

# Carbon Allowance Auction Design: An Assessment of Options for the U.S.

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## Abstract

Carbon allowance auctions are a component of existing and proposed regional cap-and-trade programs in the U.S. and are also included in recent bills in the U.S. Congress that would establish a national cap-and-trade program in the U.S. to regulate greenhouse gases (“carbon”). We discuss and evaluate the two leading candidates for the auction format for carbon allowance auctions: a uniform-price sealed-bid auction and an ascending-bid dynamic auction, either of which could be augmented with a “price collar” to ensure that the price of allowances is neither too high nor too low. We identify the primary trade-offs between these auction formats as applied to carbon allowance auctions and suggest auction design choices that address potential concerns about efficiency losses from collusion and other factors. We conclude that a uniform-price sealed-bid auction is more appropriate for the sale of carbon allowances than the other leading choices, in part because it offers increased robustness to collusion without significant sacrifice in terms of price discovery.

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## Introduction

Any future legislation aimed at reducing carbon dioxide (CO<sub>2</sub>) emissions in the United States appears likely to include, as a component, an auction to assign CO<sub>2</sub> emission permits. The basic appeal of auctions is that they can be a relatively effective and efficient way to assign permits to those with the greatest cost of abatement, thereby minimizing the overall economic burden associated with reducing CO<sub>2</sub> emissions. Auctions can also be a significant source of government revenue, reducing the need for distortionary taxes. Even if some permits are assigned to firms free of charge, an auction for a fraction of the available permits can be a valuable tool for “price discovery”. For example, the Environmental Protection Agency (EPA) auctions just 2.8% of the sulfur dioxide permits it distributes annually under the SO<sub>2</sub> emission trading program, allocating the rest outside of the auction. Such auctions provide information that can be useful to firms as they plan investment and to regulators as they develop policy and that can help establish a “market price” to facilitate more efficient trading of permits after the auction.

Less clear is what auction rules are best suited for the sale of emissions permits. The Regional Greenhouse Gas Initiative (RGGI), the cap-and-trade program regulating Northeast U.S. electric utilities, auctions CO<sub>2</sub> emission permits using a “uniform-price sealed-bid” format, in which each bidder announces the most that it is willing to pay for any given quantity of permits – a bid can be interpreted as a demand curve – and all winners pay the same market-clearing price. On the other hand, the EPA’s SO<sub>2</sub> emission permit auctions use a “discriminatory sealed-bid” format, in which bidders again submit demand curves but each bidder pays its own prices for any units won. In its June 2004 auction of nitrogen oxide emission permits, the Commonwealth of Virginia used another rule, the “uniform-price ascending-bid” auction. In

such an auction, the auctioneer calls out a sequence of prices, starting low and raising the price incrementally until demand at the announced price no longer exceeds supply. When the bidding stops, all remaining active bids win and all winning bidders pay the same market-clearing price.

The choice of auction format is significant, with potentially important ramifications for the efficiency of the final assignment revenue raised and other factors such as price discovery, price volatility, robustness to collusion and/or market manipulation, transaction costs, fairness, and transparency. In this paper, we critically review the evidence and economic arguments for and against the leading auction designs in the context of CO<sub>2</sub> emissions. In brief, we argue strongly *against* the sealed-bid discriminatory auction as used in the EPA's SO<sub>2</sub> emission permit auctions and, among uniform-price formats, in favor of a sealed-bid format as best-suited for the sale of CO<sub>2</sub> emission permits. Furthermore, we will discuss some additional market design issues that could be important in these auctions, such as those related to public disclosure of auction outcomes, management of supply across multiple vintages, and the implementation of a range-constraining price collar.

The remainder of this article proceeds as follows: First, we review relevant currently used auction designs. Then we discuss the objectives of carbon allowance auctions. We consider the tradeoffs between pay-as-bid auctions versus uniform-price auctions, and then we consider tradeoffs between ascending-bid and sealed-bid auctions. Then we discuss the issue of bounding the auction price and other design details. In the final section, we conclude.

## **Auction designs in practice**

Auctions are used to buy, sell, or trade everything from unique items such as art and cars to

multiple dissimilar objects such as spectrum rights and network service,<sup>5</sup> to multiple identical objects such as flowers, fish, stocks, bonds, and electricity. Auctions of emission permits fit within this last category, so-called “multi-unit auctions” of multiple identical objects. Four multi-unit auction formats are most common in practice. Roughly speaking, these auction formats can be characterized by (i) whether the bidding is “dynamic” or “sealed” and (ii) whether winners pay their own bids or the market-clearing price when they win. (“Dynamic” auctions involve real-time interaction between an auctioneer and multiple bidders, including so-called “ascending” and “descending” auctions in which prices are raised or lowered over time.)

		Bidding	
		Dynamic	Sealed
Pricing	Pay-as-bid	Dutch Tulips Sydney Fish Market	U.S. Sulfur Dioxide U.S. Treasury bonds (pre-1992) Mexico Treasury (pre-1990)
	Uniform-price	Virginia Nitrogen Oxide	RGGI Carbon Dioxide U.S. Treasury bonds (post-1992) Mexico Treasury (post-1990)

Table 1: Some Examples of Multi-Unit Auctions

<sup>5</sup> In the FCC's spectrum license auctions, each license has unique characteristics, and 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). By contrast, London's annual auction to procure bus network service is conducted via a discriminatory sealed-bid auction; see Cantillon and Pesendorfer (2006).

Table 1 lists some prominent examples of multi-unit auctions of each format. We shall focus here on evaluating the three formats currently used to auction emission permits in the United States: the pay-as-bid auction with sealed bids, the uniform-price auction with sealed bids, and the uniform-price auction with ascending bids.<sup>6</sup> Other auctions have significant theoretical interest, such as the Vickrey auction proposed in Vickrey (1961) by Nobel Laureate William Vickrey, but we have decided to focus here on the simplest and most common auction rules seen in practice.

