction mechanism for these sales. In 39 out of the 42 countries surveyed by Bartolini and Cottarelli (1997), the government uses a discriminatory sealed-bid auction. However, the US switched in the 1990s to a uniform-price sealed-bid auction. Bartolini and Cottarelli (1997, p.274) comment on this change saying: “Scholars of treasury bill auctions have been particularly interested in the contribution of different auction formats to collusive behavior and cornering, an issue brought to the forefront of the debate by recurrent episodes of allegedly non-competitive behavior in auctions of government securities in the United States and elsewhere. The controversy initially arose in the 1960s, and revolved around the suggestion to replace the multiple-price format of US Treasury auctions with the uniform-price format.” The Mexican government switched to a uniform-price sealed-bid auction in 1990 for similar reasons.

Despite the general preference among governments for discriminatory auctions, Hortaçsu (2002) shows that for treasury auctions, the evidence does not allow one to reject the possibility that, statistically speaking, discriminatory and uniform-price auctions deliver the same expected revenue to the government.

In a discriminatory sealed-bid auction, for any given quantity, a rational bidder would bid a price that is lower than its true (marginal) valuation for that quantity, i.e. “shade” its bid. The amount by which a bidder shades its bid relative to its valuation, depends on what he expects the market clearing price to be. The incentive for bid-shading is not as strong in the uniform-price auction because the bidder only pays an amount equal to the market clearing price times the total quantity it wins.

Since bidders do not shade their bids as much in a uniform-price auction, the market clearing price is higher than in a discriminatory auction. However, in the discriminatory price auction, final prices are above the market clearing price for the initial units sold. Therefore, the revenue trade-off between a discriminatory versus a

14 See Umlauf (1993, p.313), saying “Bidders’ profits fell dramatically in 1990 when the [Mexican] Treasury substituted uniform for discriminatory pricing to combat collusion and to increase auction revenues.”
15 See Brenner, Galai, and Sade (2009).
16 See Hortaçsu (2002) for an elaboration of this intuition.
uniform-price auction depends on the details of the bidding strategies.

3.3 Electricity

Electricity auctions are conducted in deregulated power exchanges around the world. Various governments have created two-sided auction markets for wholesale power, where generating companies bid to sell their power and wholesale customers bid to buy power. Trades are executed at the market clearing price, which equates supply and demand. Roughly speaking, each generator submits a schedule detailing the prices at which it would be willing to supply power during various blocks of time, and wholesale customers submit demand forecasts.

Cramton and Stoft (2006) describe the US market as a uniform-price sealed-bid auction, but there has been some debate among economists concerning the most appropriate format for electricity auctions.

3.4 Sulfur dioxide allowances

Sulfur dioxide emission permits have been required for certain electric utilities and freely traded in the US since 1995. The underlying legislation is Title IV of the 1990 Clean Air Act Amendments, which describes the US Acid Rain Program. This program targets electric utility emissions of sulfur dioxide, mainly those produced by coal-fired electric generating plants. The regulation was phased in over time. In Phase I (1995–1999), the 263 dirtiest large generating units were required to reduce emissions by about 3.5 million tons of sulfur dioxide per year. In Phase II, which began in 2000 and continues today, virtually all fossil-fueled electric generating plants (units exceeding 25 MW) were subject to a national cap on aggregate annual sulfur dioxide emissions.

The emission cap is enforced through the annual issuance of tradeable emission allowances, good for 1 ton of sulfur dioxide and recorded in the EPA’s allowance tracking system. Allowances can be banked for future use, but firms cannot borrow

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17 See Wolfram (1998) and Borenstein, Bushell, and Wolak (2002), as well as the papers cited therein, for descriptions and analyses of electricity auctions.

18 See Kahn et al. (2001a, 2001b) and Cramton and Stoft (2007), who argue that a uniform-price sealed-bid format is more appropriate for electricity auctions than a discriminatory sealed-bid auction, in part because of the two-sided nature of the market.

19 As a general reference, see Ellerman et al. (2000).
from the future.

The EPA holds back 2.8% of allowances for an annual auction, with the proceeds returned pro rata to the firms granted the allowances. This auction uses the discriminatory sealed-bid format, although there is debate about whether a uniform-price sealed-bid auction might be preferable.

3.5 Carbon dioxide allowances


In the June 2009 auction, the market clearing price was $3.23 per ton of carbon dioxide, and 30.8 million allowances were sold for a revenue of approximately $100 million. The largest bidder purchased 7,721,000 allowances ($25 million). Eighty-five percent of allowances were purchased by “compliance entities” (electric power generators) rather than brokers, environmental groups, private citizens, etc.

