2011

Optimal Government Auction Design for Offshore Wind Procurement:

Can transmission subsidies spur competition?

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Word Count: 16,591

MSc Economics Thesis

Tilburg University

8/9/2011

Acknowledgements

First and foremost I would like to express a sincere thank you to my thesis supervisor, Dr. Bert Willems who offered his time, support, and immense knowledge without which this piece of work would not be possible. Being mostly a consumer of knowledge in my educational experience, I am grateful to Professor Willems for helping me rise beyond the level of my incompetence and finally produce a piece of work that I believe to be relevant to issues faced by governments today. Thank you for your insight. Thank you for your patience!

I would also like to thank Dr. Florian Schütt for his time and consideration.

I am particularly grateful to Rotary District 7150 for financing my education in the Netherlands. I am grateful for the opportunity to serve the Tilburg community through my ambassadorial duties while expanding my outlook via this academic discourse. I enjoyed my European academic experience and I feel privileged to have learned from world frontrunners of environmental policy.

My interest in energy policy I attribute to my professional experience with Deloitte Consulting U.S. Federal Energy Practice. I sincerely hope to apply everything I learned from this experience in my future endeavors.

Finally, I am grateful to my family and friends for perpetual encouragement and emotional support.

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1. Introduction

A widespread practice in supporting renewable energy is to implement procurement auctions where the government attempts to minimize its procurement cost. Government procurement auctions, however, suffer from problems of asymmetric information, limited entry, moral hazard and adverse selection. I look at the case of purchasing offshore wind technologies where deep offshore wind has higher cost (larger turbines, higher transmission costs, etc) than near-shore developments and each bidder is more informed about her own cost than the rivals or the government. The firms can, therefore, misrepresent their costs and make a positive profit in the form of the information rent. First I determine the appropriate policy tool and auction type and then suggest an appropriate implementation mechanism that allows revelation of true costs.

Instead of purchasing from the lowest bidder, it may be optimal for the government to provide a subsidy in the form of information rent, allowing the more expensive technology to enter the auction. Relying on a model by McAfee and McMillan (1989), I show that in a first price sealed-bid setting, discriminating in favor of the more costly technology can stimulate competition between bidders thus minimizing government procurement cost.

Significant transmission cost differences allow for segmentation of the bidders into two types of bidders: near-shore and deep offshore developments. This discrimination provides a basis for a price preference policy that may spur competition, reducing the firms' rents. The cost of offshore wind transmission has been a major barrier to deployment of this technology and governments are striving to mitigate the issue through investments in infrastructure. Belgium, for example, is planning to invest $200 million USD to expand transmission capacity from 650 MW to 2 GW. The Netherlands already possesses a capability to integrate 2 GW of offshore wind power, but requires $390 million to $1.1 billion to add additional 4 GW. The United Kingdom plans of 25 GW additional offshore capacity require as much as $18 billion in infrastructural investment. Thus, this is a pertinent topic that is clearly at the forefront of energy policy-makers objectives.

Net welfare is considered in the case where government faces a non-zero Marginal Cost of Public Funds. If the taxes collected for the subsidy are distortive, there is a welfare tradeoff between minimizing the procurement cost and the distortion. I find an optimal subsidy function that maximizes welfare.

Finally, I consider an illustrative numerical example and provide practical extensions of designing an offshore wind auction.

1.1. Problem Definition

There are three challenges the government faces in deploying and auctioning offshore wind:

1. New technology deployment – high transmission costs keep wind projects close to shore.
2. Adverse selection problem – the government does not know the actual costs of projects.
3. Low entry – the size of the projects and cost-asymmetries among bidders cause low entry.

1.1.1. New Technology Deployment

Offshore wind technology is a relatively new technology, compared to on-shore wind that has been in deployment phase for decades. The current world installed capacity of offshore wind stands at approximately 2.2GW in 2010, which was approximately the position of on-shore wind in 1995 (at 2.5GW). The 2.2 GW of nominal capacity pales in comparison with significant experience with onshore wind amounting to 157GW world installed capacity in 2010. Despite substantial targets for future installations, offshore wind remains a niche technology with limited market experience.

Most of the offshore wind projects can be considered “near-shore.” Deeper offshore projects are in early stages of development due to technological and logistical challenges, limited experience and larger technology and transmission costs relative to the near-shore counterparts. The limited experience in deep water installation and higher operating and capital costs have kept offshore developments close to shore. Therefore, competition between near-shore and deep offshore developers is very small, if non-existent.