### **Pay-as-bid auction**

In a pay-as-bid auction with sealed bids (also commonly known as the “discriminatory auction”), each bidder simultaneously submits a collection of bids, each of which specifies a price and a quantity. The bids are then ranked to determine the market-clearing price, the price at which total demand equals the available supply. Bids at or above the market clearing price are winners, and winning bidders receive the quantity bid *at the prices they bid*. Thus, bidders will typically pay different prices, with every bidder paying at least the market-clearing price.

U.S. Sulfur dioxide. Sulfur dioxide (SO<sub>2</sub>) emission permits have been required for certain electric utilities and freely traded in the U.S. since 1995. The underlying legislation is Title IV of the 1990 Clean Air Act Amendments, which describes the U.S. Acid Rain Program.<sup>7</sup> This program targets electric utility emissions of sulfur dioxide, mainly those produced by coal-fired

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<sup>6</sup> We are unaware of any proponent of any dynamic pay-as-bid auction for emissions permits. Such auctions, including the descending pay-as-bid auction often called the “Dutch auction” in the economics literature, are most useful in settings in which many identical items need to be sold quickly, as with fish or flowers.

<sup>7</sup> Ellerman et al. (2000) provide an excellent overview of the U.S. Acid Rain Program.

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 were subject to a national cap on aggregate annual sulfur dioxide emissions.

The emission cap is enforced through the requirement that any regulated plant must surrender tradable emission permits (called allowances) for each ton of sulfur dioxide emitted by the facility that year. Allowances are recorded in the EPA's allowance tracking system. Allowances can be banked for future use, but firms cannot borrow allowances from the future. The EPA holds back 2.8% of allowances for an annual auction, with the proceeds returned pro rata to all firms granted the 97.2% of allowances that are allocated for free. This auction uses the pay-as-bid sealed-bid format,<sup>8</sup> although there is debate about whether a uniform-price sealed-bid auction might be preferable.<sup>9</sup>

*Treasury bonds and bills.* Governments sell trillions of dollars worth of securities every year. Among economists, there is little consensus as to the best auction mechanism for these sales.<sup>10</sup> Yet in 39 out of the 42 countries surveyed by Bartolini and Cottarelli (1997), the government uses a pay-as-bid sealed-bid auction. However, the U.S. 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

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<sup>8</sup> Joskow, Schmalensee and Bailey (1998) provide a descriptive analysis of bidding behavior in this market.

<sup>9</sup> Cason and Plott (1996) report experimental results suggesting a uniform-price sealed-bid auction might be preferable to the discriminatory sealed-bid format being used. However, Sjøberg (1998) disputes that conclusion.

<sup>10</sup> Unlike auctions of emissions permits, revenue generation is the primary objective of Treasury auctions of government debt. And, as we discuss later in the paper, there is no clear ranking of discriminatory and uniform-price auction in terms of expected revenue. See Chari and Weber (1992), Bikhchandani and Huang (1993), Malvey and Archibald (1998), and Klemperer (2000).

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 U.S. Treasury auctions with the uniform-price format.” The Mexican government switched to a uniform-price sealed-bid auction in 1990 for similar reasons. Afterwards, according to Umlauf (1993, p.313): “Bidders' profits fell dramatically in 1990 when the [Mexican] Treasury substituted uniform for discriminatory pricing to combat collusion and to increase auction revenues.”

### **Uniform-price auction with sealed bids**

In a uniform-price sealed-bid auction, each bidder again submits a collection of bids, each specifying a price and a quantity, and all bids at prices above the market-clearing price win. However, each winning bidder pays the market-clearing price on every unit won, regardless of his actual bid.

*RGGI and EU ETS Carbon dioxide permits.* Regional Greenhouse Gas Initiative (RGGI) for the northeast U.S. held its first auction on September 25, 2008 ([www.rggi.org](http://www.rggi.org)). RGGI encompasses Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont. Carbon dioxide allowances are sold through quarterly auctions using a uniform-price sealed-bid format. 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), the rest were purchased by brokers, environmental groups, private citizens, and others.

Six Midwestern states and seven in the West are currently developing regional carbon cap-and-trade programs similar to RGGI.<sup>11</sup> In Europe, the European Union Emission Trading System (EU ETS) covers over 10,000 facilities, generating approximately half of EU's carbon dioxide emissions. Permits are currently trading at around \$20 per ton of carbon dioxide.

The initial phases of the EU ETS relied almost exclusively on free allocation of allowances to regulated entities, rather than auctions. But some member states such as UK and Germany auctioned a small share of their permits. The next phase of the EU ETS, starting in 2013, will introduce a significant shift, with half or more of the allowances expected to be auctioned. In July 2010, the EU issued a draft set of regulations for how auctions are to be handled in this next phase.<sup>12</sup> The common auction platform will be a single-round, sealed-bid, uniform-price auction with bidders able to submit as many bids as they wish during the auction window period. Each bid specifies the number of allowances the bidder will buy at a specific price. All bidders will pay the market-clearing price, the lowest price at which the number of allowances bid equals the number available at auction. Regulated entities as well as registered financial intermediaries will be allowed to bid. There will be a central EU auction platform, but member states may have considerable flexibility to develop their own platforms as long as it is consistent with the EU platform and auctions are open and do not discriminate by nationality.

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<sup>11</sup> The Western Climate Initiative (WCI) will also involve trading with some Canadian provinces, while some U.S. states, Canadian provinces and Mexican states are signed on as “observer” states for now (<http://www.westernclimateinitiative.org/wci-partners-and-observers-map>).

<sup>12</sup>Information on the draft rules for the Phase 3 (2013 and beyond) EU Auction can be found at [http://ec.europa.eu/environment/climat/emission/auctioning\\_en.htm](http://ec.europa.eu/environment/climat/emission/auctioning_en.htm).