Six Midwestern states and seven in the West are currently developing regional carbon cap-and-trade programs similar to RGGI.

In Europe, the European Union Emission Trading System (EU ETS) covers over 10,000 facilities, which amounts to approximately half of EU’s carbon dioxide emissions. Emission permits are initially distributed for free by EU countries and can be freely traded. Permits are currently trading at around $20 per ton of carbon dioxide.

3.6 Virginia NOx

The Commonwealth of Virginia has implemented a program for the auction of tradable emission permits for nitrogen oxides (NOx). As described by Porter et al. (2009), the auction format used in 2004 and 2005 was an ascending clock auction. The choice of this format was supported by experimental results reported in Porter

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20 See Joskow, Schmalensee and Bailey (1998) for a descriptive analysis of bidding behavior in this market.

21 See Cason and Plott (1996) reporting experimental results suggesting a uniform-price sealed-bid auction might be preferable to the discriminatory sealed-bid format being used, and see Søberg (1998) disputing that conclusion.
et al. (2009), showing that an ascending clock auction performed better in terms of efficiency and revenue than a sealed-bid alternative when demand was relatively elastic.

3.7 Dutch Tulips and Sydney Fish Market

Descending clock auctions are often referred to as Dutch auctions because of their prominent use for the sale of tulips and flowers in the Dutch flower marketplace called The Bloemenveiling outside of Amsterdam.\textsuperscript{22} Due to the huge volumes and perishable nature of the products,\textsuperscript{23} there is great value to the speed with which descending clock auctions can be conducted.

As described on the website of The Sydney Fish Market (SFM),\textsuperscript{24} “SFM has been using the Dutch clock auction since 1989. Adopted from the Dutch tulip auctions, the system ensures product is sold quickly while achieving premium prices.” As the price on the clock drops, bidders can observe the number of crates left to sell in the current lot and can signal electronically their desire to purchase crates (up to a maximum number) from that lot at the current price shown on the clock. The SFM website states, “The starting price is usually set about $2 above what the product is expected to receive. Two clocks auction seafood simultaneously to ensure product is sold quickly.”

Because speed is not a critical factor in the design carbon allowance auctions, it is unlikely that the descending clock is the best choice for these markets. As far as we know, no economist has argued in favor of a descending clock format for carbon markets.

4 Desiderata for auction selection

The literature on auction design typically lays out the following desirable properties for auction selection:

\textsuperscript{22}Note that although Google’s 2004 IPO was widely described as a “Dutch auction,” it was in fact a uniform-price sealed-bid auction, not a descending clock auction. (See, e.g., http://money.cnn.com/2004/04/29/technology/googleauction/, visited July 30, 2009.)

\textsuperscript{23}According to http://www.tulip-bulbs.com/ (visited July 30, 2009), the marketplace represents 36% of the world’s tulip and flower sales.

\textsuperscript{24}http://www.sydneyfishmarket.com.au/ (visited July 30, 2009)
1. **Allocative efficiency**: objects should end up in the hands of the buyers that value them the most;

2. **Revenue**: revenue obtained by the government through auctions may be less distortionary than other sources, such as taxes;

3. **Price discovery**: auction prices provide informative signals about market prices and underlying values;

4. **Robustness to collusion and/or market manipulation**: auction rules should promote competition;

5. **Fairness and transparency**: auction rules should promote confidence in the political and regulatory process;

6. **Transaction cost minimization**: bid submission costs should be minimized.

The two primary metrics for optimal auction design in the economics literature are typically efficiency and revenue. When economists talk about the efficiency of an auction, they are usually referring to allocative efficiency, i.e., objects being ultimately assigned to the highest-valuing bidders. Straightforward sealed-bid auctions for single objects (high bidder wins and pays its bid) are not necessarily efficient because bidders with high values might shade their bids substantially, expecting weak competition, while bidders with lower values might submit relatively high bids, expecting strong competition. As a result, lower-valuing bidders can win, and this is not efficient.

The revenue from an auction is simply the money collected by the auctioneer. Revenue generated by auction can be a substitute for distortionary taxes.\(^{25}\) Also, it can be less costly politically to raise money through an auction rather than via direct or indirect taxation.

Typically, however, the two main criteria of efficiency and revenue maximization are in conflict with one another. The easiest way to see this is in the simple environment of a single-unit auction with a reserve price. The auctioneer can increase its revenue by setting a positive reserve price, but this increases the risk of not selling to buyers with positive values. This efficiency/revenue trade-off plays a central role in much of the economics literature on auctions.

