How Best to Auction Natural Resources

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Abstract

I study the design of auctions of natural resources, such as oil or mineral rights. A good auction design promotes both an efficient assignment of rights and competitive revenues for the seller. The structure of bidder preferences and the degree of competition are key factors in determining the best design. With weak competition and simple value structures, a simultaneous first-price sealed-bid auction may suffice. With more complex value structures, a dynamic auction with package bids likely is needed to promote efficiency and revenue objectives. Bidding on production shares, rather than bonuses, typically increases government take by reducing oil or mining company risk.

1 Introduction

This chapter examines the design of auctions for natural resources, such as oil and mineral rights, focusing especially on issues faced in developing countries. Of course, auctions are not the only approach to assigning oil and mineral rights. Rights are sometimes assigned via informal processes, such as first-come-first-served, or other formal processes, such as beauty contests (an administrative process). The advantage of an auction is that it is a competitive and transparent method of assignment, which if well designed, can maximize revenues for the developing country.

Whether an auction is feasible depends in large part on the quality of the resources. When the quality is high, as in the case of known proven reserves, then it is easy to attract bidders to compete in the offering. Prospective bidders anticipate that the participation costs will be covered by the expected profits from participation. In situations where the quality of the resources is not high, such as exploration rights for speculative prospects, then attracting bidders may be a difficult, especially if the country does not have a good reputation from prior sales. In the case of poor resources, what may be needed is not an auction to determine the best terms for resource exploitation, but a reverse auction to identify the companies that are willing to offer quality exploration services at minimum cost to the government. In this chapter, I focus on settings where the resources are of sufficiently high quality that attracting bids from oil and mining companies is not a problem.

Careful auction design is essential to achieving the country's goals. Indeed, design and process issues are even more important with developing countries, given their weaker administrative capacity and perhaps greater vulnerability to corruption and collusion. In general, it is necessary to tailor the design to the particular setting. Still there are a number of useful insights we can draw from recent auction theory and practice, both in oil rights auctions and in other sectors. For ease of exposition, I use oil rights auctions as my leading example, but nearly all of the design issues are the same if the country is auctioning other natural resources.

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Fortunately, the use of effective auction designs is well within the grasp of developing countries. With the help of experts, these auctions can be designed and implemented in short order.

The first step is defining the product: the term of the license, the lot size, royalties, and tax obligations. An important part of the product definition is the identification of what terms are biddable and what terms are fixed. Next a number of basic design issues must be resolved: sequential vs. simultaneous sale (with lots sold either one after another or all at once), dynamic vs. static auction (using either an ascending auction process or a single sealed-bid), the information policy (what bidders know when they place their bids), and reserve prices (the minimum selling prices). Collusion and corruption also must be addressed.

The structure of bidder preferences is an important input in the design choice. The items for sale—the right to explore and develop natural resources on a particular geographic lot—are sometimes substitutes and sometimes complements. Bidders' values are interdependent, since each bidder has private information, such as from surveys and seismic tests, that is relevant in determining the largely common value of the lot, based on the net value of the extracted resource. This preference structure suggests, it will be argued below, that some version of a simultaneous ascending auction is best, since this will promote efficient pricing and packaging of the lots.

In this chapter I consider a number of alternative auction formats.

At one extreme is the first-price sealed-bid auction used in the U.S. for offshore leases. The bidders simultaneously submit bids for each desired lot. Each lot is awarded to the highest bidder at the winning bid price. This simple format is suitable for marginal lots with nearly additive value structures (that is, the value of a package is equal to the sum of the values of the individual lots) and small value interdependencies across bidders. It also may mitigate collusion.

At the other extreme is the package clock auction (Ausubel et al. 2006, Cramton 2009). As explained below, this is a version of the simultaneous ascending auction often used in the auction of radio spectrum. The package clock auction is a method of auctioning many related items over multiple bidding rounds, allowing bids on packages of items. The auction begins with a clock stage. The auctioneer names a price for each lot and the bidders respond with the set of lots they desire at the specified prices. Prices increase on lots with more than one bid. This process continues until there are no lots with multiple bids. At this point there is a supplementary round in which bidders express values for any desired packages of lots. An efficient assignment of lots is found based on the supplementary bids and all the bids in the clock stage. Prices are determined from the competition among the submitted bids.

The package clock auction encourages effective price discovery in the clock stage and the supplementary round promotes an efficient assignment and competitive revenues. Although this approach may appear complex, it is actually simpler for bidders than common alternatives. The price discovery (the development of prices over many bidding rounds) reduces guesswork and focuses the bidders' attention on the relevant part of the price space. Then the supplementary round gives the bidders a means to further express package preferences and fine-tune the assignment of lots. The approach is well suited for high quality prospects, with complex value structures depending on the particular package of lots won as well as the private information of other bidders.

Still other designs between these two extremes are appropriate when the bidder preferences are not so complex that package bidding is essential and not so simple as additive values. Just as a fisherman tailors his equipment to the desired catch, an auction designer must tailor the auction format to the structure of bidder preferences and other aspects of the setting.

I begin with some motivating insights from auction theory and practice (section 2). Then, in section 3, I consider bidder preferences and some of the basic design issues in natural resource auctions. Section 4 addresses problems specific to developing countries. Sections 5 and 6 examine the experience with oil rights auctions and auctions in other sectors. Section 7 presents the package clock auction. Section 8 considers a number of alternative auction formats and makes recommendations based on the particular setting.

2 Motivating insights from auction theory and practice

2.1 Why auction?

Auctions allocate and price scarce resources in settings of uncertainty. Every auction asks and answers the basic questions: who should get the items and at what prices? Auctions are a competitive, formal, and transparent method of assignment. Clear rules are established for the auction process. Transparency benefits both the bidders and the country. It mitigates potential corruption and encourages competition through a fair and open process.

A primary advantage of an auction is its tendency to assign the lots to those best able to use them. This is accomplished by competition among the bidders. Those companies with the highest estimates of value for the lots likely are willing to bid higher than the others, and hence tend to win the lots. There are several subtleties, which are addressed below, that limit the efficiency of auctions. Still, a well-designed auction is apt to perform well with respect to both efficiency and revenues.

Informal processes, such as negotiation on a first-come-first-served basis, lack transparency and are vulnerable to favoritism and corruption, which undermines competition. The reduced competition inherent in an informal process reduces both the efficiency of the assignment and the country's revenues. Informal processes also tend to be more vulnerable to expropriation, further discouraging competition.

A common alternative to an auction, especially in mining, is strict first-come-first-served without discretion and without negotiation. In this case, the terms of revenue sharing are part of the tax code, although this would appear to be vulnerable to change and hence expropriation.

Another alternative to auctions is an administrative process, often called beauty contests, in which resource companies present plans for exploration and development according to a formal process. This approach may be more flexible than auctions, but it makes the assignment less transparent and more vulnerable to favoritism and corruption.[1]

2.2 How much competition is enough?

Auctions rely on competition to assign and price scarce resources. Competition is often limited as a result of significant participation costs. This is especially true when auctioning natural resources, since it is quite costly to estimate the value of a particular opportunity. Companies may decline to participate if they fear that more than four companies are apt to compete in the bidding. To motivate costly information acquisition, the country may have an initial stage, which identifies a short-list of the most qualified bidders.