Despite the technical challenges, deep offshore wind technology has a greater and potentially cheaper electricity production potential than the near-shore counterparts because of greater wind speed and larger feasible turbine size. However, tapping into that potential and making deep offshore wind competitive requires substantial government involvement.

1.1.2. Adverse Selection Problem

Since the offshore wind technology is in the early stages of market penetration, the actual technology costs of projects are not known. Deep offshore wind projects experience this problem very acutely since there are no installed deepwater projects to date. The presence of asymmetric information between the government and developers creates an adverse selection problem where developers can pretend to have higher costs in order to bid up the prices and earn higher rents. It is difficult to reveal the actual technology costs since the firms consider it as private information. The government may require developers to disclose their costs. However, the truthful disclosure of costs is not in the firm’s interest, unless cost-revealing policy is implemented.

1.1.3. Low Entry

Offshore wind project procurement typically leaves the government with a limited number of bidders, if any. There are several reasons for limited entry, and therefore competition, for offshore wind calls for tender, which have to do with technical complexity, limited number of developers worldwide, and the general characteristics of the almost-common-value auction mechanism.

Furthermore, competition between developers comes down to cost and technical specifications, and is therefore limits the market to a handful of developers similar to each other. Governments further exacerbate this problem by seeking greater control over location, technical specifications and capacities of projects. Deep offshore wind, therefore, cannot compete with near-shore projects, for example, because of significant cost asymmetry.

Theory shows that almost-common-value auctions cannot tolerate significant cost asymmetry because even the smallest edge over competitors almost always determines the winner. Therefore, projects with larger costs, such as deeper offshore developments, have very small chance of winning, and therefore do not enter the auction at all.

Common-value auctions also suffer from the “winner’s curse”, further diminishing entry. Due to the cost asymmetry issue, the weaker bidders (i.e. deep offshore projects) attempt to overcompensate for the cost disadvantage by raising their bids. This may results in bidding down the price to unprofitable levels, should the project win. Weaker bidders are afraid of the winner’s curse outcome and do not enter the bidding at all.

Finally, procurement auctions typically have some entry and/or bidding costs which may deter weaker bidders from entering. Entry costs may include costs associated with technical assessment of the site, or auction fees. Low probability of winning, the presence of the “winner’s curse” coupled with the entry costs may dissuade weaker bidders from entering.

1.1.4. The Problem Statement

With respect to issues defined above, we would like to select a policy tool along with an appropriate auction mechanism that will:

a) promote further penetration of offshore wind technology
b) mitigate the adverse selection problems and reveal the real costs and
c) encourage entry and competition between developers

1.2. Proposed Policy Solution

In order to promote the advent of deep offshore wind and mitigate competitive problems, I propose a price preference policy that discriminates in favor of the more expensive deep offshore technology. The proposed discrimination rule can be designed by implementing a truthful revealing mechanism, thus alleviating the adverse selection problem. This subsidy is a reasonable mechanism to spur investment in deep offshore wind technology, propelling it from niche applications and into the market. Finally, removing some of the cost asymmetry may mitigate the winner's curse, encouraging entry of less competitive deep offshore projects.

Several countries are attempting to implement such a subsidy to increase competiveness of deep offshore wind projects. The Netherlands, for example, provides a "correction factor" of .00125EUR/kWh for every 5 km offshore up to the maximum of .01625EUR/kWh for distances of more than 85km offshore. The latter figure more than compensates for additional transmission costs for deep-offshore wind. Making the technical tradeoff between additional transmission costs and higher production capacity amounts to only .004EUR/kWh and constitutes only a fraction of the provided subsidy. This illustrates the fact that the subsidy is meant to also compensate deeper installations for additional technology costs and risks.

1.3. Research Questions

To resolve the issues discussed above, this analysis will help answer the following question:

What is the appropriate auction mechanism design and the optimal subsidy required to mitigate competitive issues in offshore wind deployment?

The above research questions will be analyzed through the following sub-questions:

1. Auction Design – What is the most suitable auction type for this case? How will the policy be implemented?
2. Auction Mechanism and Implementation – What is auction mechanism that can accommodate the proposed policy?
3. Welfare– What are the welfare implications of the proposed policy? How does welfare change if society incurs a cost of raising public funds?
4. Auctioning Renewable Energy in Practice – What are the practical considerations for successful policy implementation?

1.4. Methodology

The approach to this analysis will involve a combination of review of literature, economic modeling and numerical illustration.