\(^{25}\)This is the so-called “double dividend” effect (see e.g., Bovenberg and Mooij, 1994; Bovenberg and Goulder, 1996; Goulder et al. (1999), and Parry, Williams, and Goulder, 1999).
Traditionally, governments tend to prefer efficiency over revenue. For example in the case of US spectrum license auctions “Congress set forth an explicit requirement that revenues not be a primary consideration in designing auctions.” (Kwerel and Rosston, 2000, p.271). In the case of carbon emissions, efficiency should also be a prominent concern. This includes allowing non-emitting parties who value reductions in emissions to buy permits (and not use them).26

Effective price discovery is desirable to provide the information required to formulate a well-reasoned, comprehensive environmental policy, as well as to provide a guide for decision making by private enterprises. Prices are more likely to reflect true market values and thus provide better information if they emerge as the final outcome of transparent, competitive auction mechanisms. Also, advance auctions for future vintages can be valuable for price discovery, reflecting expectations about the future evolution of industry fundamentals.

Robustness to collusion and/or market manipulation is clearly an important element of any effective auction design. As a prominent example, consider the early design of the FCC spectrum license auctions, which stressed the importance of high transparency and flexibility for bidders.27 Unfortunately, the information revealed during the auctions was found to facilitate retaliatory bidding, signalling, market division, and gaming of the auction’s activity rules, which were detrimental both to revenue and allocative efficiency.28 Recent FCC auctions have moved to an “anonymous” format that masks bidder identities. In this way, opportunities and incentives for anti-competitive behavior by bidders are reduced.29

It should be obvious why fairness and transparency are also desiderata. “Transparency in bidding” is a common refrain in federal auctions and procurements. However, as shown in Marshall and Marx (2009), pre-auction transparency in the form of transparent registration, and real-time transparency in the form of revelation of the identities of bidders can also have significant pro-collusive effects. Presumably,

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29See Marx (2006) and Brusco, Lopomo, and Marx (2009). The use of anonymous auction formats to reduce susceptibility to collusion is also supported by the theoretical work of Marshall and Marx (2009).
a primary motivation for “transparency in bidding” is the need to allay fears about corruption. In this case, however, the remedy is simple – post-auction transparency. Enough information regarding auction outcomes should be made available (at least to a monitoring authority) after the end of the auction in order allow the detection of any illicit activity.

The final criterion listed above is the minimization of transaction costs. This is beneficial for obvious reasons. Of course some transactions costs are unavoidable, but good auction design should minimize these. As discussed below, there can be a role for upfront payments, in order to avoid costly ex-post defaults by liquidity-constrained bidders.\(^{30}\)

## 5 The Debate on the Optimal Auction Format for Carbon Allowances

By and large, in the specific setting of carbon allowance markets, economists tend to agree that a uniform-price auction should be preferred to a discriminatory one. The main reason for this is the importance of price discovery and the information about marginal abatement costs that prices will reveal. Given the high degree of uncertainty in this initial phase, good information is especially important in providing guidance to regulators as well as private decision makers. In contrast, in the case of US treasury securities, it is less important that the auctions themselves provide a consensus price because the markets for these securities are well-established, highly liquid, and global, with dispersed ownership.

Looking back to Table 1, the above consideration allows us to focus on the two-auction formats in the second row. These are the two leading alternatives in the current debate.

Economic arguments supporting the choice of a uniform-price sealed-bid auction for carbon dioxide allowances under RGGI can be found in Holt et al. (2007, 2008); while economic arguments supporting the choice of an ascending clock auction for carbon dioxide allowances can be found in Evans & Peck (2007) and Betz et al. (2009) (for Australia) and Cramton and Kerr (2002) (for the US).

In what follows we will lay out the debate and then provide our assessment of the

\(^{30}\)See Brusco and Lopomo (2008, 2009).
merits of each side.

5.1 Ascending clock versus uniform-price sealed-bid

Evans & Peck (2007) argue in favor of an ascending clock format for the auction component of Australia’s greenhouse gas emission trading system. Their argument centers on the following elements (p.xiv):

1. “An ascending clock format is simple procedure that is easy to understand.”
2. “Implementation is web-based and transaction costs are low.”
3. “Uniform pricing scheme provides a strong signal regarding the participants’ aggregated estimates of the future value of a permit and thus the economy’s marginal abatement costs.”
4. “Revealing demand at the end of each round improves transparency and increases the information available to participants.”
5. “By allowing bidders to shift their demand from one vintage to another, a simultaneous auction offers the necessary flexibility to deal with highly substitutable items and picks up the advantages of the simultaneous multiple-round ascending bid auction.”