In situations where there are only a few bidders, then the auction design should reflect this. This is accomplished with greater reliance on reserve prices and sealed-bid mechanisms. In all cases, the

[1] It has, however, worked well in environments (such as the Norwegian continental shelf) where other features of the institutional context militate against corruption.

country should attempt to minimize participation costs. A clear and complete information memorandum, detailing the opportunity, is an important step in this process.

2.3 Does auction design matter?

One of the most important results of auction theory is the revenue equivalence theorem: under particular assumptions, the four standard methods for auctioning a single item (first-price sealed-bid, second-price sealed-bid, English ascending, and Dutch descending) all result in the same expected revenue for the seller, and indeed maximize revenues among all trading mechanisms when the seller sets an appropriate reserve price (McAfee and McMillan 1987). From this, one might conclude that auction design is of little importance—that all standard auctions perform well. This, however, is the wrong conclusion.

The assumptions required for the revenue equivalence theorem are quite special: auctioning a single item, independent private values (this term being explained later), risk neutral bidders, an exogenous number of bidders, no collusion or corruption, and symmetric bidders (the bidders appear identical aside from their private information). In practice none of these assumptions holds: many related items are for sale; bidder values depend at least in part on value estimates of other bidders and these estimates are correlated; bidders care about risk; bidder participation decisions are of paramount importance; there are ex ante differences among the bidders (e.g., some are large and some are small); and mitigating collusion and corruption are important. Each of these features impacts the performance of alternative auction designs. A good auction design must tailor the design to the particular setting.

2.4 Objective

The first step of auction design is to identify the objectives of the auction. I assume here that revenue maximization is the overriding objective. The country seeks to get as much revenue as possible over the long term from its oil and mineral resources, appropriately discounting future revenues. Certainly, there are other objectives, such as the timing of the revenues and country employment and investment, but revenue is the main objective.

Regardless of the objective it is important the auction have a clear and unambiguous method of translating bids into winners and terms. Ideally bids can be made one dimensional by fixing all but one term (e.g. bonus bid or production share), or by creating a scoring function with which to evaluate multi-dimensional bids (the scoring function determines a single-dimensional score given a vector of biddable terms).

2.5 Product definition

The second step is product definition—what is being sold. There are two key elements: 1) the contract terms of the license (duration, royalties, tax obligations) and the identification of biddable terms, and 2) the geographic scope of the lots. Lots are generally defined as rectangular blocks or tracts, as specified by a pair of longitude and latitude coordinates within what is known as a graticulation system. The appropriate size of the lots depends on the quality of the prospect. More promising regions support smaller lots. In the U.S., lots are nominated by the oil companies. This is a sensible approach in most cases because it guarantees at least some interest in the auctioned lots.

2.6 Auction process

To promote transparency, the auction process must be specified well in advance of the tender. The process should be open to all companies on a nondiscriminatory basis. The process begins with a public advertisement of the tender. The procedure for awarding a lot is described, including bidder qualification procedures and the auction rules.

A clear and complete statement of the auction process is essential to bidder participation. The country should be committed to the process. Finally, the process should allow for and encourage input from the resource companies. At a minimum this would include the nomination of lots, but allowing comments on all aspects of the rule making is generally worthwhile. Bidder participation and bids are enhanced if legitimate bidder concerns and preferences are addressed.

Today it is a simple matter to conduct the auction over the internet. This is especially desirable if a dynamic auction is used. Expert auction services are easily procured through a competitive bid request for proposals process. There are several well-developed commercial auction platforms suitable for auctioning natural resources over the internet. An internet auction reduces bidder participation costs, which increases both auction competition and auction revenues. Moreover, internet auctions can be completed without additional delay. The bottleneck typically is the administrative process, rather than the auction design and implementation.

3 Bidder preferences and auction design

3.1 The structure of bidder preferences

Before considering design issues, it is helpful to think first about the bidders' preferences. There are three standard valuation models: private values, common values, and interdependent values. *Private values* assumes each bidder's value does not depend on the private information of the other bidders. *Common values* assumes packages of items have the same value to all bidders; these values are unknown, and bidders' estimates of the common value reflect that uncertainty together with their own private information and that of other bidders. *Interdependent values* is a general valuation function in which each bidder's value of a package depends on his private information as well as the private information of the other bidders, these values being unknown.[2]

The oil rights setting (as well as that of other natural resources) is the textbook example of common values. All companies value the oil at about the same level (the world price of oil), but there is enormous uncertainty about the quantity of oil and the cost of extracting it. Before bidding, each company estimates these uncertainties from geological surveys, seismic tests, and analysis of petroleum engineers. Yet each company would like to have the private information of the other bidders to further reduce uncertainty. The common value depends not just on the bidder's estimate of value, but on all the other estimates. In practice, there are also some private value elements—the company's exploration and development capacity, its reserves, its expertise in the particular type of prospect, its ability to manage exploration and political risks—but these elements typically are of secondary importance. Thus, the oil rights setting has interdependent values with strong common value elements. Most other natural resources have similar preference structures.

[2] Formally, index bidders by $i = 1,\dots, n$, and let S be any subset (or package) of the items up for auction. With private values, bidder i's value for the package S is given by $v_i(S)$. With common values, bidders have only estimates $v(S, s, t_1, \dots, t_n)$ of the value to each, where, s is the state of the world (reflecting common uncertainty) and t_i is bidder i's private information (with the common value increasing in each bidder's estimate t_i.). With interdependent values, each bidder i only has estimates of the value $v_i(S, s, t_1, \dots, t_n)$, this being increasing in t_i and weakly increasing in the others' estimates t_j, $j \neq i$.

An important feature of the common values model is the *winner's curse*. This is the insight that winning an item in an auction is bad news about the item's value[3], 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. In natural resource auctions, adjusting bids in light of the winner's curse is a key element of strategy. In contrast, in private values auctions, there is no winner's curse: each bidder knows its value and that value does not depend on the values of the others.

Thus far we have focused on how package values depend on private information. A second important dimension is the structure of package values. How does the bidder value a package of lots?

The simplest valuation model is *additive values*: the value of a package is the sum of the values of the individual lots. In natural resource auctions, additive values is a good first approximation. The primary determinant of value is the quantity of oil, and the quantity of oil in a package of lots is the sum of the quantities in each lot.

Values may also be subadditive or superadditive.

With *subadditive values*, the value of a package is less than the sum of the individual values. One source of subadditive values is capacity constraints on exploration and refining. Additional lots have less value if the company lacks the resources to efficiently exploit that value. Another source is risk, holding many lots within the same region where values are highly correlated is riskier than holding a few lots in each of many dispersed regions. Values for substitute goods are subadditive.

With *superadditive values*, the value of a package is greater than the sum of the individual values. Superadditive values is the case of complements or synergies. One source of complements is exploration and production efficiencies that arise from holding many neighboring lots. Traditional economies of scale may arise in drilling from sharing staff and equipment. A more subtle form of complements comes from more efficient exploration. For example, if two neighboring lots are owned by different companies, each may have an incentive to free ride on the exploration efforts of the other—waiting to see if the other's drilling is successful. As a result, the exploration of both tracts may be inefficiently delayed. Hendricks and Porter (1996) provide both a theoretical model and empirical support for this behavior in the U.S. offshore oil lease auctions. If instead, the two lots are held by the same company, there is no information externality and the lots are explored efficiently. A related synergy comes from the common pool problem, in which neighboring lots are drawing oil from the same pool. When the lots are held by the same company, the exploitation of the pool is efficient; whereas, with separately held lots, the companies would need to negotiate a unitization agreement to coordinate the development. Ideally, lots are defined to avoid this problem, but the country may not have sufficient information to avoid it entirely.