1. Auction Design – An in-depth review of auction and game-theoretic literature will provide the basis for this analysis. A first-price sealed-bid auction and an ascending auction will be evaluated against qualitative criteria. I will recommend a design and implementation procedure that will guide further analysis.
2. Auction Mechanism and Implementation – I rely on McAfee and McMillan (1989) auction design model, with some alternative assumptions and extensions. I provide a numerical illustration for clarity.
3. Welfare – I use a model analyzing welfare implications of the policy, with an extension to accommodate marginal cost of public funds. I also provide a numerical illustration.
4. Auctioning Renewable Energy in Practice – I rely on various economic literature as well as government sources to discuss practical considerations. I rely on McAfee and McMillan (1985) and Rothkope, et al (2003) for brief practical extensions.

1.5. Structure

The structure of the analysis is as follows. Section 2 is a review of auction, economic and energy literature. Section 3 considers the best auction type and proposes an implementation procedure. Section 4 presents the auction mechanism model. Section 5 considers welfare implications of the proposed policy. Section 6 provides a numerical example. Section 7 looks at renewable energy auctions in practice. Section 8 considers extensions for future study. Section 9 concludes.

2. Literature Review

2.1. Auction Literature

2.1.1. Optimal Auctions

While the use of auction mechanisms stems from primeval time, the game theoretic aspects of auctions were first characterized by Vickrey (1961) through the concept of Revenue Equivalence Theorem. The theorem states that in auctions where

a) the bidder with the highest valuation always wins,
b) the bidder with the lowest possible valuation has zero surplus in expectations,
c) bidders are risk neutral and
d) bidders are drawn from strictly increasing atomless distribution

lead to the same revenue to the seller and the bidders can expect the same surplus regardless of the auction type.

Myerson (1981) and Riley and Samuelson (1981) expressed the optimal auctions more generally, applying the results to not only private-value models but also to more general common-value models as long as bidders' signals are independent. Myerson used the revenue equivalence concept to derive optimal auctions, or auctions that maximize the sellers' expected revenue. To make the claim Myerson relies on independent private values assumption which means that bidders values (costs) are not correlated. In the model, Myerson shows that under certain conditions the seller can design a mechanism that extracts the entire social surplus, as in the case where bidders' information is public. Myerson's claim assumes risk-neutrality and inability of bidders to collude.

2.1.2. Auction Design

Using the usual economic intuition, according to Klemperer (2002), the most important considerations in auction design are to

a. Discourage collusion
b. Prevent entry deterrence and predation

In simultaneous ascending auctions for multiple objects (in our case, offshore wind sites), the bidders can tacitly collude by dividing up the sites between themselves and signaling this so as to not continue bidding down the prices. There is a credible punishment mechanism in such auctions where bidders can punish each other in other stages of the auction. Collusion in sealed-bid auctions is much more difficult because firms are unable to retaliate against uncooperative bidders.

Attracting a sufficient number of bidders is essential for a revenue-maximizing auctioneer. As shown by Bulow and Klemperer (1996), failure to attract bidders may be unprofitable for the government and may cause inefficiencies. Ascending auctions are vulnerable to insufficient entry since weaker bidders may not enter at all, assuming that the stronger bidders almost always win. Weaker bidders are also more susceptible to the "winner's curse" (overpaying for the object), and will not only bid more cautiously, but may elect not to enter at all. In sealed bid auctions the weaker bidders have a chance to win the object, unlike in ascending auctions (Vickrey, 1961). However, sealed-bid auctions can also suffer from insufficient entry if the cost asymmetries and/or entry costs are high.

2.1.3. Common Value Auctions

For the purposes of this analysis an "almost common-value model" will be used, where bidders have asymmetric costs and different private information about costs. Rothkopf (1969), Wilson (1977) and Milgrom and Weber (1982) developed the common-value auction framework. Milgrom and Weber also provided a framework for analyzing affiliated (correlated) information for this mechanism.

There are no efficiency concerns with pure common-value auctions since all bidders have the same value (and if entry is determined exogenously). Our case will resemble what is called an "almost common value model" since the actual values of each bidders are not identical functions of the signals (Klemperer, 1999). In this type of auction one bidder possesses a slight advantage. Literature by Klemperer (1998) and Bikhchandani (1988) illustrate how even the smallest advantages, such as reputational edge, can allow the bidder to almost always win a pure-common-value auction. Furthermore, Klemperer (1998) also claims that in almost-common-value situations, the first-price sealed bid auctions continue to be optimal for the auctioneer despite small changes to the equilibrium. The use of second-price sealed bid or ascending mechanism in almost-common-value auctions has also been shown to have a large negative impact on entry if there are bidding costs, since the advantaged bidder will almost always win (Klemperer, 1998).

