PILOT AUCTION FACILITY FOR METHANE AND CLIMATE CHANGE MITIGATION: RELEVANT AUCTION THEORY

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POWER AUCTIONS

Contents

Terminology

The following terms are used throughout this document.

Term	Description
Activity percentage	A mechanism that is sometimes used with a point-based activity rule to give bidders some flexibility to switch between packages from round to round in a clock auction – without losing eligibility points. The activity percentage might start out at 80% and then be raised to 90% (or 100%) later in the auction.
Activity rule	The rule that limits what bids a bidder can make in subsequent rounds of a multiple round auction based on the bidder's bids in earlier rounds. The activity rule is intended to avoid bid sniping. A bidder with large demands late in the auction must express large demands in the earlier rounds when prices are lower.
Aggregator	A firm/bidder that wants to purchase put options in order to fund a large number of methane abatement projects which it is not implementing itself.
Bid sniping	The tendency to wait until the last possible opportunity to place a serious bid as in an eBay auction. Auctions often have activity rules in place to prevent bid sniping.
Bidder discount	A bidder-specific percentage discount that is applied after winners and gross payments are determined. A bidder's gross payment is reduced by the bidder discount.
Cap	A competition constraint rule that would prohibit a single bidder from winning more than some percentage (e.g., 25%) of the available supply.
Clearing price[1]	The price at which the demand for a put option is no longer above its supply, and thus is the price when the put option "clears." This clearing price may be less than the winner's bid price.
Clock auction	A multiple round auction in which in each round the auctioneer announces prices and the bidders respond with demands at the specified prices. Prices then increase on products with excess demand and the process repeats.
Clock price	A price for a put option in a round of a clock auction.
Collusion	Two or more bidders working together to manipulate the auction outcome.
Competition	A rule designed to encourage competition. Competition constraints may be

[1] Price either refers to the put option's premium (in the case of a forward auction) or the strike price (in the case of the reverse auction). In this glossary, price refers to the premium but these concepts apply similarly in a reverse auction.

constraint	implemented in a number of ways, such as setting caps.
Dynamic auction	An auction format that involves multiple opportunities to bid and where some information about the bidding is revealed to the bidders during the course of the auction.
Eligibility points	A bidder's eligibility points define the upper limit of put options that the bidder can bid for (based on the sum of bidding points associated with the put options in his/her bid). In the first round, the number of eligibility points is set by the upfront deposit amount for the bidder. In subsequent rounds, the number of eligibility points is set by the bids placed by the bidder in the previous round (and the activity percentage for that round).
Gross payment amount	The amount a winner pays, before the deduction of the bidder-specific discount.
Information policy	The policy that determines the information that is revealed to bidders during the course of a dynamic auction. The information revealed might include bid-specific information such as the price of the bid and the identity of the bidder, or aggregate information such as the total number of bids made on a certain product (demand for that product).
Payment amount	The amount a winning bidder pays for the number of put options it wins. This is the gross payment amount less the bidder discount if any.
Point-based activity rule	An activity rule based on eligibility points. Bidders initially qualify for eligibility points at the beginning of the auction; the number of eligibility points is adjusted based on the bidding history.
Price discovery	A feature of dynamic auctions in which information about bidder demands is reported to bidders, giving bidders the opportunity to adjust subsequent bids based on the information.
Pricing rule	The rule that determines the price paid by the bidder for each lot that it has won.
Proxy bid	A mechanism by which a bidder may submit a bid ahead of time before the auction reaches a given price. The proxy bid is automatically entered into the system when certain conditions are met.
Reserve price	The minimum price at which the seller will sell an item.
Sealed-bid auction	An auction in which bidders submit bids without receiving any information relating to the bids placed by other bidders.
Set-aside	A competition constraint rule that sets aside specific items for bidders meeting certain criteria. A set-aside is sometimes used for new entrants in a market where new entry is desirable to increase competition. Alternatively, a

	set-aside can be used for small firms or for projects in low-income countries.
Winner's curse	The insight that winning an item in an auction is bad news about the item's value, because winning implies that no other bidder was willing to bid as much for the item. Hence, it is likely that the winner's estimate of value is an overestimate. Since a bidder's bid is only relevant in the event that the bidder wins, the bidder should condition the bid on the negative information winning conveys about value. Bidders that fail to condition their bids on the bad news winning conveys suffer from the winner's curse in the sense that they often pay more for an item than it is worth.