In the natural resource setting, additive values may be a good first approximation. Nonetheless, complements (superadditive) and substitutes (subadditive) likely are important in at least some applications. If this is the case, then the auction design needs to allow for efficient packaging. Otherwise, if values are largely additive, then packaging issues can be safely ignored, resulting in a much simpler auction design.

[3] In the sense that $E(v_i \mid i \text{ wins}) < E(v_i)$, where v_i is bidder *i*'s uncertain value.

3.2 Basic design issues

I now address several key issues of auction design in the natural resource setting.

3.2.1 With sufficient competition, open ascending bidding is better than a single sealed bid

An essential advantage of open bidding is that the bidding process reveals information about valuations. This information promotes the efficient assignment of lots, since bidders can condition their bids on more information. Moreover, since bidders' private information likely is positively correlated, open bidding may raise auction revenues (Milgrom and Weber 1982). Intuitively, bidders are able to bid more aggressively in an open auction, since they have better information about the item's value. The open bidding reveals information about the other bidders' estimates of value. This information reduces the bidder's uncertainty about value, and thus mitigates the winner's curse—the possibility of paying more than the value of the item. Thus, bidders are able to bid more aggressively, and this translates into high revenues for the seller.

The advantage of a sealed-bid design is that it is less susceptible to collusion (Milgrom 1987). Open bidding allows bidders to signal through their bids and establish tacit agreements. With open bidding, these tacit agreements can be enforced, since a bidder can immediately punish another that has deviated from the collusive agreement. Signaling and punishments are not possible with a single sealed bid.

A second advantage of sealed bidding is that it may yield higher revenues when there are ex ante differences among the bidders (Maskin and Riley 2000, Klemperer 2002). This is especially the case if the bidders are risk averse and have independent private values. In a sealed-bid auction, a strong bidder can guarantee victory only by placing a high bid. In an open auction, the strong bidder never needs to bid higher than the second-highest value; that is, the point at which all of the weaker bidders dropped out.

In natural resource auctions, an open auction probably is best, provided the design adequately addresses potential collusion. The reason is that values have a strong common value element. The exception to this recommendation is drainage lots (ones adjoining developed tracts) in which one bidder has much better information about value.

3.2.2 Simultaneous open bidding is better than sequential auctions

A frequent source of debate is whether items should be sold in sequence or simultaneously. A disadvantage of sequential auctions is that they limit information available to bidders and limit how the bidders can respond to information. With sequential auctions, bidders must guess what prices will be in future auctions when determining bids in the current auction. Incorrect guesses may result in an inefficient assignment. A sequential auction also eliminates many strategies. A bidder cannot switch back to an earlier item if prices go too high in a later auction. Bidders are likely to regret having purchased early at high prices, or not having purchased early at low prices. The guesswork about future auction outcomes makes strategies in sequential auctions complex, and the outcomes less efficient. Nonetheless, some amount of sequencing may be desirable to avoid having too much riding on a single auction event at a single time. Both government and companies may face less risk with some sequencing.

In a simultaneous ascending auction, a large collection of related items is up for auction at the same time. Hence, the bidders get information about prices on all the items as the auction proceeds. Bidders can switch among items based on this information. Hence, there is less of a need to anticipate where prices are likely to go. Moreover, the auction generates market prices. Similar items sell for similar prices. Bidders do not regret having bought too early or too late.

Proponents of sequential auctions argue that the relevant information for the bidders is the final prices and assignments. They argue that simultaneous auctions do not reveal final outcomes until the auction is over. In contrast, the sequential auction gives final information about prices and assignments for all prior auctions. This final information may be more useful to bidders than the preliminary information revealed in a simultaneous auction.

Supporters of sequential auctions also point out that the great flexibility of a simultaneous auction makes it more susceptible to collusive strategies. Since nothing is assigned until the end in a simultaneous auction, bidders can punish aggressive bidding by raising the bids on those items desired by the aggressive bidder. In a sequential auction, collusion is more difficult. A bidder that is supposed to win a later item at a low price is vulnerable to competition from another that won an earlier item at a low price. The early winner no longer has an incentive to hold back in the later auctions.

In natural resource auctions, the virtues of the simultaneous auction—greater information release and greater bidder flexibility in responding to information—would improve efficiency. So long as collusion is addressed a simultaneous sale is preferred.

3.2.3 Package bidding should be considered

Another design issue is whether to accept package bids—bids for a particular package of lots—or only accept bids on individual lots. Package bidding is desirable when a bidder's value of a lot depends on what other lots it wins, because values are not additive. Package bidding also has advantages when bidders have budget constraints or other constraints that depend on the package of lots won, such as minimum size constraints. Then bidders may prefer being able to bid on a combination of lots, rather than having to place a number of individual bids (bids on individual lots). With a package bid, the bidder either gets the entire combination or nothing. There is no possibility that the bidder will end up winning just some of what it needs.

With individual bids, bidding for a synergistic combination is risky. The bidder may fail to acquire key pieces of the desired combination, but pay prices based on the synergistic gain. Alternatively, the bidder may be forced to bid beyond its valuation in order to secure the synergies and reduce its loss from being stuck with some low-value lots. This is the exposure problem. Individual bidding exposes bidders seeking synergistic combinations to aggregation risk.

Not allowing package bids can create inefficiencies. For example, suppose there are two bidders for two adjacent parking spaces. One bidder with a car and a trailer requires both spaces. She values the two spots together at $100 and a single spot is worth nothing; the spots are perfect complements. The second bidder has a car, but no trailer. Either spot is worth $75, as is the pair; the spots are perfect substitutes. Note that the efficient outcome is for the first bidder to get both spots for a social gain of $100, rather than $75 if the second bidder gets a spot. Yet any attempt by the first bidder to win the spaces is foolhardy. The first bidder would have to pay at least $150 for the spaces, since the second bidder will bid up to $75 for either one. Alternatively, if the first bidder drops out early, she will “win” one lot, losing an amount equal to her highest bid. The only equilibrium is for the second bidder to win a single spot by placing the minimum bid. The outcome is inefficient, and fails to generate revenue. In contrast if package bids are allowed, then the outcome is efficient. The first bidder wins both spots with a bid of $75 for both spots.

This example is extreme to illustrate the exposure problem. The inefficiency involves large bidder-specific complementarities and a lack of competition. In natural resource auctions, the complementarities are less extreme and the competition likely is greater.

Unfortunately, allowing package bids creates other problems. Package bids may favor bidders seeking large aggregations due to a variant of the free-rider problem, called the threshold problem. Continuing with the last example, suppose that there is a third bidder who values either spot at $40. Then the efficient outcome is for the individual bidders to win both spots for a social gain of 75 + 40 = $115. But this outcome may not occur when values are privately known. Suppose that the second and third bidders have placed individual bids of $35 on the two lots, but these bids are topped by a package bid of $90 from the first bidder. Each bidder hopes that the other will bid higher to top the package bid. The second bidder has an incentive to understate his willingness to push the bidding higher. He may refrain from bidding, counting on the third bidder to break the threshold of $90. Since the third bidder cannot come through, the auction ends with the first bidder winning both spaces for $90.