Common value auctions suffer from the "winner's curse" due to asymmetric information problem. Failure to take into account all "bad" signals may induce the winner to pay more, on average, than the worth of the object.

2.1.4. Procurement Auctions

Procurement auctions, or "reverse auctions" are mechanisms where the auctioneer is the purchaser and the bidders are the sellers. This type of auction is relevant for this analysis since we are considering a monopsonistic buyer, typically the government, and offshore wind developers as bidders.

Like other auctions, procurement auctions suffer from issues of adverse-selection, risk-sharing and moral-hazard problems especially in situations where the item for procurement has not be standardized and costs are private information of the bidders. Laffont and Tirole (1987) characterize the optimal procurement mechanism incorporating asymmetric information and moral hazard concerns.

Baron and Besanko (1987) provide a model that analyzes the monopsonists ability to design an optimal contract that induces the bidder to exert effort to reduce cost, in the face of the issues listed above.

Setting an optimal reserve price above which the government will not purchase the good is particularly important. Too high of a reserve price may encourage collusion. Furthermore, the reserve price must be credible.

2.1.5. Equilibria with Bidder Asymmetries

To understand the implications of bidder asymmetries one needs to rely on complex asymmetric auctions models. Nash equilibrium may not exist even for some simpler symmetric models, as discussed by Maskin and Riley (2000b).

Asymmetric equilibria, however, have been found for private-values auction models. Marshall, Meurer, Richard and Stromquist (1994) found an equilibrium for the case of two bidders with uniformly distributed types for independent private-values model. For independent private values, other asymmetric equilibria have been found by Waehrer (1994), Maskin and Riley (2000a), and Lebrun (1999). In his model, Myerson (1981) was one of the first to allow for bidder asymmetries with correlated costs, as long as the correlation is additive.

Due to the sheer size of offshore wind developments and the need for masterful completion of worlds' first installations, many auctioning schemes consider developers of a certain size and experience. In this case bidders form coalitions and consortiums to be in consideration. Analyzing the efficiency of such coalitions may be difficult, considering that certain anti-trust issues arise. However, Mares (2001) considered a model for analyzing asymmetrically sized coalitions, provided that coalition members also have symmetric information.

In designing an optimal procurement mechanism, bidder cost asymmetries have also been modeled by Vickrey (1961), Griesmer, Levitan and Shubik (1967), and Maskin and Riley (1983).

2.1.6. Additive and Multiplicative Bidder Strategies

The way to characterize bidder strategies relies on the presence of adverse-selection problems. Less efficient bidders might pose as more cost-effective actor, thus having a greater chance of securing the contract. This issue is particularly relevant to asymmetric information cases where the monopsonist faces a single seller and has to monitor this seller to ensure lowest costs. In such cases, McAfee and McMillan (1986) show that additive, or "cost-plus" bids (cost plus an additive mark-up), lead to optimal contract with lower equilibrium bid. The monopsonist, therefore, is interested in designing the bidding rules to closely resemble "cost-plus" bid.

In the early work, Rothkopf (1969) found a closed-form solution for equilibrium by characterizing the bidder asymmetries in terms of multiples (instead of additives) of their costs. Rothkopf's work considered a two-bidder scenario since additional bidders add too much complexity.

From practical standpoint, it appears that bids typically contain both an additive and a multiplicative component. For example, if a bidder has a suspicion that she will be outbid, she will typically alter her bid in an "additive" way rather than change the "mark-up" percentage. Rothkopf (1980b) considers such cases and shows that as variation of the value distribution increases, the fixed component becomes a negligible component of the bid.

2.1.7. Subsidizing a Disadvantaged Bidder

The government may wish to subsidize disadvantaged bidders for many reasons, including civil rights and affirmative action, to support small business or in situations where domestic firms are preferred to foreign firms. In our case, offshore wind project is "disadvantaged" relative to a near shore project and, therefore, it may be beneficial from efficiency standpoint to provide them with a bidding advantage in a form of a compensation for additional transmission.