1. Introduction

The reduction of Greenhouse Gas (GHG) emissions is a global concern. While they have not received as much attention as CO_2 emissions, methane emissions are also a large component of global climate change. Specifically, methane emissions make up a fairly significant amount of the GHGs, and methane is 21% more effective at trapping heat than carbon (EPA 2001). In the "Global Non-CO_2 GHG Emissions 1990-2030 Report," the EPA suggests that the effect of methane emissions would be noticeable within a decade. Therefore, it is important to develop a system that incentivizes methane abatement.

A large number of methane abatement projects had counted on carbon revenues at the time of investment. However, carbon prices have plummeted since mid-2011, largely because of the economic downturn. As a result many methane abatement projects are now at risk. These "shovel-ready" projects could be implemented quickly with a financial incentive.

The Pilot Auction Facility for Methane and Climate Change Mitigation (PAF) is developing plans for incentivizing the reduction of methane emissions in developing countries by auctioning put options to project implementers or third parties. Such a contract gives the holder the right, but not the obligation, to sell a ton of CO_2e in achieved methane emission reduction at a given "strike" price. These contracts could provide project implementers the fixed price certainty they need in order to proceed with their investment or continue operation. The put options will not be linked to any particular project, but to a quantity of emission reductions that must meet certain eligibility criteria that will be announced ahead of the time of the auction. Put options will be tradable after the auction.

Three types of bidders are likely to participate in an auction for put options: project implementers, aggregators and financiers. A project implementer is associated with one or more specific methane abatement projects in a developing country. On the other hand, aggregators and financiers will generally not be associated with a specific methane abatement project at the time of the auction and are expected to be more sophisticated bidders in the auction. An aggregator is a firm that wants to purchase put options in order to fund a large number of methane abatement projects which it is not implementing itself. A financier is a firm that is interested in purchasing put options in order to roll them into their financing by taking the upside.

This paper reviews relevant auction designs and provides guidance on what auction designs are best for this application. These auctions will determine, in an open competitive process, which organizations can provide the desired emissions reductions in the most cost effective way. Not only will a good auction format provide an effective way of allocating these put options, it will also be a flexible format that could be adopted by many other environmental projects in the

future. In particular, a similar format could be used to encourage projects that reduce other GHGs, for instance black carbon, or could even be used in other results-based financing programs that are not related to GHGs.

1.1. Desirable Properties

Over the last fifteen years, we have researched auction problems in many markets, including spectrum auctions and capacity markets; and we have brought that research to practice in many markets around the world. Our experience suggests two main principles of effective auction design in the environmental setting.

Encourage Price Discovery. Encouraging price discovery is extremely important. There is considerable uncertainty in an auction like this. Not only there is uncertainty about what the future carbon prices will be, but also bidders may not be sure about how much it would cost to meet the required emission reductions. An open, dynamic auction format will allow bidders to benefit from the market insights of the other participants, allowing them to form more informed estimates of future prices and abatement costs.

Induce Truthful Bidding. It is important for an auction format to encourage truthful bidding. If the auction encourages bids to be bidders' intrinsic valuations, the auction will be able to better select which projects are the most cost effective. A good pricing rule and activity rule are necessary to encourage truthful bidding.

2. Auction Design

The goal of this project is to design a mechanism to encourage organizations to engage in projects that reduce methane emissions in developing countries. The PAF intends to do this through a pay-for-performance auction facility for methane.

2.1. Objectives and Performance Metrics

The primary objective of the Pilot Auction Facility is:

- *Efficiency*: Awarding the put options to the group of firms that can most cost effectively reduce methane emissions.