Electricity procurement. Electricity auctions are conducted in deregulated power exchanges around the world, for the most part by uniform-price auction.<sup>13</sup> 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. Although there has been considerable debate concerning the most appropriate format for electricity auctions, most economists have argued strongly against the pay-as-bid auction format for electricity. For example, Kahn et al. (2001a) argue that switching to a pay-as-bid format would lead to “a radical change in bidding behavior that would introduce new inefficiencies, weaken competition in new generation, and impede expansion of capacity.”<sup>14</sup>

### **Uniform-price ascending-bid auction**

In a uniform-price ascending-bid auction, the auctioneer announces a sequence of increasing prices. At each price, bidders indicate the quantity they would be willing to purchase. The auction typically begins at a low price, at which bidders are likely to demand more than the entire supply, and continues at higher and higher prices until the total quantity demanded equals that supplied. Every bidder then pays the final, market-clearing price for each unit won.

VA Nitrogen oxide. In response to a budget shortfall in 2004, the Commonwealth of Virginia

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<sup>13</sup> See Cramton and Stoft (2006) for a discussion of electricity auctions in the United States, and Wolfram (1998) and Borenstein, Bushell, and Wolak (2002) for analyses of electricity auctions.

<sup>14</sup>See also Kahn et al. (2001b) and Cramton and Stoft (2007).

sold tradable emission permits for nitrogen oxides (NO<sub>x</sub>) using a uniform-price ascending-bid auction. The choice of this format was supported by experimental results reported in Porter et al. (2009), showing that an ascending (“clock”) uniform-price auction performed better in terms of efficiency and revenue than a sealed-bid alternative when demand was relatively elastic.

The proliferation of auction formats, even among auctions of emissions permits for various pollutants, demands a careful evaluation of the strengths and weaknesses of each format for selling CO<sub>2</sub> emissions. In the next section, we will propose criteria by which to evaluate different CO<sub>2</sub> auction designs and critically examine the theoretical arguments and experimental evidence for and against each format.

## **Objectives of carbon allowance auctions**

An effective auction for carbon dioxide emission permits must achieve several objectives. First, the auction needs to assign the scarce permits to those who are willing to pay the most to continue to emit, thereby minimizing the total economic cost of any given emissions reduction. The auction should also provide useful “price discovery” to help guide firms’ long-term planning and investment, as well as government policy development. In addition, the auction process should be fair and transparent, to promote confidence among market participants. Finally, since revenue generated by the auction may be less distortionary than other sources of government funds, it can have a corrective efficiency benefit; as such, revenue maximization may be a complementary objective of the auction design.

In some cases, governments explicitly state a preference for efficiency over revenue when designing auctions. For example, Congress set forth an explicit requirement that revenues *not* be a primary consideration in designing the FCC spectrum license auctions (Kwerel and Rosston

2000, p.271). The Kerry-Lieberman Senate bill states, “the Administrator ... shall not consider maximization of revenues to the Federal Government or allowance owners.”<sup>15</sup>

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).<sup>16</sup>

Effective price discovery is desirable to provide the information required to formulate a well-reasoned, comprehensive environmental policy, as well as to guide 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 help to elicit information about expectations regarding the future evolution of industry fundamentals.<sup>17</sup>

Achieving an efficient assignment of goods is an important challenge of auction design. First, the cost of bidding must be low enough to induce full participation, so that the bidders who need permits most have an opportunity to bid for them. Even if all bidders participate, however, there is no guarantee that those willing to pay the most to avoid further abatement will win. For example, coordinated bidding (“collusion”), market manipulation, and/or the exercise of unilateral market power all have the potential to distort auction outcomes. Collusion can distort market outcomes, undermining the efficiency and price discovery benefits of an auction. Hence, minimizing collusion and other forms of market manipulation is another important element of effective auction design.

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<sup>15</sup> [http://lieberman.senate.gov/assets/pdf/APA\\_full.pdf](http://lieberman.senate.gov/assets/pdf/APA_full.pdf) (accessed August 24, 2010), p.521.

<sup>16</sup> See Israel (2007) on environmentalist participation in U.S. sulfur dioxide emission permit markets.

<sup>17</sup> For example, Burtraw et al. (2010, p.4) argue that the Virginia NOx auction prices “seemed to provide important information about evolving market conditions.” Furthermore, they argue (p.6) that when considering the RGGI auction prices, “the early auction prices outperformed futures prices in terms of predicting allowance prices in subsequent auctions” and that “the RGGI auction provided informative signals about the anticipated scarcity of the RGGI allowances.”

How best to combat collusion can be surprisingly subtle, since firms with an interest in colluding can respond to market rules in creative and sometimes unexpected ways. 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.<sup>18</sup> Unfortunately, the information revealed during the auctions facilitated retaliatory bidding, signaling, market division, and gaming of the auction's activity rules, which were detrimental both to revenue and allocative efficiency.<sup>19</sup> Recent FCC auctions have moved to an anonymous format that masks bidder identities and thereby reduces bidders' opportunities and incentives for anti-competitive behavior.<sup>20</sup> Novel features of carbon emissions auctions, such as a "price collar" to bound the price of permits, could also create an environment more conducive to collusion. We will explore this potential theoretical concern at length below, including how to modify the auction design to limit opportunities for successful collusion.

Fairness of auction outcomes and transparency of the auction process are also obviously desirable properties of any auction. Transparency in bidding is a common refrain in federal auctions and procurements. However, 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 (Marshall and Marx 2009). Presumably, 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 after the auction (at least to a monitoring authority)

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<sup>18</sup> The FCC has held auctions for spectrum licenses since 1994 using primarily a simultaneous multiple round auction. See McMillan (1994), McAfee and McMillan (1996), Cramton (1997), Kwerel and Rosston (2000), and Marx (2006).

<sup>19</sup> See, e.g., McAfee and McMillan (1996), Cramton and Schwartz (2000, 2002), Kwasnica and Sherstyuk (2001), Brusco and Lopomo (2002), Reitsma, et al. (2002), and Marx (2006).

<sup>20</sup> See 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).

to detect any illicit activity.

Finally, the auction should be designed to minimize transaction costs. The auction should impose minimal burdens on bidders, of course, but also deter exploitative behaviors (such as costly ex-post defaults by liquidity-constrained bidders<sup>21</sup>) that disrupt the auction process.