Subsidies to "disadvantaged" technologies may be seen as unnecessary financial burden on the public and have been widely proclaimed as inefficient expressions of favoritism. Studies that try to estimate the welfare costs of procurement preferences while ignoring bidding behavior effects such as Joson (1985) and Lowinger (1976), significantly overestimate the consequences. Ayres and Cramton (1996) provide an analytical framework and empirical evidence to the contrary, analyzing the outcomes of subsidizing minority bidders in Federal Communications Commission (FCC)'s procurement of radio spectrum. The authors point out that the effects of the subsidy on the other bidders must be considered when determining costs and benefits of the policy. Schotter and Corns (1999) arrive at similar empirical results in laboratory experiments, illustrating that including a disadvantaged participant, induces others to compete more aggressively, increasing revenue for the seller.

Rothkopf, Harstad and Fu (2003) also discuss how distortions can actually be decreased by provision of such a subsidy. Since funds for procurement are raised by governments using distortive taxes, greater competition and revelation of information may actually reduce these costs and, therefore distortions.

Subsidies to cost-disadvantaged bidders have been explored by Bulow and Roberts (1989) in the context of independent (uncorrelated) costs. Branco (2002) also utilizes the independent private-values model to explore efficiency of such subsidies. Rothkopf, Harsad and Fu (2003) expand the framework for common-value auction model.

2.1.8. Asymmetric Information, Cost Uncertainty and the Revelation Principle

Due to the existence of information asymmetry between the sellers and the buyer in a form of uncertain costs, one of the essential outcomes of the auction process is the revelation of seller “types”, or their costs. More precisely, the Revelation Principle states that “to any Bayesian Nash equilibrium of a game of incomplete information, there exists a payoff-equivalent revelation mechanism that has an equilibrium where the players truthfully report their types.”[1] In this analysis we will attempt to find an auction mechanism that reveals the costs of the near-shore wind farm through a competitive effect resulting from discriminating in favor of her deep offshore wind competitor.

While the Revelation Principle was first introduced in an analysis of dominant strategies by Gibbard (1973), other extensions for Bayesian equilibrium were provided by Dasgupta, Hammond and Maskin (1979), Holmstrom (1977), and Myerson (1979 and 1985).

In their model, McAfee and McMillan (1989) utilize the Revelation Principle to determine the competitive benefit of subsidizing domestic firms relative to foreign firms in bidding for government contracts. In their model they assume independently distributed costs, depending on comparative advantage of countries and use a subsidy to reveal the costs and let the foreign bidder bid more aggressively.

2.2. Other Economic Literature

In further sections I also rely on concepts such as optimal taxation, renewable energy policy options and general literature about obstacles to renewable energy implementation.

2.2.1. Marginal Cost of Public Funds

Marginal Cost of Public Funds (MCPF) is a concept from taxation theory that measures the loss to society from revenue collection. This concept will be used for the purposes of welfare analysis of the proposed policy.

Basic public economics encompassed in the Samuelson condition states that an extra unit of public good is desirable if the sum of marginal benefits of the good, or Marginal Rate of Substitution (MRS) between public and private good is greater than the direct marginal cost of resources, or Marginal Cost of Transformation of public good (MRT). In the optimum,

$$\sum \mathrm{MRS} = \mathrm{MRT}.$$

However, there is an indirect cost that must be considered. Pigou (1947) discussed this indirect effect of taxation.

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[1] R. Gibbons, Game Theory for Applied Economists, p 165.

Typically, the literature on MCPF has focused on tax distortions in the labor market (Wildasin, 1984; Browning 1987). Snow and Warren (1996), for example, evaluate the different measures of MCPF based on a variety of models, and find that much of the differences stem from disagreement on elasticity of labor supply with respect to public spending.

In addition to labor supply distortions, taxes also impact investment decisions. Fullerton and Henderson (1989) discuss the idea that it is difficult to calculate a general MCPF, and instead focuses on calculating the excess burden for each instrument. The authors found that corporate tax rate is particularly important since it distorts allocation of resources between sectors and assets by impacting the investment decision.

Dahlby (2006) develops a measure for MCPF due to public sector borrowing and suggests that this rate should be a “hurdle rate” for government investment. The author calculates the MCPF to be 1.455 for Canada and 1.355 for the U.S. (in 2006). While we do not dwell on the exact number and methodology for such calculations, a potential 40% distortion presents a challenge to the implementation of the optimal subsidy which will be considered in the welfare analysis section.

2.2.2. Renewable Energy Policy

A large portion of relevant literature is devoted to identifying and implementing sound environmental policies through promotion of renewable energy. The policy tools available to policymakers include feed-in tariffs, quotas and competitive tender (auction) approach. There is much discussion among economists about effectiveness of these tools in deploying alternative energy.