By achieving efficiency, the PAF will maximize the achieved methane reduction given its available budget. In addition to efficiency, there are other desirable goals, including:

- *Competition:* Encouraging competition in the auction.
- *Simplicity:* A simple process for bidders.
- *Neutrality:* All bidders are treated equally.
- *Transparency:* An open process where bids are comparable and it is clear who won and why.
- *Encourage participation of project implementers:* The PAF wants to encourage a large participation in the auctions, including from project implementers. Aggregators and financiers are likely to be more sophisticated and well capitalized and should find it easier to participate. This is also related to the goal of efficiency. If only aggregators are bidding in the auction, the auction may no longer be identifying the lowest cost projects. Instead, it may be simply identifying the bidders with the most optimistic expectations of the costs of these projects. However, the participation of aggregators is critical in the PAF's pilot phase as they would need to play an instrumental role in a successful scale-up of the mechanism.
- *Maximize learning benefits*

2.2. Product Design

The facility will auction put option contracts, which specify a strike price that the facility would pay for each ton of CO_2e in emission reduction achieved. In order to acquire a put option, a bidder needs to pay the premium to the facility. An important decision with respect to product

design is whether bidders bid on the premium or on the strike price. We discuss this issue in Section 2.2.1. Other product design issues (related to offering multiple products in the same auction) are discussed in subsequent sections.

2.2.1. Reverse and Forward Auction

Depending on whether bidders bid on the strike price or the premium, the resulting auction is either a reserve or a forward (direct) auction.

2.2.1.1. Reverse Auction: Bidders Bid on Strike Price

In the reverse auction, the premium is fixed at an amount specified before the auction (e.g., $0.30), and bidders bid down on the strike price. Reverse auctions are often used in the context of procurement, where the auctioneer is the buyer and bidders/sellers compete to provide a good or service at a lower price to the buyer.

In the context of the pay-for-performance auction facility for methane, a potential advantage of using a reverse auction is that the payment that a bidder has to make per put option is fixed (and equal to the fixed premium). As a result, a project implementer that expects to achieve a certain amount of emission reduction can accurately forecast the budget he/she needs in order to purchase the corresponding put options in the auction. However, the strike price is bid down during the auction and is not known in advance. As a result, even though a bidder knows the payment per put option prior to the auction, he/she will not know what type of put options that payment is for. It could be that the strike price ends up being so low that the bidder is not interesting in buying any put options, and thus he/she drops out of the auction.

A drawback of the reverse design is the risk that the strike price ends up being so low that no serious/credible bidders are willing to buy any put options with that strike price at the fixed premium. In this case, there is a risk that the abatement does not materialize, because the winners of the reverse auction are not credible counterparts. In particular, if the premium is set too low, speculators and bidders who are not familiar enough with the economics of methane may bid the strike price down too much. This would lead to firms winning options that pay off too little when compared to the costs of funding any of the proposed methane abatement projects and, as a result, there is a risk that the methane abatement does not materialize.

The PAF can reduce this risk by setting a sufficiently large premium. On the other hand, by setting a lower premium, the World Bank will create a greater opportunity for more diverse firms to participate in the auction. In this sense, when the premium is low, the reverse auction may be a more inclusive approach than the forward auction.

2.2.1.2. Forward Auction: Bidders Bid on Premium

In the forward auction, the strike price is fixed at an amount specified before the auction (e.g., $5), and bidders bid up the premium. In a forward auction, the auctioneer is typically the seller and bidders/buyers compete to buy the items that the auctioneer is selling. This would be the case for the PAF where the facility would sell its put options and the bidders compete to buy them.

With the forward auction, bidders know in advance the strike price, and thus what type of put options they are bidding for, but do not know the payment per option prior to the auction. A potential disadvantage of the forward auction is that it favors bidders that have better access to capital, because the payment per option is not known is advance and will generally be bid up.

An advantage of the forward auction is that bidders have more "skin in the game", and thus the winners may be more credible counterparts. Moreover, if the strike price is set at a reasonable level, the put options will have some resale value and would provide a reasonable amount of funding to other firms should the original winner choose to sell them. The forward design is expected to clear at a higher premium than a reverse auction.

2.2.2. Different Strike Prices

In the case of a forward auction, the PAF could auction similar auctions together with different strike prices. If the strike price of one type of put option is too low for there to be much demand for it, including a put option with a higher strike price helps ensure that the auction does not fail due to low participation. This design would favor highly capitalized firms, who would be able to compete for the put option with the higher strike price (or higher premium) while less highly capitalized firms would be excluded. It could hurt efficiency, since bidders with better access to capital but with more expensive projects in mind could be selected because the lower cost firms are unable to bid on the put option they are winning.