The next four sections discuss the specific auction design issues of: 1. pay-as-bid versus uniform-price auctions; 2. ascending-bid versus sealed-bid auctions; 3. bounding the auction price and issues with the price collar; and 4. other design issues.

## **Pay-as-bid versus uniform-price?**

There is broad consensus among economists specializing in auction design that a pay-as-bid auction is *not* best-suited for CO<sub>2</sub> emissions. Several disadvantages of this auction format have been noted in the literature (see e.g. Cramton and Stoft 2007), but perhaps the most damning has received relatively little notice. Even in an idealized “perfect competition” setting in which all bidders lack market power, the pay-as-bid auction need not lead to an efficient – or even an approximately efficient – assignment of the permits at offer (Jackson and Kremer 2007).

To see why pay-as-bid auctions are not “asymptotically efficient,” consider a scenario in which each emitter knows its own cost of reducing emissions, but the economy-wide distribution of such costs depends on some underlying factor about which each party receives a noisy signal. (In the carbon emissions context, such a factor could be the rate of economic growth, the adoption rate of a new technology that decreases the marginal cost of carbon emissions, the availability of carbon offsets from uncapped sectors, etc.) Emitters who believe that the distribution of costs is higher will bid higher in the auction, since they will expect stiffer

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<sup>21</sup> See Brusco and Lopomo (2008, 2009).

competition to win permits and greater payoff from reselling extra permits to higher cost entities if they can cut their own emissions. Consequently, bidders who have overestimated the distribution of others' costs will tend to outbid others with higher abatement costs who have underestimated this distribution, leading to an inefficient assignment of permits.<sup>22</sup> By contrast, in the uniform-price auction (whether with sealed or ascending bids), each bidder knows that it will pay the market-clearing price whenever it wins. Thus, each bidder has a dominant strategy to bid up to its true willingness to pay, so that the bidders with the highest marginal value for permits win them and the efficient outcome is realized.<sup>23</sup>

In our view, the asymptotic inefficiency of the pay-as-bid auction is highly relevant in the context of carbon dioxide permits, and sufficient to disqualify pay-as-bid auctions from serious consideration as the best auction format for CO<sub>2</sub> permits. Beyond its asymptotic inefficiency, however, the pay-as-bid auction suffers from several other significant weaknesses relative to the uniform-price auction.

Since each winning bidder pays its own bid, each bidder has an incentive to bid as close as possible to the realized market-clearing price, so as to win at the lowest possible price. "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" (Cramton and Stoft 2007, p.33). By contrast, since each winning bidder in a uniform-price auction pays the market-clearing price, bidding one's true value is a dominant strategy in the uniform-price auction for any bidder with no influence over the market-clearing price. Thus, the uniform-price auction does not impose as steep an

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<sup>22</sup> As described below, this effect can provide an incentive for bidders to adjust their bids downward.

<sup>23</sup> When bidders have some market power, uniform-price auctions will lead to some inefficiency. However, the convergence to efficiency is rapid as the number of bidders grows. See Gresik (1991), Satterthwaite and Williams (1989a, 1989b), and Wilson (1985, 1993) for theoretical results and Gjerstad and Dickhaut (1998) for experimental evidence.

informational burden on small bidders as the pay-as-bid auction: to determine its optimal bid, a small bidder need know nothing about the distribution of others' abatement costs. Consequently, such small bidders may be more willing to participate in a uniform-price auction.

Since different bidders pay different prices, the pay-as-bid auction may be viewed as unfair. Furthermore, since bidders optimally bid strictly less than their true willingness to pay for permits, the market-clearing price in the auction does not provide clear information about the true marginal cost of abatement.

Finally, from the perspective of revenue generation, there is no clear revenue ranking of pay-as-bid vs. uniform-price auctions. Indeed, Ausubel and Cramton (1998) provide examples in which each auction generates greater expected revenue. In a more recent study, Rostek, Weretka, and Pycia (2010) have shown that the pay-as-bid auction generates greater expected revenue in a particular class of environments with symmetric bidders and complete information (with ex ante uncertainty resolved before the bidding). However, even in these environments, the uniform-price auction outperforms the pay-as-bid auction in the limit as the number of bidders grows large, as both auctions generate the same expected revenue but the pay-as-bid auction generates riskier returns.

## **Ascending-bid versus sealed-bid?**

While the economics literature generally suggests that a uniform-price auction format would be more suitable than a pay-as-bid format to sell CO<sub>2</sub> emission permits, there is much less consensus regarding whether to use a sealed-bid or an ascending-bid uniform-price auction. For instance, whereas Holt et al. (2007) and Burtraw et al. (2009) support sealed bids, Evans & Peck

(2007), Betz et al. (2009) (for Australia) and Cramton and Kerr (2002) (for the U.S.) support using an ascending-bid format.

Evans & Peck (2007)'s argument in favor of an ascending-bid format is a helpful starting point for our own discussion. Their argument centers on the following desirable properties of an ascending-bid uniform-price auction (p.xiv):

- 1) "An ascending-bid uniform-price auction is a simple procedure that is easy to understand. Implementation is web-based and transaction costs are low."
- 2) "Uniform pricing provides a strong signal regarding the participants' aggregated estimates of the future value of a permit and thus the economy's marginal abatement costs."
- 3) "Revealing demand at the end of each round improves transparency and increases the information available to participants."
- 4) "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."

Many of these desirable properties, such as easy implementation (point 1) and uniform pricing to provide information about the economy's marginal abatement cost (point 2), are shared by both ascending-bid and sealed-bid versions of the uniform-price auction. Furthermore, sealed-bid auctions are arguably even simpler to understand than ascending-bid auctions.

Ascending-bid auctions require activity rules to function well,<sup>24</sup> as well as certain add-on features such as intra-round bidding, second-stage sealed-bid rounds, or roll-back procedures to

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<sup>24</sup> 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-bid auction.

deal with unsold units.<sup>25</sup> By contrast, in a sealed-bid auction, a bidder need only determine how to bid once. Overall, any case for an ascending-bid format rests primarily on point 3 and/or point 4.