Competitive tendering is a policy instrument where a designated government body issues a solicitation for proposals to develop a particular site or zone in a competitive manner within a certain period of time. The winner of the tender process is typically the lowest “per kWh” price bidder, although many governments also take other project characteristics into consideration when determining the winner. The winner develops the project within a certain regulatory framework and receives a “per kWh” compensation agreed upon during the tender process.

Feed-in tariffs also constitute a major driver of renewable energy, particularly in European countries. Under this mechanism, a particular price per kWh is set into law, under which any developer of that particular technology, after meeting certain technical requirements, can receive this set “per kWh” amount. While there are many approaches to setting a feed-in tariff, it is not particularly relevant to this discussion.

Unlike the competitive tendering and the feed-in tariff mechanisms, the quota approach deals with quantities rather than prices. Under such schemes, the policy places a requirement to produce a certain percentage of electricity using renewable energy.

The two main concerns of policymakers when selecting the policy tool are cost effectiveness and high deployment potential. Butler and Neuhoff (2008) evaluate the costs and amount of installed capacity resulting from these schemes. The authors then use qualitative and quantitative analysis to conclude that feed-in tariffs seem to provide both cheapest prices for consumers and highest market penetration. Klaassen, Miketa and Larsen (2005), however, discuss the success of competitive policies such as auctions to promote cost-reducing innovations, siting Denmark as an example.

Experience in Denmark, Germany, the U.K. and the Netherlands suggests that the path to successful policy may be originating with competitive tenders and honed with eventual introduction of feed-in tariffs (Butler and Neuhoff 2008). Offshore wind developments, in particular, require such a substantial amount of funds and cooperation among various players that competitive tenders seem to be the best option. However, as discussed by Lewis and Wiser (2005), most feed-in tariffs are based on results of competitive tenders. Thus, successful auctions in the initial stages of deployment play an important role on future deployment.

The discussion of welfare implications of the policies culminates in the point that whatever policy is selected, the cost is ultimately borne by the consumers. Energy costs impact many aspects of the economy and electricity price increases due to renewable energy subsidies may result in economic loss (Ofgem 2007). Thus, the policymakers must consider not only the impact of the subsidy on deployment, but also the social cost (dead weight loss).

The desire to keep renewable energy prices down has brought a lot attention to firm's rents and risks. The government's desire to keep rents low has steered policymakers away from a uniform subsidies for different technologies and locations (Oxera 2005). The risks associated with the project determine the return to investors (capital cost). Auctions and tenders seem to be riskier than feed-in tariff approach, since there is more potential for the "winner's curse" (Ofgem).

Targeted renewable policy (where a particular technology is favored) is also relevant to our discussion since the proposed solution provides an option of favoring a particular player "type" for its own sake. Neuhoff (2005) discusses economic reasons behind such targeting in policy.

Finally, it is important to note that other non-pecuniary reasons such as institutional and organizational quality, may impact the policy outcome. Finon and Perez (2007), for example discuss the welfare implications of renewable energy policy and the importance of government's objectives in policy selection. The quality of institutions and the general policy process is also important in success of the deployment tool, as suggested by Foxton and Pearson (2007).

The literature suggests that optimal design of competitive tenders is relevant. Also, in addition to purely cost-related objectives a variety of other policy aspects must be considered.

3. Auction Design

This section selects the auction mechanism that fits the characteristics of a typical offshore wind tender and that that will be most conducive to the application of the selected policy.

3.1. Renewable Energy Auction Characteristics

I first describe inherent characteristics of a typical renewable energy auction.

Procurement Auction

It is clear that we are considering an auction where the "auctioneer" is the government attempting to procure a service and the "bidders" are the sellers of the service. This mechanism is contrary to a typical auction where the bidders are the purchasers of the good, and is called a "reverse auction" or a "procurement auction." Procurement auctions have been used by governments in various contexts, the most relevant of which are probably defense contracts and auctioning of the telecommunications spectrum in Europe; reverse auctions are also used to procure renewable energy.

Information Asymmetry

Government procurement auctions are often characterized by asymmetric information. The government possesses some information about the firms' costs while the firms might have additional information. The issue is that the low cost firms may pose as high cost firm and extract additional profit (information rent). There are certain tools that the government can use to avoid the inefficient outcome through the use of transfers.

Common Value Auction

In a private-value auction the bidders know how much they value the object, but this value is private information to each bidder. In this case, each bidder's value is independent to other bidders' preferences and valuations. Conversely, in a common-value action, the actual value is common and is the same for every bidder. However, bidders might possess varying information about the actual value. The value of a bidder might change due to other bidders' signals and information (Klemperer 2000a).