Points 1, 2, and 3 apply more or less equally to both an ascending clock format and a uniform-price sealed-bid format. So in our view they should be removed from the debate between these two formats. As a further comment regarding point 1, proponents of sealed-bid auctions might argue that activity rules, which are necessary to make an ascending clock auction function well, as well as certain “add-on” features, such as intra-round bidding, second-stage sealed-bid rounds, or roll-back procedures to deal with unsold units, have the potential to make those auctions less simple and easy to understand than a sealed-bid auction.

Regarding point 4, Holt et al. (2008) find that in experiments clock auctions perform no better in terms of price discovery than single-round auctions. This undermines the presumed superiority of the ascending clock auction in terms of transparency and information revelation, and it is also consistent with the idea that the

31 Activity rules are required to prevent bidders from “sniping,” whereby they wait until late in the auction before bidding seriously. See Cramton (2007) on the implementation of activity rules in an ascending clock auction.
key piece of information required by a firm bidding for carbon allowances is its own marginal abatement cost. In contrast, in other markets, a bidder may be more uncertain of its own value for an object being sold and so the observation of other bids might reveal useful information about its own value.\textsuperscript{32}

Regarding point 5, it is clear that firms may value the ability to build a portfolio of allowances of different vintages. As argued by Evans \& Peck (2007), properly synchronized simultaneous ascending clock auctions for multiple vintages might allow this, although the change would increase the complexity of the auction design and bidding strategies. Cramton (2007, p.2) states that, “The primary disadvantage of the uniform-price auction in this setting is the potential to have prices for the two vintages (spot and forward) that do not reflect the bidders’ preferences.” In particular, Cramton provides an example of how sealed-bid auctions could result in a higher price for forward allowances than for spot allowances. However, Holt et al. (2008) describe how a combined vintage auction could be held using a uniform-price sealed-bid auction. In that format, a bid for a later vintage would be treated as a request to purchase either a later vintage or an earlier vintage, whichever is less expensive, thereby preventing price inversions. Thus, it appears that both auction formats are capable of dealing with the vintage portfolio issue in a satisfactory way.

Beyond the key elements 1–5 above, Evans \& Peck (2007) argue that the intrinsic flexibility and openness of the format will be beneficial in allowing dynamic adjustment of the auction design. However, while flexibility and openness can allow the auction designer to incorporate information in a way that improves efficiency, revenue, and other aspects of the auction, these features also provide the bidders with opportunities for coordinating with collusive schemes that can ultimately be detrimental to the auction outcome. The preference for sealed-bid over dynamic auctions when collusion is a concern is supported by the theoretical literature in economics.\textsuperscript{33}

More specific to the current debate, Holt et al. (2008) show that an ascending clock auction is more susceptible to collusion than a uniform-price sealed-bid auction in laboratory experiments.

\textsuperscript{32}See Porter (1995) on the information advantage in offshore oil and gas lease auctions held by bidders that have experience with adjacent tracts.

\textsuperscript{33}See Klemperer (2003) arguing that an open iterative auction increases the ability of the bidders to collude (tacitly or explicitly). See also theoretical results in Lopomo, Marshall, and Marx (2005) and Marshall and Marx (2007) and the discussion in Kovacic et al. (2006).
5.2 Assessment

The relevant differences between the ascending clock and uniform-price sealed-bid formats come down to two issues:

1. the importance of robustness to collusion, and
2. the value of within-auction price discovery.

Experimental evidence suggests that an ascending clock auction is more susceptible to collusion than a uniform-price sealed-bid auction. Thus, issue #1 above argues in favor of a uniform-price sealed-bid auction. However, because a sealed-bid auction does not allow for within-auction price discovery, issue #2 argues in favor of an ascending clock auction.

We view both of these two issues as important. Furthermore, we view them as jointly identifying the central trade-off in the choice between an ascending clock and a uniform-price sealed-bid auction for carbon markets.

As stated by Holt et al. (2007, p.7), “The literature suggests that multiple-round auctions can be more conducive to collusion, as they provide participants with opportunities for signaling and detecting when someone has reneged on a collusive agreement.” As stated by Holt et al. (2008, p.2), “We addressed the effects of collusion in clock auctions by running additional sessions with clock auctions in which participants could discuss any aspect of the auction in a chat room that was open prior to each round of bidding. The results provide strong evidence that collusion is more effective in a clock auction than under other auction formats. The average prices were lower for the clock format than for the uniform and discriminatory price [sealed bid] auctions.”