A second problem with allowing package bids is complexity. If all combinations are allowed, even identifying the revenue maximizing assignment is a difficult integer programming problem when there are many bidders and items. Nonetheless, our understanding of and experience with package auctions has advanced considerably in recent years (Cramton, et al. 2006). I therefore consider package bids as a viable option. Whether package bids are desirable will depend on the details of the setting.

3.2.4 Reserve prices

Reserve prices in natural resource auctions have two main purposes: 1) to guarantee substantial revenue in auctions where competition is weak but the reserve is met, and 2) to limit the incentive for—and the impact of—collusive bidding. Reserve prices mitigate collusive bidding by reducing the maximum gain of the collusive bidding. Setting reserve prices for natural resource auctions is difficult given the enormous uncertainty of values. The approach taken in the U.S. is to have a low minimum bid that applies to all lots, and then accept or reject winning bids ex post. Thus, the reserve price is secret and can depend on the observed bidding behavior.

3.2.5 Bonus bid, royalties, and production sharing

Natural resource auctions, especially for oil and gas rights, commonly involve bonus bids and either royalties or production sharing. The bonus bid or signature bonus is the payment determined in auction for the right to explore and develop the lot during the license period. If exploitable reserves are found, the license is renewed for a nominal fee as long as development continues. The royalty is the share of the oil and gas revenues that goes to the government. Royalty rates vary country to country and even within countries. For example, in the U.S. offshore oil lease auctions, the royalty rate is 1/6; whereas, the onshore rate typically is 1/8. The motivation for royalties is to have the oil company payment more closely reflect ex post realized value. This reduces the risk of the oil company. The disadvantage of royalties is that like a tax it distorts investment decisions. A larger royalty rate reduces the incentive for the oil company to invest in exploration and development activities. In contrast, the signature bonus is a sunk cost after the auction and does not distort subsequent investments. In a setting where there is no uncertainty about values, then only a bonus bid is needed (a zero royalty rate); in a setting where exploration and development are costless, then a 100 percent royalty rate is optimal. In practice, natural resource auctions have large uncertainty about values as well as large exploration and development costs. Thus, an intermediate rate is generally best.

Production sharing contracts attempt to further reduce oil company risk and better manage investment incentives by specifying the terms of cost sharing and profit sharing throughout exploration and development.[4] The contract can allow the oil company to recover exploration and development

[4] For further elaboration and discussion, see, for instance, in Nakhle (2009).

capital costs (in whole or in part) before the country shares in the revenues. Then the government's profit share increases with the success of the project, allowing the terms to handle both marginal and windfall economics. The contracts often are made immune to tax changes by having the government counterparty, typically the national oil company, liable for all taxes. Work programs specify a lower bound on exploration effort. This is an important constraint on more marginal lots, where high government profit shares might otherwise discourage exploration.

With production sharing contracts, it is common for bidding to be over the government's highest profit share, rather than the signature bonus. Thus, bidders compete on their willingness to share profits in the most favorable circumstances. This approach, used recently in Libya and Venezuela, reduces oil company risk without upsetting development incentives, since the bid share only applies for lots that are highly successful. Development incentives are further maintained by having the government share in the development capital costs and the operating costs. If the government's share of development capital and operating costs is the same as its production share, then post-exploration the project essentially is a joint venture with first-best incentives for development.

4 Problems specific to developing countries

Developing countries face additional challenges in establishing an effective auction program. These include political risk, fear of expropriation, favoritism, and corruption. These issues are not unique to developing countries, but may be more pronounced. All of these challenges tend to discourage participation, reducing competition in the auction. A country must recognize that resource companies seek out the most desirable opportunities for auction participation.

The strongest indicator of success of the auction program is robust competition. The geological prospect of the region is a primary factor in attracting resource companies, but political, legal, and process factors are also important. Unfortunately, there is little a country can do in the short term to reduce political risks. Over the medium term, the country can pass laws and create other institutions that provide the ground rules for resource exploration and development, and support long-term investment. Legal risks can be further reduced through choice of contract law.

Fear of expropriation or adverse renegotiation can be mitigated somewhat through the cash flow structure of the contract terms. For example, a pure bonus bid system (zero royalty) is problematic in light of expropriation risks. This would force the oil company to sink most funds upfront, making the company vulnerable to expropriation. Even developed countries, such as the U.K. and the U.S., have a tendency to adjust tax rates to capture a larger share of "windfall" profits. As a result, companies heavily discount bonus bids. Some reliance on royalties or production sharing is better, since these payments are not due until after revenues or profits have been received by the oil company. Another option is share bidding in which oil companies offer equity shares in the venture (the highest offered share wins the lot). In this case the country and the oil company are partners. Each makes investments and reaps rewards according to its share. This approach further shifts risks from the oil companies to the country. More importantly, it aligns the interests of the company and the country, reducing expropriation risks.

Favoritism and corruption are addressed in the auction process. A transparent, nondiscriminatory process is the key to mitigating favoritism and corruption. Independent third-party auction managers can help as well. Likewise, a trustee observing and commenting on all aspects of the auction process can further reduce the possibility of corruption. This step is common of auctions in a regulatory setting.

Developing countries may have strong preferences or constraints with respect to cash flows, especially if they have limited access to world capital markets. For example, a country may be unable to make upfront outlays and may have strong preferences for early payments. Such a country, however, must recognize that too much focus on early revenues may greatly reduce total revenues, especially in an environment where renegotiation risk is high; that is, where the company fears that terms may deteriorate in the event early investments prove successful. For this reason countries often are better off with production sharing contracts with small upfront payments and large government shares in the event of successful finds.

5 Experience with oil rights auctions

Oil rights have been auctioned in many countries throughout the world. The United States, Russia, Venezuela, Brazil, and Libya are examples.

5.1 The U.S. experience

The most studied program is the U.S. offshore oil lease auctions. Porter (1995) provides a survey of this work and is the basis for this discussion. These auctions began in 1954. The product auctioned is a lease granting the right to explore and develop a particular tract for a period of five years (U.S. auctions use the terms 'lease' and 'tract', rather than 'license' and 'lot'). If oil is found and developed, the lease is renewed for a nominal fee as long as production continues. The process begins with the oil companies nominating tracts for auction. The government then makes a list of tracts to be auctioned. The auction, in its most common form, is a simultaneous first-price sealed-bid cash auction. Each bidder simultaneously submits a dollar bid on each of the tracts it desires. The bid must meet or exceed the minimum bid, which is stated as a dollar amount per acre. The per-acre minimum depends only on the type of tract. A tract is either awarded to the high bidder or all bids on the tract are rejected; thus, the reserve price is secret and determined after the bids are observed by the government. A winning bidder pays its bid, which is referred to as the bonus. In addition, the company pays a royalty of 1/6 of revenues for any oil extracted. Bidders are allowed to bid jointly; however, after 1975, none of the top-eight oil companies could combine in a joint bid with another top-eight company.

Tracts are of three types. Wildcat tracts are new offerings that are not adjacent to developed tracts; drainage tracts, as mentioned, are adjacent to developed tracts; and development tracts are a reoffering. There is an important economic difference between wildcat tracts and drainage tracts. With a drainage tract, bidders holding leases on adjacent tracts may have a much better estimate of value than those without adjacent tracts. Thus, the drainage tract sales may have large asymmetries among the bidders; whereas in the wildcat sales bidders are more symmetric. This difference has important implications for both bidding behavior and auction design.