It becomes apparent that offshore-wind procurement falls under the common-value model since there is some specific actual value of the project that takes form in a wind energy production potential. The problem is that the value is closely tied to the operating costs and a return on capital costs (usually to compensate investors for risk) and these costs can be different among bidders. Therefore the values might be different, although they remain "common." This form of bidder asymmetry is referred to as "almost-common-values" as opposed to "pure-common-values" (Klemperer 2000a).

To conclude, our analysis addresses a procurement almost common value auction with asymmetric values due to cost and value asymmetry.

3.2. Design Options

This section discusses the various auction design options from the perspective of different auction rules, timing (sequential vs. simultaneous) and amount (one site or multiple sites).

3.2.1. Auction Type

There are four standard auction types: first-price sealed bid, second-price sealed bid, ascending (English) auction and descending (Dutch) auctions (Klemperer 2000a). Please refer to Appendix A.1 for definitions.

3.2.2. Auction Timing and Number of Sites

Multiple Unit Auctions

The auction design options thus far have been discussing procurement of offshore-wind power for a single location. However, it is probable that governments wish to issue more than one site for development. The timing and sequencing of the different sites and the various rules and requirements become an important determinant of success of the auction. While we do consider future site bids in selecting the general design of the auction, multiple unit auction is beyond the scope of the analysis.

Sequential Auctions

Sequencing matters in cases where the government wishes to auction multiple locations for offshore-wind developments. Depending on the auction design, simultaneous and sequential auctions may be pro-collusive since bidders can keep their valuations low by tacitly agreeing to split up the sites (Klemperer 2000a). This is particularly important for cases where several firms will form consortiums that will bid for various offshore-wind sites. Once again, this will be considered in selection of the auction mechanism for the analysis, but is out of scope for general conclusions of this paper.

3.3. Selection of the Auction Type

According to Klemperer, the biggest concerns of a well-designed auction are to discourage "collusive, entry-deterring and predatory behavior" (2000a). Below we will examine each auction against the above criteria, taking into consideration the other issues described in the previous sections.

3.3.1. Criteria for Selection

The auction design options will be considered against the following criteria

a. The extent to which the auction mechanism encourages entry
b. The extent to which the auction mechanism discourages collusion
c. Ability of auctioneer to mitigate asymmetric information distortions and extract maximum surplus from the bidders
d. Implications for long-term horizon: multiple site auctions and sequential auctions

Please note that the first-price sealed bid and descending auctions are equivalent in the single unit cases. The second-price sealed-bid and ascending auction also have similar qualities and are equivalent under several conditions (Klemperer 2000a). Therefore, in the analysis we will refer mainly to the first-price sealed bid and the ascending auctions.

3.3.2. Entry

One of the main issues underlying this analysis is the limited number of firms that can participate in government procurement auctions for offshore wind. As discussed previously, firms must have sufficient scale and experience to undertake such large projects; furthermore, firms have to meet very particular technical specifications. This, along with large cost asymmetries, essentially keeps deep-offshore wind companies out of the auction, diminishing competition and incentivizing developers to build projects closer to shore. Encouraging entry is one of the underlying reasons for the proposed policy of subsidizing transmission for deeper offshore wind projects.

In ascending auctions the bidder with the highest signal wins the auction. Therefore, even the slightest cost advantage in an almost-common value auctions will cause the bidder with the highest signal to win almost always. Therefore, weaker bidders have very little chance to win the auction and may not enter the auction at all. This problem is exacerbated with the presence of entry costs or bidding costs. This may leave the auctioneer to face a single bidder, which is not conducive to "extracting highest economic value" by the auctioneer (Klemperer 1999).

In first price auctions the weaker players bid closer to their marginal costs, thus eroding their profits and allowing them a higher probability of winning the auction. Therefore weaker bidders have a higher chance to win the auction, which encourages entry.

Not surprisingly, entry costs and/or an efficient reservation price can influence entry, thus making it endogenous. If reservation price is set to the auctioneer's actual value, it can be shown that bidders make the socially correct decision about entry. Firms enter until their profits are zero. Since typically number of (efficient) entrants must be an integer, it is possible that entrant's profits in expectation can exceed zero. This is a case where the auctioneer can set an entry cost to extract the access profit.

In our case, bidders are asymmetric; therefore, it may be better for the auctioneer to run a less efficient first price auction, where demand exceeds supply instead of an auction that will clear the market (ascending auction) and create an expected profit of zero. The former will encourage more entry. Gilbert and Klemperer (2000) show that it is more profitable for the auctioneer to forgo some auction efficiency for the sake of encouraging entry. In fact, it may be profitable to pay weaker bidders ("white knights) to enter the auction in order to encourage more competition.