## Transparency

Consider point 3, that revealing bidding information during the auction increases transparency and the information available to participants. Transparency is a double-edged sword. The main benefit of transparency is that information about others' bids may help bidders assess the true value of the permits being sold.<sup>26</sup> This enhances efficiency and can induce more aggressive bidding as bidders fear less "the winner's curse." In the context of CO<sub>2</sub> emissions permits, this benefit of transparency is likely to be mitigated by the fact that most bidders can be viewed as having "private values" – their willingness to pay for a permit depends primarily on their own cost of reducing emissions – in which case revealing others' bids has no impact on bidders' individual estimates of a permit's value to them.

On the other hand, common value concerns could be significant in auctions of permits for *future* emissions, as every bidder will be uncertain about underlying common factors such as economic growth and technological change.<sup>27</sup> If the common component of bidder values is sufficiently important, an ascending-bid format could create substantial benefits relative to a sealed-bid format. However, it is important to note that "common values" only arise when bidders have private information relevant to the common factors driving bidders' willingness to

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<sup>25</sup> In addition, auction designers may want to offer proxy bidding so that bidders have the option of using automated bidding procedures rather than having to repeatedly access the auction website to participate in the auction.

<sup>26</sup> Transparency by itself does not necessarily result in complete price discovery. For example, Burtraw et al. (2010) provide evidence that the information provided in open auction formats need not be sufficient for auction prices to incorporate the effects of shifts in the demand for permits.

<sup>27</sup> Common value components may also be relevant in contemporaneous markets, for example Burtraw et al. (2010) raise the possibility that uncertainty over federal climate change legislation and its interaction with RGGI affected pricing of RGGI allowances.

pay for permits. If, instead, information about common factors such as economic growth, seasonal weather forecasts and energy market conditions is public, each bidder's *private information* about its willingness to pay will simply be those private factors that impact its value (such as the profitability of its output, its own installed emissions-reduction technology, etc). In that case, bidding transparency would not have any meaningful information-sharing benefits.

A liquid after-market could also lead bidders to have a common value, as every bidder tries to estimate whether the price of permits will increase or decrease after the auction. However, in the presence of even small after-market imperfections, non-speculative bidders will typically prefer to acquire their permits in the auction, thereby potentially reducing transaction volumes in the after-market, which could in turn reduce after-market liquidity.<sup>28</sup> For this reason, we feel that it is prudent to design the initial auction bearing in mind the possibility that after-market trading may be imperfect in which case, again, bidders can best be viewed as having private values and bidding transparency has little information-sharing benefit.

The main cost of bidding transparency is that revealing bids may change bidding behavior and lead to less desirable auction outcomes. In particular, revealing bids at each stage of a multi-round bidding process can facilitate collusive bidding. As Holt et al. (2007, p.7) explain, "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."<sup>29</sup> Burtraw et al. (2009) conducted experiments to assess the importance of collusion as a concern in an ascending-bid ("clock") uniform-price auction. As they state

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<sup>28</sup>Hortacsu and McAdams (2009) provide evidence of illiquidity in a Treasury after-market. After-market transactions costs can also arise from negotiation with private information; see e.g. Myerson and Satterthwaite (1983).

<sup>29</sup>Klemperer (2000) argues 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).

(pp.688-689): “In laboratory auctions with communication among participants, collusion is more effective in clock auctions than in discriminatory and uniform price auctions. An analysis of the “chat” (instant message communications) suggests that clock auctions may facilitate collusion by allowing bidders to focus on a single dimension (quantity reductions). The effects of this collusion are reflected in clock prices at or near reserve price levels, with subsequent trading at much higher prices in the spot markets.”

## Multiple vintages

Consider next point 4, that an ascending-bid format is better suited to facilitate substitution between different permit “vintages.” In most emission permit markets, permits are available that allow emissions at different times. For example, should permits be bankable for future use, a 2012-vintage permit could be used in 2012 or any later time. Naturally, firms may value the ability to build a portfolio of permits of different vintages. A properly synchronized *simultaneous ascending-bid* auction for multiple vintages could allow bidders to do this in a single auction, although at the cost of increased complexity of the auction design and bidding strategies. As Cramton (2007, p.3) notes, “The chief advantage of [an ascending-bid 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.”

Cramton (2007, p.2) argues that sealed-bid auctions may not be well-suited for such simultaneous multi-vintage auctions, warning against “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 in which a sealed-bid uniform-price auction results in a higher price for future vintages than for the current vintage. (Such price inversions will never arise in an auction that correctly elicits bidders' true marginal willingness to pay for permits of every vintage, as bidders always prefer a permit with an earlier vintage since it can be banked and used later.) To deal with this concern, Holt et al. (2008) proposes a multi-vintage auction using a uniform-price sealed-bid auction, with the twist that a bid for a particular vintage is treated as a request to purchase that vintage or an earlier vintage, whichever is less expensive. Given this rule, price inversions are impossible. This shows that a suitably-designed sealed-bid auction can deal with the vintage portfolio problem in a reasonably satisfactory way. However, even the Holt et al. (2008) auction may not fully capture bidders' preferences for substitution across vintages, as in principle a simultaneous ascending-bid auction can do. Burtraw et al. (2009) address this potential weakness experimentally, finding that a single-round sealed-bid uniform-price auction achieves as much price discovery as a simultaneous ascending-bid format.

## Summary

Within the context of uniform-price auctions, there are valid arguments to be made in favor of a sealed-bid format and in favor of an ascending-bid format. Ultimately, the question of which auction format is better-suited to the context of CO<sub>2</sub> emissions boils down to the relative importance of two factors: *robustness to collusion* and *within-auction price discovery*.

Because an ascending-bid format allows bidders to change their bids based on others' bidding behavior, such an auction may be able to better assign permits to those who value them the most. When multiple vintages are sold simultaneously, an ascending-bid format may have

the additional advantage of generating more accurate price signals about bidders' willingness to pay for permits of different vintages. Yet this very transparency and flexibility of ascending-bid auctions creates an important potential concern, that bidders will coordinate their bidding behavior and, through this collusion, distort both the assignment of permits and the quality of the price signals sent to the market.