2.2.3. Maturity Dates

The PAF is likely to bundle put options with different maturity dates together and sell them as one product. For instance, the PAF could stagger options over a 5 year period in equal quantities and require bidders to bid for equal quantities of each maturity. This would ensure that late maturities are purchased at the same quantity as early maturities. A disadvantage of this approach is that it does not allow bidders to express their true tradeoffs for different maturity dates. This could hurt the efficiency of the final allocation. Bidders who want put options with maturities in less popular periods may not be able to win them because the price of the bundle has been driven up by demand for the more popular maturity. However, since

put options are tradable, this is likely to be mitigated by the secondary market. On the other hand, an advantage of bundling put options with different maturity dates together is simplicity.

Alternatively, the PAF may offer put options with different maturity dates as separate products in the auction. For instance, there could be two products (types of put options) in the auction: the first product is a put option that matures in 2016, and the second product is a put option that matures in 2017. In the case of a reverse auction, the two types of put options could have the same fixed premium or different fixed premiums. Similarly, in the case of a forward auction, the two types of put options could have the same fixed strike price or different fixed strike prices. A drawback of offering put options with different maturity dates as separate products is that the number of products in the auction is larger, which would result in a more complex auction.

2.3. Auction Design

The PAF may decide to auction one or multiple types of put options in the same auction (e.g., options with different strike prices or options with different eligibility criteria such as low-income country or targeted sector like household biogas). If only one type of put options is being auctioned in a given auction, then all put options in the auction have the same fixed premium in the case of the reverse auction, and the same fixed strike price in the case of the forward auction. If multiple types of put options are being auctioned in the same auction, then each type of put option could be associated with a different fixed premium in the case of the reverse auction, and a different fixed strike price in the case of the forward auction.

In Section 3, we describe two appropriate auction formats for the facility in the case of a single type of put options (single product): the uniform-price sealed-bid format, and the ascending or descending clock format. Then, in Section 4, we describe how these auction formats generalize in the case of multiple types of put options (i.e., multiple products).

3. Potential Auction Formats for a Single Product

3.1. Uniform-Price Sealed-Bid Format

This is a single-round format. Bidders submit bids in a concealed fashion. While this process can be done as simply as submitting bids in sealed envelopes (hence its name), best practice today uses an online system. Each bidder may submit (possibly multiple) price-quantity pairs, where the quantity is the number of put options that the bidder would be willing to buy at that price.

In the case of the forward auction, the expressed demand curve is restricted to be (weakly) downward sloping: the quantity can only stay the same or decrease as the (premium) price increases. In the case of the reverse auction, the expressed demand curve is restricted to be (weakly) upward sloping: the quantity can only stay the same or decrease as the (strike) price decreases.

The auctioneer then forms an aggregate demand curve and determines the market-clearing price, i.e., the price at which supply and demand intersect. All bids above the clearing price are winning bids. Bids at the clearing price are accepted according to some well-specified tie-breaking rule. In the uniform-price sealed-bid auction, all winners pay the clearing price. Bidders pay a uniform price in this auction, not the price they bid; the uniform-price pricing rule incentivizes truthful bidding.

We conclude this section by noting that the pay-as-bid sealed-bid auction is a variation of the uniform-price sealed-bid auction with a different payment rule. In particular, winners pay their bid, instead of paying the clearing price. We do not recommend that the PAF uses the pay-as-bid sealed-price auction, because (1) it does not incentivize truthful bidding, and (2) it would require the PAF to issue multiple bonds in the case of the reverse auction because different bidders could win put options with different strike prices.

3.2. Descending or Ascending Clock Format

This is a multiple-round auction process. In the case of the forward auction, where bidders bid on the premium (for a fixed strike price), this is an ascending clock auction. In the case of the reverse auction, where bidders bid on the strike price (for a fixed premium), this is a descending clock auction.