From 1954 to 1990, there were 98 auctions. On average, 125 leases were sold per auction. Eight percent of the high bids were rejected. The auctions raised $282 billion from bonus bids and $202 billion from royalties (2009 dollars). Hendricks, Porter, and Boudreau (1987) estimate from ex post price and quantity data that the government share of rent was 77 percent with the oil companies receiving 23 percent.

Porter (1995) concludes that the U.S. auction program in many respects is well designed. Certainly the government is getting the lion's share of the value. On drainage tracts informed bidders (those with leases on adjacent tracts), reap informational rents. The government could consider using a higher royalty rate on these tracts to the extent that the informational rents are not capitalized in the earlier wildcat sales.

One potentially troubling feature of the U.S. offshore program is the use of the simultaneous first-price sealed-bid format. This is easy for the government to implement, but poses challenges to bidders, which may reduce efficiency and revenues. In particular, the format prevents the bidders from expressing preferences for packages of tracts and it provides no price discovery. In addition, a bidder's budget constraints or other package-based constraints either cannot be satisfied or can only be satisfied by greatly distorting one's bids.

Onshore auctions in the U.S. are conducted at the state level. These auctions often are done as sequential open outcry auctions: each tract is sold in sequence using an English auction. This approach allows for some price discovery and better handles budget constraints, but it still forces bidders to guess auction prices for leases sold later.

5.2 Experience outside the U.S.

Unfortunately, there is little publicly available information about oil rights auctions in developing countries, and little research on the topic. Sunley, Baunsgaard and Simard (2002) provide a study of government revenue sources from oil and gas in developing countries. Typically, countries employ a number of revenue methods: bonus bids, royalties, production sharing, income taxes, and state equity. Not surprisingly, the terms vary widely across countries, reflecting at least in part differences in political risks and geological uncertainty. A reasonable conclusion is that auctions are a desirable method of allocating the rights among companies, but multiple revenue sources should be used to best manage risks and incentives.

Recent auctions conducted in an environment of high oil prices have been highly competitive, especially in regions with known reserves. For example, in the Libyan auction of 15 lots on 29 January 2005, some lots received as many as 15 bids.

Johnston (2005) examines the contract terms and bidding in the 2005 Libyan auction. This case study offers insights into modern contract terms and bidder competition in a major auction of excellent prospects during a period of high price expectations. The 15 lots were offered in a simultaneous sealed-bid auction, in which oil companies bid a production share and a signature bonus for each desired lot. Each lot was awarded to the company with the highest production share (share of gross revenues going to the government). In the event of a tie, the signature bonus was used as a tie breaker.

The contract terms fully specify the split of revenues and costs between the government and the oil company. For example, on lot 54, the winning production share was 87.6 percent. This means that the government gets 87.6 percent of the gross revenues, for which it pays none of the exploration costs, 50 percent of the development capital, and 87.6 percent of the operating costs. The oil company uses the remaining 12.4 percent of the gross revenues to recover its costs (100 percent of exploration costs, 50 percent of development capital, and 12.4 percent of operating costs). Once these costs are recovered from the 12.4 percent, the excess ("profit oil") is split between the government and the oil company according to a sliding scale based on a revenue/cost index. The government's share of this excess increases from 10 percent to 50 percent as the company's cumulative revenue/cost index increases from 1.5 to 3. Under these terms, the initial upfront capital expense is limited to the exploration cost and a modest signature bonus. Since development capital costs are split 50-50, the high production share does mean that some profitable fields may go undeveloped. However, once development capital is sunk, the 87.6-12.4 split of operating costs results in first-best incentives for extraction.

Competition in the Libyan round was intense with an average of 7 bidders per lot. The winning production shares ranged from 61.1 to 89.2 percent with a mean of 80.5 percent. The government take (share of project profits) depends on the assumptions one makes on costs and revenues. Johnston (2005) estimates the government take to range from 77.0 to 97.7 percent with a mean of 89.9 percent, well above the 80 percent that is more typically captured for good prospects or the 77 percent realized in the U.S. auctions before 1990.

The 1996 Venezuela auction of 10 lots had similar contract terms and also was highly successful. There were some important differences. The 10 lots were offered in sequence. Also to maintain better development incentives, the production share bids were capped at 50 percent. First, the bidders bid production shares, and then in the event of a tie (e.g., two or more bid 50 percent) the bidders bid signature bonuses to break the tie. This resulted in large signature bonuses for desirable lots, shifting risk to the winning oil companies. However, the Venezuela terms were more favorable than the Libya terms with respect to cost recovery, so it is unclear which terms were riskier. Indeed, the government take estimate of 92 percent remains a landmark figure (Johnston 2005).

Although negotiated rather than auctioned, the Kashagan production sharing agreement in Kazakhstan demonstrates the flexibility of these contracts for providing risk sharing and investment incentives (Johnston and Johnston 2001). The Kashagan contract terms were unusual in allowing the oil company to recover costs and a return on investment before the government shares much in gross revenues. Then the government take increases to a maximum of 94 percent after high cumulative production. Such terms reduce oil company risk and fears of expropriation. In contrast, the U.S. approach with bonus bids and a small royalty implies a significantly smaller government take.

6 Recent experience with auctions in other industries

Over the last ten years there has been a great advance in the development of methods for auctioning many related items. Innovative auction designs have been proposed and applied to allocation problems in several industries. The auction of radio spectrum is one important example, but these methods have been adopted in several industries, such as energy and transportation.

6.1 Simultaneous ascending auction

The simultaneous ascending auction is one of the most successful methods for auctioning many related items. It was first introduced in U.S. spectrum auctions in July 1994, and later used in dozens of spectrum auctions worldwide, resulting in revenues in excess of $200 billion.

The simultaneous ascending auction is a natural generalization of the English auction when selling many items. The key features are that all the items are up for auction at the same time, each with a price associated with it, and the bidders can bid on any of the items. The bidding continues until no bidder is willing to raise the bid on any of the items. Then the auction ends with each bidder winning the items on which it has the high bid, and paying its bid for any items won.

The reason for the success of this simple procedure is the excellent price discovery it affords. As the auction progresses bidders see the tentative price information and condition subsequent bids on this new information. Over the course of the auction, bidders are able to develop a sense of what the final prices are likely to be, and can adjust their purchases in response to this price information. To the extent price information is sufficiently good and the bidders retain sufficient flexibility to shift toward their best package, the exposure problem is mitigated—bidders are able to piece together a desirable package of items, despite the constraint of bidding on individual items rather than packages. Moreover, the price information helps the bidders focus their valuation efforts in the relevant range of the price space.

Auctions have become the preferred method of assigning spectrum and most have been simultaneous ascending auctions. (See Cramton 1997 and Milgrom 2004 for a history of the auctions.) There is now substantial evidence that this auction design has been successful (Cramton 1997, McAfee and McMillan 1996). Revenues often have exceeded industry and government estimates. The simultaneous ascending auction may be partially responsible for the large revenues. By revealing information in the auction process, bidder uncertainty is reduced, and the bidders safely can bid more aggressively. Also, revenues may increase to the extent the design enables bidders to piece together more efficient packages of items.