As we have discussed, the experimental evidence to date – while not completely conclusive – suggests that the risk of collusion is real and significant while the risk of inadequate price discovery is relatively slight. If this is correct, a sealed-bid uniform-price auction is best-suited to auction CO<sub>2</sub> permits. Of course, if such an auction is implemented, it will be essential to monitor and evaluate its performance.

## **Bounding the auction price: issues with a price collar**

We have focused on the strengths and weaknesses of various *pricing rules* that determine how much bidders pay for a fixed supply of permits. However, the supply of permits need not be fixed ahead of the auction. Indeed, taxation of carbon emissions can be interpreted as a system in which the supply of permits is perfectly elastic at the price specified by the tax. Between these two extremes of perfectly inelastic and perfectly elastic supply are many possible *supply rules*. Such supply rules can potentially improve auction outcomes, by allowing the social cost of incremental emissions to influence the total quantity of permitted emissions.

In particular, we will focus here on one supply rule that has received much attention in the debate over climate change legislation, the so-called *price collar*.<sup>30</sup> The simplest sort of price

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<sup>30</sup> The Carbon Limits for Energy and American Renewal (CLEAR) Act introduced in late 2009 by Senators Cantwell (D-WA) and Collins (R-ME) included a price collar with a floor of \$7 per ton of CO<sub>2</sub> and a ceiling price of \$21 per ton, rising over time.

collar is characterized by a price ceiling, a price floor, and a target supply. Bidders submit bids for the target supply and, if the resulting market-clearing price falls within the “collar” bounded by the price ceiling and price floor, the auction proceeds as if there were no collar. However, if the market-clearing price that would result exceeds the price ceiling, the quantity supplied is increased enough to meet all demand at the ceiling. Similarly, if the market-clearing price that would result falls below the minimal price, the quantity supplied is decreased so that only those bidding above the floor win any permits.

### **Benefits of a collar**

Price collars can provide helpful guidance to emitters as they plan long-term investments. For instance, if the price ceiling will remain in effect throughout their planning horizon, sufficiently profitable businesses can be confident that they will be able to avoid shutting down, and hence will not delay to make necessary investments to sustain their operations. Similarly, if allowances will not cost less than the price floor, such businesses will not delay to invest in carbon-reducing technologies which can reduce emissions at a per-unit cost less than the price floor. Also, as a supply rule, a price collar allows demand information that is revealed through the bids to influence how many allowances are issued. Namely, should the cost of emission reductions be revealed to be high, the price ceiling will bind and more allowances will be issued, and vice versa. This flexibility could allow for a more efficient carbon-reduction regime, if policy-makers are confident that the social cost of emissions lies within the collar.

For these reasons, a price collar can be an attractive modification to a standard uniform-price auction with fixed supply, *if* one is willing to assume that the presence of the collar will not itself change bidding behavior. Such an assumption is easily justified in settings with many negligibly

small bidders. Indeed, in the extreme case in which each bidder demands just one allowance, each bidder has a weakly dominant strategy to bid its true value in the uniform-price auction, with or without a price collar. Consequently, such a uniform-price auction will lead to an efficient assignment of the permits, subject to the price collar.

### **Risk of collusive-seeming bidding**

Unfortunately, when some bidders are large, price collars may actually provide a sort of focal point for harmful coordination or collusion among bidders. (This could be of particular concern in regional carbon allowance markets in which a handful of energy companies and/or financial intermediaries may be positioned to buy a sizable fraction of the allowances being sold.) To see this point, consider the following simple example.

*Example:* Suppose that 100 allowances are for sale in a uniform-price auction, with a price floor of \$10, a price ceiling of \$20, and a minimal price increment of \$1. There are two large bidders A and B and twenty small bidders. The large bidders' carbon-emitting operations are sufficiently profitable that they are each willing to pay up to the price ceiling of \$20 for all of the allowances at offer. The small bidders' operations each require just one allowance to continue, and their profitability (and hence maximal willingness to pay) ranges from \$0 to \$19.

The small bidders have a weakly dominant strategy to bid their true willingness to pay (bid truthfully), i.e., ten of them shut down operations without even bothering to bid while the other ten bid from \$10 to \$19 and hope for the best. If the large bidders were also to bid truthfully, the auction would generate an efficient outcome in which only the large bidders receive allowances at a market-clearing price equal to \$20, the true marginal cost of abatement. However, notice in

this case that the auction has squeezed all of the bidders of all of their profits: the small bidders are all put out of business while the large bidders pay all of their profits to secure allowances. Consider now the following alternative strategies for bidders A and B bid \$20 for 45 units each and then bid \$10 for all further allowances. Since there are exactly ten small bidders willing to pay more than \$10, the market-clearing price given these strategies will be \$10. Furthermore, neither A nor B has any incentive to bid more aggressively to increase its allotment. For example, to win a 46-th allowance, each large bidder would have to raise the market-clearing price from \$10 to \$11, at an overwhelming cost of \$45 on the allowances that it has already won.

Thus, these collusive-seeming strategies constitute an equilibrium in which (i) the market-clearing price is not reflective of the true marginal cost of abatement, (ii) some small bidders inefficiently remain in operation, and (iii) all bidders who receive allowances are strictly better off than in the truthful-bidding equilibrium.<sup>31</sup> (Bidders in such an equilibrium are not colluding in the traditional sense of that word, since they are each playing a best response to the other's strategy -- hence the term "collusive-seeming bidding".)

In an experimental study, Goswami, Noe, and Rebello (1996) showed that bidders in a repeated setting with the ability to communicate successfully coordinated on a collusive-seeming bidding scheme. Furthermore, communication was only necessary as the bidders discussed ways to take advantage of the auction rules; it was not a necessary ingredient of continued collusive-seeming behavior, once established.