The auction starts at the reserve price, at which there is presumably excess demand. In each round, the auctioneer announces a price or a price range, and each bidder submits the quantity (i.e., number of put options) that he would be willing to buy at the current price. In the case of the forward auction, the price then increases if the aggregate demand for put options exceeds the available supply. In the case of the reverse auction, the price decreases if the aggregate

demand for put options exceeds the available supply. The auction ends when there is no excess demand.

Activity rule: In the forward auction, a bidder is not allowed to increase its demand as the (premium) price increases. In the reverse auction, a bidder is not allowed to increase its demand as the (strike) price decreases. This rule is intended to avoid bid sniping.

This type of dynamic auction encourages price discovery and is easy for bidders to participate in. Best practice is to include the ability to enter "proxy bids"—expressions of demand at future prices. This gives bidders flexibility in the timing of their bid submission[2]. For example, bidders not interested in price discovery can enter their full demand curves in round 1, if they desire; this is called *proxy bidding*.

Both the theoretical (Milgrom and Weber 1982) and experimental (Porter et al. 2009, Kagel and Levin 2005, Kagel and Levin 2001, Betz et al. 2014) literature suggests that, with an appropriate information policy, the clock format enables more price discovery and generally performs better than the sealed-bid format.

3.2.1. Information Policy

An important consideration when designing a dynamic auction is how much information to reveal between rounds. There are three possible options:

- Do not show any information
- Show aggregate demand
- Show individual demand

We recommend showing aggregate demand. Even if nothing was shown, bidders would still know that there was excess demand as long as the auction continued. But, bidders would not have a good sense of how close the auction was to concluding, or how much interest there still was in the auction. By showing the aggregate demand after each round, the auctioneer enables price discovery; in particular, the aggregate demand information gives bidders some sense of what other bidders believe about the current price.

Showing individual demand would provide even more information; in particular, a bidder would know how much every other bidder demands at these prices. However, this would create more opportunities for gaming. Furthermore, a bidder may be uncomfortable with this information policy, because it provides a lot of information about his/her costs to competitors. To

[2] See Cramton 1998 and Ausubel & Cramton 2004 for a detailed overview of the many advantages of the clock format.

encourage price discovery and truthful bidding, we believe that the most effective information policy is to display the aggregate demand after each round.

3.3. Example

As an example, suppose that 100,000 put options are being auctioned with the forward auction and a sealed-bid uniform-price format. There are two bidders who submit the following price-quantity pairs:

Bidder 1

Price	Quantity
$.1	100,000
$.2	90,000
$.3	70,000
$.4	40,000
$.5	10,000

Bidder 2

Price	Quantity
$.1	80,000
$.2	40,000
$.3	30,000
$.4	10,000
$.5	5,000

The auctioneer computes the aggregate demand as follows:

Aggregate demand

Price	Quantity
$.1	180,000
$.2	130,000
$.3	100,000
$.4	50,000
$.5	15,000

In this example, the market clears at $.3, bidder 2 receives 30,000 options and bidder 1 receives 70,000 options. Note that with the sealed-bid format, bidders need to submit all their

valuations at once. This format does not encourage price discovery at all since there is only one round.

Now suppose that an ascending clock auction is used for the forward auction. In every round, the auctioneer calls a price for the premium and each bidder states his/her demand, i.e., how many put options of a given strike price he/she is willing to buy for this premium. Then, if the total quantity demanded by bidders exceeds the total supply of options, the auctioneer announces a new higher price and the process repeats. Otherwise the auction ends.

Round	Round Price (Premium)	Bidder 1 Demand	Bidder 2 Demand	Excess Demand	Supply
1	$.1	100,000	80,000	80,000	100,000
2	$.2	90,000	40,000	30,000	100,000
3	$.3	70,000	30,000	0	100,000

When the price is $.1, Bidder 1 demands 100,000 put options and Bidder 2 demands 80,000 put options. As the price increases the demand of each bidder decreases until, in round 3, the aggregate demand is equal to the supply and the auction ends. The price the auction ends at is the price that the bidders pay. All winners pay the same price per put option; this pricing rule incentivizes truthful bidding. So in this auction, Bidder 1 buys 70,000 options for $.3 each, and bidder 2 buys 30,000 options for $.3 each.