Despite the general success, the simultaneous ascending auctions have experienced a few problems from which one can draw important lessons (Cramton and Schwartz 2002). One basic problem is the simultaneous ascending auction's vulnerability to revenue-reducing strategies in situations where competition is weak. Bidders have an incentive to reduce their demands in order to keep prices low, and to use bid signaling strategies to coordinate on a split of the items.

A second problem in the early U.S. auctions arose from overly generous installment payment terms for small businesses. This led to speculative bidding. Winning prices were well above subsequent market prices, and most firms defaulted on the installments and went into bankruptcy. The end result was that substantial portions of the mobile wireless capacity lay fallow for nearly ten years. Some 3G auctions in Europe (notably the U.K. and German auctions) also ended at prices well in excess of subsequent market prices. However, the European auctions did not allow installment payments, so the outcome was simply a wealth transfer from the shareholders of the telecommunications companies to the taxpayers.

6.2 Simultaneous clock auction

A variation of the simultaneous ascending auction is the simultaneous clock auction. The critical difference is that bidders simply respond with quantities desired at prices specified by the auctioneer. Clock auctions are especially effective in auctioning many divisible goods, like electricity, but the approach also works well for indivisible items like oil lots. There is a clock for each item indicating its tentative price. Bidders express the lots desired at the current prices. For those lots with excess demand the price is raised and bidders again express their desired lots at the new prices. This process continues until supply just equals demand. The tentative prices and assignments then become final.

If we assume no market power and bidding is continuous, then the clock auction is efficient with prices equal to the competitive equilibrium (Ausubel and Cramton 2004).

Discrete, rather than continuous rounds, means that issues of bid increments, ties, and rationing are important. This complication is best handled by allowing bidders in each round to express an exit bid—the bidder's maximum willingness to pay—whenever they drop a lot. Since preferences for intermediate prices can be expressed, the efficiency loss associated with the discrete increment is less, so the auctioneer can choose a larger bid increment, resulting in a faster and less costly auction process.

A second practical consideration is market power. Although some auction settings approximate the ideal of perfect competition, most do not. In the U.S. oil auctions, especially in recent years when more marginal tracts have been offered, it is common for tracts to receive one or zero bids. In such a setting, tacit collusion is a real concern with the dynamic auction. The chosen information policy can help mitigate this possibility. By controlling the information that the bidders receive after each round of the auction, the auctioneer can enhance the desirable properties of price and assignment discovery, while limiting the scope for collusive bidding. In the clock auction, this is done by only reporting the total quantity demanded for each lot, rather than all the bids and bidder identities, as is commonly done in the simultaneous ascending auction.

Clock auctions have been used with great success in many countries to auction electricity, gas, pollution allowances, and radio spectrum. Participants value the simplicity and price discovery of the auction.

6.3 Details matter

Not all auctions are successful. The most common source of failure is a lack of participation. Sometimes this is because what is being sold has little value. Other times the lack of competition is the result of a poor auction process, for example the product is ill-defined, the marketing is inadequate, or the political risks are too great. Recognition of the needs of the bidders is critical in getting participation. An important lesson is that careful planning and design are essential to maximizing results. These efforts can translate into billions of dollars in higher revenues.

7 A practical package auction

In this section, I describe a practical method for auctioning many related items, which allows package bids—the package clock auction (Ausubel et al. 2006, Cramton 2009). This method is suitable for oil and mineral rights auctions, especially in situations where packaging issues are important. For example, different bidders combine lots in different ways, and business plans depend on the package of lots won. Then, I describe variations in situations where packaging issues are less important. All methods are described with oil or mineral rights auctions in mind. The items sold are licenses to explore and develop specified geographic lots. The bidder expresses quantities of either 0 or 1 for each lot offered.

The package clock auction begins with a clock stage and concludes with a supplementary round.

The clock stage is an iterative auction procedure in which the auctioneer announces prices, one for each of the lots being sold. The bidders then indicate the lots desired at the current prices. Prices for lots with excess demand then increase, and the bidders again express quantities at the new prices. This process is repeated until there are no lots with excess demand.

Following the clock stage, the bidders submit supplementary bids. The supplementary bids are either improvements to clock bids or bids on additional packages that were not bid on in the clock stage.

Once the clock and supplementary bids are collected, the auction system takes all these bids and performs a series of optimizations to determine the value maximizing assignment, and the prices to be paid by each winner.

7.1 Clock stage

The clock stage has several important benefits. First, it is simple for the bidders. At each round, the bidder simply expresses the set of lots desired at the current prices. Additive pricing means that it is trivial to evaluate the cost of any package—it is just the sum of the prices for the selected lots. Limiting the bidders' information to a reporting of the excess demand for each item removes much strategizing. Complex bid signaling and collusive strategies are eliminated, as the bidders cannot see individual bids, but only aggregate information. Second, the clock stage produces highly useable price discovery, because of the item prices. With each bidding round, the bidders get a better understanding of the likely prices for relevant packages. This is essential information in guiding the bidders' decision making. Bidders are able to focus their valuation efforts on the most relevant portion of the price space. As a result, the valuation efforts are more productive. Bidder participation costs fall and efficiency improves.

There are several design choices that will improve the performance of the clock stage, when packaging issues are important. Good choices can avoid the exposure problem, improve price discovery, and handle discrete rounds.

7.1.1 Avoiding the exposure problem

To avoid the exposure problem, bids in the clock stage are package bids. The bidder wins the entire package or nothing.

The disadvantage of this rule is that the clock stage may end with a substantial number of unsold lots. However, this undersell will be resolved in the supplementary round.

7.1.2 Improving price discovery

In auctions with more than a few items, the sheer number of packages that a bidder might buy makes it impossible for bidders to determine all their values in advance. Bidders adapt to this problem by focusing most of their attention on the packages that are likely to be valuable relative to their forecast prices. A common heuristic device to forecast package prices is to estimate the prices of individual items and combine these with the corresponding quantities to estimate the likely package price. Clock auctions with individual prices assist bidders in this *price discovery* process.

Price discovery is undermined to the extent that bidders misrepresent their demands early in the auction. One possibility is that bidders will choose to underbid in the clock stage, hiding as a “snake in the grass” to conceal their true interests from their opponents. To limit this form of insincere bidding, the U.S. Federal Communications Commission (FCC) introduced an activity rule, discussed in a moment, and similar activity rules have since become standard in both clock auctions and simultaneous ascending auctions. In its most typical form, a bidder desiring large quantities at the end of the auction must have bid for quantities at least as large early in the auction, when prices are lower.

A common activity rule in clock auctions is monotonicity in quantity for each lot. As prices rise, quantities cannot increase. Bidders must bid in a way that is consistent with a weakly downward sloping demand curve for each lot. This works well when auctioning a single product, but is overly restrictive when there are many different products. If the products are substitutes, it is natural for a bidder to want to shift quantity from one product to another as prices change, effectively arbitraging the price differences between substitute products. This lot-by-lot rule is sometimes referred to as “no switching,” since the bidder cannot switch from one lot to another.

A weaker activity requirement is a monotonicity of a bidder’s *aggregate* quantity. This allows flexibility in switching among lots. This aggregate monotonicity, rather than lot-by-lot monotonicity, is the basis for the FCC’s activity rule. A weakness of this rule is that it assumes that quantities are readily comparable. Oil lots, however, are not comparable. For example, the area of the lot is a poor measure of quantity.