A simple and intuitive way to think about collusive-seeming bidding in the uniform-price auction is as a means to divide the quantity being offered into auction shares and to avoid

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<sup>31</sup> For more on such collusive-seeming equilibria", see Back and Zender (1993), Wang and Zender (2002), and McAdams (2002, 2007).

bidding against others for their shares. To deter others from competing for its share, each bidder bids a high price on those allowances; to create a low market-clearing price, each bidder then bids a low price on allowances that it is not supposed to win. Once bidders have carved out shares of the offering in this way, they have little if any incentive to try to steal away another bidder's share, since doing so will raise the price paid on all other units. This can make collusive-seeming behavior persistent once established.

To determine whether collusive-seeming bidding is a practical concern in a uniform-price auction for carbon allowances, one must first determine whether bidders can realistically be expected to coordinate on a division of supply into auction shares. In the carbon allowance setting, the combination of well-defined total quantity for sale and pre-existing market shares in energy markets could provide the ingredients for effective coordination, making collusive-seeming behavior a potential concern in carbon allowance auctions.

In other types of markets, collusive-seeming behavior is not a significant concern.<sup>32</sup> For instance, in many Treasury auctions there is substantial uncertainty about how much is being sold<sup>33</sup> and/or who is bidding (see e.g. Hortaçsu and McAdams 2009). Similarly, in spot electricity auctions, the quantity of electricity demanded depends on usage patterns that generators cannot perfectly predict when bidding. In such scenarios with random supply, bidders cannot easily divide up the quantity being offered.

To see that collusive-seeming behavior is more difficult to sustain in settings with random supply, suppose that two bidders would like to split an offering of allowances in half and always

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<sup>32</sup> In this vein, Cramton and Stoft (2007) argues that collusive-seeming bidding is not a serious concern in uniform-price electricity procurement auctions.

<sup>33</sup> In many Treasury auctions (including those in the United States), buyers outside of the set of authorized bidders are able to secure quantity through non-competitive bids. In this sort of setting, the quantity being sold to the bidders may be unknown even when total supply is known.

pay a low price, but are not sure whether 100 or 120 allowances will be offered. To avoid paying a high price when supply is only 100 allowances, they cannot bid aggressively for more than 50 allowances. But, in that case, each bidder has the tempting opportunity to bid a little more aggressively and win 70 allowances when supply turns out to be 120. In this way, random supply tends to undermine players' ability to enjoy equilibrium prices below the true marginal cost of abatement.<sup>34</sup>

Predictability of supply is an important aspect of carbon allowance markets. Without such predictability, market transactions would fail to provide as much meaningful information about future costs of emission reductions, and emitters would face an unnecessary additional source of risk. However, while there is a compelling efficiency rationale for all market participants to know the total quantity of emission allowances to be issued, there is no such rationale for why large bidders in a particular auction need to know how many allowances are available *to them* in that particular auction.

For example, in the United States' auctions of Treasury bonds, any individual can acquire a limited quantity of bonds at the market-clearing price by submitting a non-competitive bid (i.e., a market order). Even though the total supply of bonds is known, the residual supply available to the primary bidders in the auction is random to the extent that the quantity of non-competitive bids is difficult for them to predict. A crucial aspect of non-competitive bidding in Treasury auctions is that it encourages participation from extra buyers who normally would not participate, and hence are not well-known to the primary bidders in the auction. In other words, each large bidder faces random *residual* supply in the auction, even if the total supply of bonds is known.

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<sup>34</sup> Auction rules that provide for the consignment of allowances for sale in the auctions can potentially contribute to this effect.

## Residual supply uncertainty eliminates concerns about collusive-seeming bidding

Economic theory has identified several ways in which to modify the standard uniform-price auction in order to reduce concerns related to collusive-seeming bidding, two of which appear potentially relevant in the context of carbon emissions. First, one could give the auctioneer flexibility to reduce the quantity sold after receiving the bids, if collusive-seeming bidding were to be suspected (Back and Zender, 2001). In the context of carbon emissions, “reducible supply” could be implemented by allowing some of the allowance sales scheduled for a particular auction to be deferred to the next auction, at the discretion of the auction monitor. Second, one could create some uncertainty about the quantity being sold (Wang and Zender, 2002). In the context of carbon emissions, some such uncertainty could be created by allowing interested non-emitters to participate, including non-emitting speculators who plan to re-sell their permits in a later auction and/or in the allowance exchange at some later time and (ii) environmentally-sensitive individuals or organizations who are willing to pay to reduce the number of allowances available to emitters. Participation by both sorts of bidders could be encouraged through a variety of measures.

First, participation by non-emitting traders could be encouraged by spreading the release of allowances of a specific vintage over time in several auctions, and permitting two-sided trading in these auctions. This would allow bidders who won allowances in an earlier auction to sell them in a later auction. Such a sequence of auctions could make speculative bidding more convenient, as a ready and liquid market will be periodically available for re-sale.

Second, participation by “environmentalists” may be encouraged by creating a special category of bid (buy-down bidding) that only wins when doing so will reduce total emissions.

Although the significance of bidding by this group is unclear, their participation may still serve a beneficial role.

To encourage the participation of environmentally-sensitive non-emitters, one wants to make the bidding process as simple and transparent as possible. Unfortunately, non-competitive bids as in Treasury bond auctions are not suitable for the purpose of reducing the quantity of allowances available to emitters, because of a complication that arises with the price ceiling. In particular, if demand from emitters is so strong as to trigger the price ceiling, the auctioneer will increase the number of allowances to meet all demand at the price ceiling, regardless of the number of non-competitive bids.

To see why this creates a problem, consider a simple example: 100 allowances are for sale, environmentalists submit non-competitive bids for 50 allowances, while emitters demand 150 allowances at the price ceiling. The auctioneer will increase the quantity supplied to 200 (at a price equal to the ceiling), rendering futile the environmentalists attempts to reduce the quantity supplied to the emitters. Nonetheless, the auction takes their money. For this reason, environmentalists in such a scenario would most likely shun the auction and instead acquire allowances afterward through bilateral transactions, or through some other exchange, rendering them useless as a source of random residual supply to combat collusive bidding.<sup>35</sup>

One simple way to address this issue would be allow bidders who do not plan to use or re-sell the allowances that they win to submit a special sort of non-competitive bid, that we shall call a “*buy-down bid*,” designed with that purpose in mind. When the price ceiling is binding, a bidder who submits a buy-down wins nothing and pays nothing. Otherwise, such a bidder pays the market-clearing price and causes a reduction of the supply of allowances relative to what supply

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<sup>35</sup> As we have discussed earlier, such after-auction transactions may for several reasons be less efficient than transactions mediated by the auction.

would have been without their bid. (In particular, when the price floor is binding, supply is first reduced so that the price floor is binding, after which the buy-down bid is used to further reduce supply.)