As stated by Cramton (2007, p.3), “The chief advantage of [an ascending clock format] is price discovery: bidders can learn about the demand of other bidders from the bidding process and condition their bids on this information. This is especially useful when there are multiple products, as is the case here where both the spot and forward products are sold at the same time. The clock auction allows bidders to substitute freely between spot and forward products, so that any price separation is a reflection of the difference in value of the two products.”

34 See Holt et al. (2008).
Economists may differ in how they weigh the relative importance of the two main issues identified above. If one believes that price discovery is less important, perhaps because values for carbon allowances are primarily derived from a firm’s own marginal abatement cost that is known to the firm, then the issue of price discovery fades in importance. Also, if one adopts the bidding procedure proposed by Holt et al. (2008) whereby a bid for a later vintage is treated as a request to purchase either a later vintage or an earlier vintage, whichever is less expensive, then one of the main criticisms of the sealed-bid format, the possibility of price inversions between spot and forward contracts, disappears.\(^{35}\) Combining these with a concern about collusion and reliance on the related experimental evidence, we conclude that, all things considered, a uniform-price sealed-bid auction is more appropriate for carbon allowance auctions.

Of course, the optimal auction may well involve a hybrid approach, but the relative distance from the auction formats discussed above will depend on the response to the strengths and weaknesses we have described here.

### 6 Other design details

Once the overall auction format has been determined, there are of course a variety of other details that must be addressed.\(^ {36}\) The main focus of this paper has been the overall auction design issue for carbon markets. In this section, we provide a list of some, although certainly not all, of the details that will ultimately need to be addressed.

- **Reserve price**: The government should ensure that some incentives for emission reduction are put in place as a result of the auction by setting a reserve price.

- **Ties**: In Treasury security auctions, if there are multiple bids at the market clearing price, those orders are filled on a pro rata basis. We agree with the recommendation of Holt et al. (2007) for RGGI that ties be resolved by a random process to help guard against collusive bidding.

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\(^{35}\)Holt et al. (2007, p.1): “Interpreting bids in this manner prevents a price inversion in which the uniform price for the later vintage is higher than the price for the earlier vintage, although theory suggests this price inversion is inefficient and would not occur in the secondary market. This addendum describes a simple procedure for combined vintage auctions that implements this idea.”

\(^{36}\)See Klemperer (2002) emphasizing that the details of auction design matter.
• **Limited disclosure**: Limit public disclosure, with exceptions for a monitoring body and potentially for analysis by academics with appropriate guarantees for the privacy of the individual bidders. This has implications for collusion reduction.

• **Buyer qualifications**: Steps should be taken to avoid problems associated with default that have affected government agencies such as the FCC.

• **Anti-collusion rules**: All auction participants should be required to certify that they are not engaged in any type of coordination or collusion with other bidders.\(^{37}\)

• **Experimental testing**: It can be valuable to conduct experimental testing of auction designs. This approach has been useful to government agencies such as the FCC considering adjustments to their auction designs.

• **Market power**: There is an ongoing debate over the desirability of “spectrum caps” in telecommunications, to limit the market power of wireless telecommunications providers. It may be valuable to consider “allowance caps” if there are concerns that firms could use control of large numbers allowances to limit competition.

• **Monitoring market conditions and managing supply**: It may be important for the market designer to take steps to manage expectations about future prices. For example, in the absence of stable expectations about prices for future vintages of allowances, there may be extreme price fluctuations for current vintages as demand for the purpose of banking allowances varies. One possible way to manage these risks is to “jump start” the market by issuing some allowances of a variety of vintages for free. Trading of these allowances would provide signals as to the relevant prices. Another, perhaps complementary, risk management option would be to develop a schedule of supply increases associated with various price hurdles. Under such a scheme, market prices above fixed hurdle levels for a set period of time would trigger the release of fixed numbers.

\(^{37}\)Section 1.2105(c) of the FCC’s rules prohibits bidders that are eligible to compete for the same licenses from communicating with each other during the auction about bids, bidding strategies, or settlements unless the nature of the relationship is declared to the commission.
of incremental allowances. Or, additional discretion could be given to market authorities in the form of a strategic reserve.

7 Conclusion

An appropriate choice of auction design fundamentals, as well as the fine details, is obviously of crucial importance for the success of a US carbon allowance market. Regardless of which design is selected initially, it is important to continue to evaluate the auction’s performance and remain open to design changes that research suggests are beneficial.
References