Ausubel et al. (2006) and Cramton (2009) propose alternative activity rules, based on revealed preference ideas of standard consumer theory, that do not require any aggregate quantity measure. Straightforward bidding—bidding on the most profitable package in every round—will always satisfy these revealed-preference activity rules. The rules prevent bidders from shifting to packages that have relatively more expensive.

7.1.3 Handling discrete rounds

As described above, discrete bidding rounds are handled with exit bids, enabling the bidder to express quantity reductions at intermediate prices. This allows the use of much larger bid increments without much loss in efficiency. In this way, the auctioneer can better control the pace of the auction, which is important here given the large uncertainty in lot values.

7.2 Supplementary round

The supplementary round is a final sealed-bid opportunity for the bidder to improve its bids on packages bid on in the clock stage as well as submit bids on additional packages. Day and Raghavan (2007) and Day and Cramton (2008) provide a practical method to implement the supplementary round. For further details of the pricing rule and activity rule see Cramton (2009).

7.3 The package clock auction

The package clock auction begins with a clock stage for price discovery and concludes with the supplementary round to promote efficiency.

7.3.1 Why include the clock stage?

The clock stage provides price discovery that bidders can use to guide their calculations in the complex package auction. At each round, bidders are faced with the simple and familiar problem of expressing demands at specified prices. Moreover, because there is no exposure problem, bidders can bid for synergistic gains without fear. Prices then adjust in response to excess demand. As the bidding continues, bidders get a better understanding of what they may win and where their best opportunities lie.

The case for the clock stage relies on the idea that it is costly for bidders to determine their preferences. The clock stage, by providing tentative price information, helps focus a bidder's decision problem. Rather than consider all possibilities from the outset, the bidder can instead focus on cases that are important given the tentative price and assignment information. Rather than simply decide whether to buy at a given price, the bidder must decide which lots to buy. The number of possibilities grows exponentially with the number of lots. Price discovery can play an extremely valuable role in guiding the bidder through the valuation process.

Price discovery in the clock stage makes bidding in the supplementary round vastly simpler. Without the clock stage, bidders would be forced either to determine values for all possible packages or to make uninformed guesses about which packages were likely to be most attractive. My experience with dozens of bidders suggests that the second outcome is much more likely; determining the values of exponentially many packages becomes quickly impractical with even a modest number of items for sale. Using the clock stage to make informed guesses about prices, bidders can focus their decision making on the most relevant packages. The bidders see that they do not need to consider the vast majority of options, because the options are excluded by the prices established in the clock stage. The bidders also get a sense of what packages are most promising, and how their demands fit in the aggregate with those of the other bidders.

In competitive auctions where the items are substitutes and competition is strong, we can expect the clock stage to do most of the work in establishing prices and assignments—the supplementary round would play a limited role. When competition is weak, demand reduction may lead the clock stage to end prematurely, but this problem is corrected in the supplementary round, which eliminates incentives for demand reduction. If the clock auction gives the bidders a good idea of likely package prices, then expressing a simple approximate valuation in the supplementary round is made easier.

7.3.2 Why include the supplementary round?

The main advantage of the supplementary round is that it pushes the outcome toward efficiency by collecting bids for additional packages and improvements of clock bids.

A natural concern with the supplementary round is that it may discourage bidding in the clock stage. The activity rule that operates between the clock stage and supplementary round is essential in mitigating this possibility. Bidders bid aggressively in the clock stage, knowing that a failure to do so will limit their options in the supplementary round.

7.4 Implementation issues

We briefly discuss three important implementation issues.

7.4.1 Confidentiality of values

One practical issue with the supplementary round is confidentiality of values. Bidders may be hesitant to bid true values in the supplementary round, fearing that the auctioneer would somehow manipulate the prices with a "seller shill" to push prices all the way to the bidders' reported values. Steps need to be taken to assure that this cannot happen. A highly transparent auction process helps to assure that the auction rules are followed. Auction software can be tested and certified to be consistent with the auction rules. At the end of the auction, the auctioneer can report all the bids. The bidders can then confirm that the outcome was consistent with the rules. In addition, there is no reason that the auctioneer needs to be given access to the high values. Only the computer need know.

7.4.2 Price increments in the clock stage

When auctioning many items, one must take care in defining the price adjustment process. This is especially true when some goods are complements. Intuitively, the clock stage performs best when each item clears at roughly the same time. This gives the bidders the best opportunity to make use of the price information in the dynamic process. Thus, the goal should be to come up with a price adjustment process that reflects relative values as well as excess demand.

One simple approach is to build the relative value information into the initial starting prices. Then use a percentage increase, based on the extent of excess demand. For example, the percentage increment could vary linearly with the excess demand, subject to a lower and upper limit.

7.4.3 Expression of supplementary bids

Even with the benefit of the price discovery in the clock stage, expressing a valuation function in the supplementary round may be difficult. When many items are being sold, the bidder will need a tool to facilitate translating preferences into values. The best tool will depend on the circumstances.

At a minimum, the tool will allow an additive valuation function. The bidder submits its maximum willingness to pay for each lot. The value of a package is then found by adding up the values on each lot in the package. This additive model ignores all value interdependencies across lots; it assumes that the value for one lot is independent of what other lots are won. Although globally (across a wide range of packages) this might be a bad assumption, locally (across a narrow range of packages) this might be a reasonable approximation, especially in the setting of oil rights. Hence, provided the clock stage has taken us close to the equilibrium, so the supplementary round is only doing some fine-tuning of the clock outcome, then such a simplistic tool may perform reasonably well. And of course it performs very well when bidders actually have additive values.

The bidders' business plans are a useful guide to determine how best to structure the valuation tool in a particular setting. Business plans are an expression of value to investors. Although the details of the business plans are not available to the auctioneer, one can construct a useful valuation tool from understanding the basic structure of these business plans.

8 Alternative auction formats and recommendations

It is not possible to specify one "best" design—the best approach depends on the setting. The package clock auction as described above is an excellent choice in settings where packaging issues are important. It has been used in recent spectrum auctions in the UK and the Netherlands. In other settings, variations are worth considering. The variations depend on how four issues are handled.

1. Clock bidding
   a. Package bids
   b. Individual lot bids
   c. None
2. Activity rule
   a. Revealed preference
   b. Lot-by-lot monotonicity
3. Supplementary bids
   a. Package bids
   b. Individual lot bids
   c. None
4. Pricing in supplementary round
   a. Bidder-optimal core (a winner pays the smallest amount that respects competitive constraints coming from the other bids; in the case of a single lot, this is the second-highest bid)
   b. Pay-as-bid (a winner pays its bid)

With clock bidding for packages, bidders are allowed to drop a lot whose price did not increase, so long as the price did increase for another lot. Also the prices increase along the line segment from the start-of-round prices to the end-of-round prices. In contrast, with clock bidding on individual lots, a bidder cannot drop a lot when the price does not increase, and the price path is not constrained to move along the line segment from the start-of-round prices to the end-of-round prices. For example, the price of one lot may move all the way to the end-of-round price, while another lot stops increasing halfway between the start and end price as a result of a drop by one or more bidders.

The standard package clock auction is defined by the first option (a) for each issue: clock bidding for packages with the revealed preference activity rule, followed by a supplementary round with package bids and bidder-optimal core pricing. This is a sensible choice when packaging issues are important as well as value interdependencies and price discovery. This approach is the most difficult to implement, but accommodates the richest set of bidder valuations.