4. Potential Auction Formats for Multiple Products

In this section, we discuss auction formats for multiple products, or equivalently, multiple types of put options. There could be various reasons for which the PAF may decide to auction multiple types of put options at the same time. First, as discussed in Section 2.2.3, the PAF could decide to auction put options will different maturity dates as separate products. Second, the PAF may decide that it is beneficial to offer put options with different strike prices in the same auction; e.g., the PAF may expect that some bidders want a put option with a strike price of $5, whereas other bidders are interested in put options with a strike price of $10. Third, the PAF may decide to offer a separate product for projects in low-income countries or from certain technologies with the goal of preferential treatment (see Section 5.5 for details).

4.1. Uniform-Price Sealed-Bid Format

The uniform-price sealed-bid format becomes significantly more complex when more than one products (types of put options) are auctioned at the same time. In particular, instead of submitting a list of price-quantity pairs, a bidder would submit the quantity he wants for each type of put options for various price vector. For instance, if only two products (e.g., two types of put options) are auctioned at the same time, the bidder may submit the following bid:

Bidder 1:

Price for Product 1	Price for Product 2	Quantity of Product 1	Quantity of Product 2
$.1	$.1	100,000	0
$.2	$.1	50,000	30,000
$.1	$.2	100,000	0
$.2	$.2	40,000	20,000
$.3	$.2	20,000	30,000

With the uniform-price sealed-bid format, the bidder experience becomes significantly more complicated when more than two products are auctioned together.

4.2. Ascending or Descending Clock Format

In contrast to the sealed-bid format, the generalization of the clock format to a setting where multiple types of put options are auctioned simultaneously provides a simple bidding experience. Before each round, the auctioneer announces a price for each product (i.e., each type of put option). Every bidder then state the quantity of each put option that he/she demands at that price vector. Prices of products with excess demand increase (respectively, decrease) in the case of the forward (respectively, reverse) auction. The auction ends when there is no excess demand for any product.

With multiple products, the clock format has a number of advantages compared to the sealed-bid format. First, bidders are only asked to state their demands at a single specific price vector in each round. Second, bidders are able to learn as the auction progresses and update their valuations. Third, it is easy for bidders to switch between products if a product becomes relatively more expensive in a round. Fourth, the clock format enables assignment discovery. These features make participation in the auction easier. The simplicity of the clock format and its potential to encourage price discovery make it a very attractive auction format for this context.

4.2.1. Activity Rule

Like in the clock auction for a single product, a clock auction for multiple products needs an activity rule to ensure participation in each round. Generally in clock auctions, the activity rule is based on eligibility points. Each product is assigned a different number of eligibility points. Products that the auctioneer anticipates being more valuable are given a higher number of eligibility points. A bidder's eligibility in a round is equal to the sum of the eligibility points of the items he bid on in the previous round. A bidder can bid on any combination of products as long as the eligibility points of that package add up to at most the bidder's eligibility. A bidder's initial eligibility is determined by its initial deposit.

This activity rule can be modified so that a bidder only needs to be active on x% of his/her eligibility to maintain the same level of eligibility, where x% is the eligibility percentage. For instance, if a bidder has 100 eligibility points, and the eligibility percentage is 80%, the bidder will maintain his/her eligibility of 100 points as long as he/she bids on a package with 80 or more eligibility points.

5. Auction Procedures and Other Considerations

5.1. Reserve Price

In the case of the forward auction, the reserve price is the lowest premium that the PAF is willing to accept. In the case of the reverse auction, the reserve price is the highest strike price that the PAF is willing to accept. The reserve price ensures that a put option is not sold for a very low price (premium) or does not have a very high strike price. A low reserve in the forward auction (respectively, a high reserve price is the reverse auction) encourages entry into the auction and helps ensure that the entire supply is allocated. In public auctions, the reserve prices are generally announced to the bidders before the start of the auction, and we recommend that the PAF follows this practice.