## Other design details

We have focused here on design issues that arise with the pricing rule and, to a lesser extent, the supply rule to be used in carbon emissions permit auctions. Of course, there are a variety of other details that must be addressed. In this section, we gather together a list of some, although certainly not all, of the more prominent details that will ultimately need to be addressed.

- *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.
- *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. As mentioned earlier, such limited monitoring can reduce the potential for collusion; however, it also limits public interest groups from monitoring corporate behavior that they deem in the public interest
- *Buyer qualifications*: Steps should be taken to ensure that winning bidders do not default on their bids. Such default has been a real problem in a number of auction markets, and can be

deterred by requiring bidders to post a bond to qualify to bid.<sup>36</sup>

- *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.<sup>37</sup>
- *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. With the exception of the EPA SO<sub>2</sub> auction, the auctions that have been used for selling emission allowances have been designed with the help of considerable experimental testing.
- *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. These concerns may be more salient in regional markets than national ones, since the largest single emitters in the U.S. tend to be regionally concentrated electric power utilities.

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<sup>36</sup> See, e.g., the testimony of Robert D. Reischauer, Director, Congressional Budget Office, on Auctioning FCC Spectrum Licenses before the Committee on the Budget, U.S. House of Representatives, September 29, 1994 (available at <http://www.cbo.gov/doc.cfm?index=4910&type=0>, accessed May 4, 2010). Reischauer states that: "Receipts from the [FCC's] second auction, which offered interactive video and data services (IVDS) licenses--so-called interactive television--amounted to \$214 million, also exceeding most estimates. That auction was also notable because in its aftermath 27 successful bidders, whose payments would have accounted for \$96 million, defaulted on their bids, triggering the penalty provisions in the FCC's auction rules." He continues to say, "The major defaults that occurred in the IVDS auction illustrate the importance of auction rules and the difficulties the commission encounters in extending special standing to small businesses or ones that are owned by women or minorities. ... The importance of default rules in an auction is illustrated by the Australian experience in auctioning satellite-television licenses, in which the failure to include default penalties led to disappointing results."

<sup>37</sup> 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.

- *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. Indeed, this has been the rule rather than the exception with the U.S. proposals to date – a majority of allowances are given for free to emitters and a minority are auctioned, with the split changing over time toward more auctioning. Another, perhaps complementary, risk-management option would be to develop a schedule of supply increases associated with various price hurdles.<sup>38</sup> Under such a scheme, market prices above fixed hurdle levels for a set period of time would trigger the release of fixed numbers of incremental allowances. This is consistent with the allowance reserve mechanism. Or, additional discretion could be given to market authorities in the form of a strategic allowance reserve (Murray, Newell and Pizer 2009), as was included in the Waxman-Markey cap-and-trade bill (HR 2454) that passed the U.S. House of Representatives in 2009.<sup>39</sup>

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<sup>38</sup> For example, under RGGI, regulated power plants may use CO<sub>2</sub> offset allowances to satisfy 3.3 percent of their CO<sub>2</sub> compliance obligation, but this amount may be expanded to 5 percent and 10 percent, if CO<sub>2</sub> allowance prices reach thresholds of \$7 and \$10 per allowance, respectively. ([http://www.rggi.org/docs/RGGI\\_Offsets\\_in\\_Brief.pdf](http://www.rggi.org/docs/RGGI_Offsets_in_Brief.pdf), accessed July 24, 2010)

<sup>39</sup> This strategic reserve is designed to contain prices between \$10 and \$21 per ton, via a “soft collar”: a *fixed* supplement of allowances is triggered when price exceeds a reserve price, thereby not absolutely guaranteeing that prices will fall within that range.

## Conclusion

For carbon emission allowances, a uniform-price sealed-bid auction with a sensibly-chosen price collar is likely to perform its primary functions well: (i) assign the allowances efficiently; (ii) create reliable price signals that can be useful for long-term planning and policy; and (iii) ensure that prices are high enough to provide meaningful incentives to reduce emissions while low enough to avoid too much economic pain. What this paper has emphasized is the *possibility* that such an auction will be vulnerable to collusive and/or the more troubling “collusive-seeming” bidding behavior,<sup>40</sup> in which case it would fail in its first two functions of efficient assignment and price discovery. Fortunately, it appears that this potential concern can be alleviated by augmenting the auction rules to encourage participation by both “speculators” and “environmentalists.” In particular, speculators can be encouraged to participate by allowing two-sided trading within each auction, while environmentalists can be encouraged to participate by creating a special type of bid (the “buy-down bid”) that serves their interests. Even if such bidders demand only a small fraction of the total supply at auction, their presence can disrupt large bidders’ ability to coordinate upon a division of supply, an essential ingredient of collusive-seeming bidding.

Auction design fundamentals, as well as the fine details, are of crucial importance for the success of a U.S. carbon allowance market. This paper evaluates the leading fundamental design options for auction type and discusses some design details that can be adjusted to address potential shortcomings. We recommend an approach to auctioning carbon allowances that U.S.

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<sup>40</sup> Collusive-seeming bidding is perhaps even more troubling than outright collusion, since it can be legal and hence cannot be regulated directly. (In a collusive-seeming scheme, each bidder submits a “competitive” bid in the sense of maximizing individual profit given others’ bids.)

policymakers can initiate with a cap-and-trade program. Regardless of which design is selected initially, it is important to continually evaluate the auction's performance and remain open to design changes that research suggests are beneficial.

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