At the other extreme is the U.S. offshore approach, which is simultaneous seal-bid for individual lots with pay-as-bid pricing (1c, 3b, 4b). This approach makes sense if there are no packaging issues (for example, additive values), little value interdependencies, weak competition, and potentially large asymmetries among the bidders. Although this method is easy to implement, it is problematic for bidders unless values are additive.

Another variation, close to the U.S. approach, has clock bidding on individual lots, a lot-by-lot activity rule, and no supplementary round (1b, 2b, 3c). This effectively is a simultaneous ascending auction version of the U.S. approach. This is sensible in settings where packaging is of only minor importance (nearly additive values), but value interdependencies makes price discovery important. This approach also works best when competition is not too weak and bidder asymmetries are not too large.

A similar variation, close to the U.S. spectrum auctions is clock bidding on individual lots, a revealed preference activity rule, and no supplementary round (1b, 2a, 3c). This would work well when there are moderate packaging issues and value interdependencies. The approach has good price discovery and does allow bidders to piece together desirable packages of lots. The format improves on the U.S. spectrum auctions in two respects. Tacit collusion is mitigated with the use of clocks and only reporting excess demand, rather than all bids. Efficient packaging is facilitated with the revealed preference activity rule. This method is easy to implement and yet accommodates a richer set of valuations.

A final variation, related to the Anglo-Dutch format (Klemperer 2002), has clock bidding on individual lots, a revealed preference activity rule, and a supplementary round with individual lot bids and pay-as-bid pricing (1b, 2a, 3b, 4b). However, in this variation, the price clock stops when demand falls to two on the lot, so there is still excess demand. The excess demand is then resolved in the simultaneous pay-as-bid supplementary round. This approach is well-suited to situations where packaging is of minor importance (nearly additive values), but value interdependencies make price discovery valuable, and competition is weak with potentially large bidder asymmetries. The approach enjoys some of the price discovery benefits of the dynamic methods, but handles weak competition and bidder asymmetries better than the approach without a last-and-final round.

The approaches are summarized in Table 1.

Table 1. Alternative Auction Approaches

Auction Format	Ideal Setting	Features
<u>First-Price Sealed-Bid</u> Simultaneous sealed-bid Pay-as-bid pricing	Private values Additive values	Easiest to implement No price discovery Handles weak competition Handles bidder asymmetries
<u>Anglo-Dutch Clock</u> Clock individual bids (stops with demand = 2) Revealed preference activity rule Supplementary with individual bids Pay-as-bid pricing	Mostly private values Nearly additive values	Harder to implement Some price discovery Handles weak competition Handles bidder asymmetries
<u>Clock No Switching</u> Clock individual bids Lot-by-lot activity rule	Interdependent values (both private and common values) Nearly additive values	Easy to implement Good price discovery with nearly additive values Handles production shares
<u>Clock with Switching</u> Clock individual bids Revealed preference activity rule No final supplementary round	Interdependent values (both private and common values) Substitutes and mild complements	Harder to implement Very good price discovery
<u>Package clock</u> Clock package bids Revealed preference activity rule Supplementary bids Bidder-optimal core pricing	Interdependent values (both private and common values) Complex structure of substitutes and complements	Hardest to implement Excellent price discovery Excellent efficiency Competitive revenues

For settings where there are sets of lots with substantially different value structures, it makes sense to use different formats with different sets of lots. For example, a country may have 12 wildcat tracts that are excellent prospects, 36 drainage tracts that are good to excellent prospects, and 200 tracts that are marginal prospects. The excellent prospects could be done as a standard package clock, the drainage lots as an Anglo-Dutch, and the marginal prospects as a first-price sealed-bid. With this approach the package clock auction is not complicated by the great number of drainage and marginal lots. Moreover, the drainage lots may have large asymmetries among the bidders as a result of private drilling information from neighboring lots. The Anglo-Dutch design handles these asymmetries well. Finally, additive values is probably a good assumption on marginal prospects and in any event the economic loss from the less efficient first-price sealed-bid approach is not great when auctioning marginal lots. Alternatively, since implementing three different formats is probably too much, the country could split the lots into two sets: those with high prospects and those with low prospects. The first-price sealed-bid format could be used for the low-prospect tracts and one of the dynamic formats could be used for the high-prospect tracts.

8.1 Some simple examples

Much of the discussion has been focused on more complex settings where a country has many lots to auction and the bidders are interested in packages of lots. Here I consider some simple examples involving a single lot and therefore no packaging issues, such as a single offshore prospect, privatization of an existing mining facility, or rehabilitation of a mining project. In each of these cases there is a single partially known prospect. The two main approaches are either a sealed-bid first-price auction or an ascending auction. The sealed-bid approach is preferable in situations where there is weak competition (one or two bidders) or the bidders are highly asymmetric (there are large differences among the bidders). An ascending auction is preferable in situations where competition is strong and differences among the bidders are not large. With both formats a reserve price should be set to protect the country from the possibility of little competition. In addition, competition should be encouraged by reducing participation costs as much as possible.

8.2 Libya and Venezuela reconsidered

Although the 2005 Libya auction and 1996 Venezuela auction were successful, I do believe they could be improved. The Libya auction, using simultaneous sealed-bids, prevented both price discovery and efficient packaging. The Venezuela auction, using sequential sealed-bids, allowed only minimal price discovery and packaging. In both auctions, competition was anticipated to be strong. Values included both private and common elements, although the common elements were more important. Values probably were nearly additive, although bidders likely faced budget and risk constraints given the size of the commitment.

In such a setting, a simultaneous clock auction is desirable, and especially simple given the small number of lots. Bids would be over the production share. In the case of Venezuela, I would drop the 50 percent cap on production share and adjust the terms so that the government shares in the development capital expense, thereby improving the development incentives without limiting the production share. A lot-by-lot activity rule (no switching) is desirable given the bidding is on production shares. Under this rule, once a bidder stops bidding on a lot, the bidder cannot return to the lot at higher production shares. This simple rule allows price discovery and some degree of packaging.

9 Conclusion

Auctions are a desirable method of assigning and pricing scarce natural resources. A well-designed auction encourages participation through a transparent competitive process. The design promotes both an efficient assignment of the rights and competitive revenues for the seller.

I find that a variety of auction formats are suitable for auctioning natural resources. The best auction format depends on the particular setting, especially the structure of bidder preferences and the degree of competition. When bidders have additive values and competition is weak, a simultaneous first-price sealed-bid auction may be best, especially if the lots are marginal prospects (relatively low value). When bidders have nearly additive values and competition is stronger, then one of the clock auctions should be considered. This approach will improve price discovery and reduce bidder uncertainty, improving efficiency and revenues. Finally, for high-value lots in which packaging issues are important (bidders care about the particular package of lots won), a package clock auction is appropriate. The package clock auction has excellent price discovery and handles complex bidder preferences involving substitutes and complements. The package clock auction does well on both efficiency and revenue grounds.

Regardless of the auction format, a critical element of the design is defining what is being sold. Possibilities include bonus bids, royalty rates, and/or production shares. These contract terms determine the allocation of risk between country and company, the cash flows over time, and the incentives for exploration and development. Bidding on production shares, rather than bonuses, typically increases government take by reducing company risk and fears of expropriation.

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