5.2. Deposits

In order to ensure that bidders are credible and serious, a bid deposit should be required by each bidder. A bidder's bid deposit will determine the maximum quantity for which he/she will be allowed to bid during the auction. The required deposit should be the product of a specified price (set by the PAF) and the maximum quantity the bidder wants to bid on. For instance, if a bidder wants to bid on a quantity of 100,000 put options and the PAF has set a fixed price of $.05 per unit for the deposit, the required deposit would be $5,000. In the case of a clock auction, the bid deposit determines an upper bound on the quantity that the bidder can bid for throughout the auction, because of the activity rule. This deposit should be large enough that the bidder is unlikely to default on his/her obligation, but small enough that it does not create unnecessary barriers to entry. A reasonable deposit might be 25% of the estimated (or fixed) premium in the auction, although a lower deposit might be preferred in order to minimize barriers to entry for less capitalized firms.

5.3. Number of Auctions

We recommend that the PAF uses a relatively small number of auctions ("auction rounds"). The supply in each auction should be sufficiently large that a bidder could win all the options he needs in one auction and would perceive a reasonable probability of winning. A reasonable budget per auction seems to be about $25 million. Since participation in an auction is costly, a bidder may be less likely to participate if he believes that he will need to participate in multiple auctions in order to win the number of put options he wants. Similarly, types of products should not be broken up between different auctions if this makes each individual auction too small for any bidder to be interested in the auction.

It may be desirable to avoid holding different auctions for different types of put options that are close substitutes. By holding multiple auctions, a bidder who only wants to participate in one auction has to choose which to participate in, even if he/she is almost indifferent between the two types of assets. By auctioning multiple assets in one auction, it is much easier for a bidder to substitute between the assets. In a single auction with multiple assets a bidder can express at what price he is willing to substitute more restricted assets for the less restricted ones. This enables more price discovery, since the increased flexibility allows the different assets to be priced relative to each other more easily. The additional information conveyed by the demand for each asset helps bidders make better decisions during the auction.

5.4. Granularity of Prices and Quantities

From an auction design perspective, there is no advantage in limiting the prices and quantities that a bidder can select in his/her bid (e.g., there is no advantage in requiring a bidder to bid on an amount of put options that is divisible by 1000). There may be advantages to setting limits on how much specific bidders can win; see Section 5.6. The PAF may decide to limit the possible values for other reasons, not related to auction design. In that case, we would recommend allowing small quantities in order to not discourage small firms from participating.

5.5. Preferential Treatment for Certain Projects and Bidders

In a single auction, there are two ways to provide preferential treatment to certain bidders (such as smaller firms or bidders from low-income countries). One way is to set aside some of the supply specifically for these bidders[3]. While these bidders would be able to bid on and receive any of the options being sold, there would be some amount of options (for instance 30,000 out of the total 100,000), that only these bidders could bid on, and potentially receive for a different, lower price. Alternatively these bidders could pay a reduced price, like 90% of the final price. Additional restrictions would need to be placed on the trade of these options, to ensure that the bidders receiving preferential treatment do not resell the options immediately to the bidders who did not receive preferential treatment.

5.6. Caps and Competition Constraints

The PAF may want to encourage competition in a given market. In this case, the PAF may want to implement a cap that would prohibit a single bidder from winning more than some percentage (e.g., 25%[4]) of the available supply of put options. With a bidding cap, all bidders

[3] Athey *et al.* 2011 and Krasnokutskaya & Seim 2011 discuss different policies for preferential treatment in forestry and highway auctions.

[4] For any tentatively-selected cap, it would be worthwhile to examine the plausible projects to be bid for the auction, and make sure that plausible projects are not cut out by a given cap.

are limited in what they can bid for. In some government auctions where there are existing players and new entrants bidding for scarce resources (as is the case for FCC spectrum auctions), the competition caps can be bidder-specific; that is, each bidder has a different cap such that their overall holdings after the auction would be below a specified percentage (e.g., 25%). This issue is probably not a concern for the initial auctions for the pay-for-performance auction facility for methane.

5.7. Comparing the Clock and the Uniform-Price Sealed-Bid Formats

While it does not match donor preferences to establish a simple and straightforward auction, it would be possible to do an experiment, for the purposes of maximizing the learning benefits around auctions, either in the lab[5] or in the field, to compare a sealed bid auction and a clock auction. Bidders would submit bids in the sealed-bid format and then participate in an ascending clock auction. After the two auctions have ended, the PAF would use a randomized method to select which of the auction results would be followed: sealed-bid or ascending clock. Since either result is possible, bidders have the incentive to take both auctions seriously. By comparing the bids from both auction formats, the PAF can determine how much bidders revise their bids during the clock auction. This can help determine if price discovery is important in this context.

5.8. Fail-safes

In very rare cases it may be necessary to cancel the auction. These cases should be specified clearly in the rules. For instance, if an extremely low number of bidders show up for the auction, the PAF may want to cancel the auction. An auction should be almost never be canceled after bids have been submitted, but it may be necessary if either bidders are cheating or if there are serious problems on the seller's side (for instance bugs in the software that seriously compromise the auction results). It should be very clear that the PAF will never cancel the auction after bids have been submitted to try to avoid unappealing outcomes.

5.9. Avoiding Collusion

Collusion is always a concern in auctions. In order to discourage collusion, it should be made very clear in the rules (and even before the rules are published) that collusion is illegal. Even without strong enforcement powers, a variety of steps can be taken to mitigate collusion. It should be made clear to the bidders that if collusion is detected, their deposit will be forfeit and

[5] Many universities, including the University of Maryland, have lab facilities to run economic experiments. Participants would participate in a mock auction that simulates the real auction. In order to ensure credible results, the participants compete with each other and receive payment at the end of the experiment based on their performance in the auction.

they will not be allowed to participate in future PAF auctions. An appropriate reserve price should be set, to make sure bidders cannot collude to make the put options sell for a very low price. High levels of participation should be strongly encouraged; the possible gains from collusion are greatly reduced when there is a large number of bidders in the auction. The auction should be conducted over the internet or in another way that ensures bidders' identities are kept anonymous. Only aggregate demand should be reported to minimize a bidder's ability to enforce collusive agreements. In-person conferences and events should be avoided when possible, so that the participants in each auction remain secret until the auctions have concluded.

5.10. Post-auction Information Policy

Once the winners are announced, many government auctioneers disclose all bidding information publically including the package definitions, bid prices, and the identities of the bidders. Winning bidders generally do not want regulators to disclose their final bids since they normally represent their true value for the packages and could be considered confidential business information. The advantage of full disclosure is that interested parties can replicate the results of the auction. If bidding information is withheld after the auction, it is important to have an independent auditor validate the auction results so that losing bidders are assured that the process was conducted fairly and in full compliance with the stated auction rules.

6. Summary

As discussed in this paper, either a sealed-bid or a clock format would be suitable for the PAF. We believe a clock auction is a preferable auction format, due both to the simplicity of the format for bidders and its potential to encourage price discovery. A clock auction will simply and efficiently choose firms to reduce methane emissions. The following tables summarize what we believe are the three major design choices.

Table 1 – Auction Format

Format	Advantages	Disadvantages
Uniform-Price Sealed-Bid	Provides incentives for bidders to bid truthfully	Limited price discovery, submitting bids is difficult especially with multiple products, no substitutability between different types of options
Clock Auction	The same advantages as the uniform price auction, in addition encourages greater price discovery, easier for bidders, enables substitutability	

Table 2 – Bid on Strike Price or Premium

Format	Advantages	Disadvantages
Format: Bid on Premium	Less susceptible to winner's curse, implicit supply decreases more slowly, more likely to yield a high strike price which will lead to a more vibrant secondary market	Limits access to bidders who have trouble raising capital.
Reverse: Bid on Strike Price	Requires less capital up front, so helps bidders with less capital	More susceptible to speculation/winner's curse, which could reduce the amount of abatements that are actually realized

Table 3 – Single or Multiple Types of Options in a Single Auction

Format	Advantages	Disadvantages
Single Product: One Type of Put Options in the Auction	Easier to implement and simpler	Bidders have to decide in advance which auction/s to participate in, limits how they can substitute between assets, risk of supply in individual assets being too low to encourage participation
Multiple Products: Multiple Types of Put Options in the Auction	Enhanced substitutability, allows for larger auctions, participation decision is easier for bidders	Harder to implement, bidding in the auction itself may be more complicated.

Clock auctions have been used in a variety of industries around the world to allocate assets like spectrum, electricity and natural gas to great success. A similar strategy can be used by the Pilot Auction Facility to allocate put options for methane reduction.

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