The issue of the winner’s curse and other psychological issues like avoiding embarrassment of overbidding may influence entry. Participating in auctions can be costly and therefore bidders enter only if they feel that there is a realistic chance of winning without suffering the embarrassment of overbidding. Despite the issue with ascending auctions described above, they allow for bidders to learn of their opponent’s valuations, making bidders more comfortable about their bids and decreasing the chance for the winner’s curse and “strategic uncertainty”. In sealed bid auctions the bidders run a risk of significantly “overbidding”, thus they are more cautious about their bids and may not enter at all if this uncertainty is too high (Milgrom and Weber 1982a). On the other hand, this same intuition can be applied in favor of sealed-bid auctions. In the presence of strategic uncertainty in sealed bid auctions, advantages of strong bidders are less pronounced, thus making weaker bidders less intimidated about entering the auction.

Finally, ascending auction allows for bidders to learn from each other, thus creating a problem of strategic behavior by bidders that limits entry. For example, in an ascending auction bidders may preemptively make a high bid to discourage others from entering (Fishman 1998).

3.3.3. Collusion

A major concern of auction design is to prevent possibilities for collusion. The occurrence of collusion increases if there is a possibility of bidding strategically and then sharing the profits. Furthermore, collusion is more likely if there are possibilities to credibly punish the defector. Waterson (1984) defines five characteristics that support collusion which provide the basis for this analysis:

1. Firms can easily identify divisions of the market
2. Firms can easily agree on divisions
3. Firms can easily detect defection
4. Firms can credibly punish defection
5. Firms can deter entry

Ascending auctions, especially in multi-product sequential scenarios, create an almost perfect environment for collusion. The available sites and components of the offshore wind developments are well defined, therefore making division of the market relatively easy. However, in ascending auctions firms can easily agree on divisions of these components by signaling during the auction. Furthermore, detection is almost immediate, since the bids/prices are announced aloud. The threat of punishment is credible, especially in multi-unit cases since the punisher can easily raise prices for by bidding for the object designated for the defecting bidder. Finally, we have already argued that entry in ascending auctions is difficult for weaker bidders.

Conversely, first price auctions do not provide an environment conducive for collusion. Despite the fact that the market divisions can be easily identified, as in ascending auctions, the other conditions are a lot less favorable. Since bidding is simultaneous and hidden, bidders cannot signal and agree on divisions; they cannot detect and credibly punish defection. As seen previously, entry is more likely in first price auctions.

The above arguments are best illustrated through the second price sealed bid auctions which produce essentially identical results as ascending auctions. Robinson (1985) illustrates this through a simple example where bidders agree to have one bidder to bid infinitely high while other bidders bid zero; afterwards the spoils of collusion are shared. Bidders do not have an incentive to cheat in this scenario. In first price auctions, however, collusion is less sustainable since bidders have the opportunity to cheat. In order to collude, bidders must agree that the winner bids a small amount while others bid zero. However, there is an incentive to cheat and outbid the designated winner slightly. Thus collusion is less sustainable (Robinson 1985).

Therefore first price auctions are clearly preferred if discouraging collusion is an important criterion for auction design.

3.3.4. Asymmetric Information Distortions and Highest Economic Value

As previously discussed, possessing private information may leave information rents to the firm, thus leading to inefficiency. The government, however, typically tries to extract the full revenue of the bids to avoid information rents and the distortions they may cause. For example, in the case of designing the UK third generation mobile phone auction, one of the objectives set by the European Commission was to "realize the full economic value to consumers, industry and the taxpayer" (Klemperer 2002).

Without taking into consideration potential cost asymmetries, ascending auctions tend to lead to higher revenues for the sellers (lower bids in procurement case) than first-price sealed bid auctions. This stems from the concept that winners of ascending auctions gain a surplus due to the private information. Since in common auctions information is affiliated, the winners' information rent gets eroded and so does her surplus since other bidders can follow the stronger bidders' signals. Therefore the government is able to extract a higher value from the bidders.

However, when value asymmetries are present, first-price sealed bid auctions may have the advantage of collecting "highest economic value." From theory we know that revenue-maximizing auction allocates objects to firms with the highest marginal revenue (value minus cost) rather than to those with the highest nominal value (Myerson, 1981; Bulow and Roberts, 1989). Thus, in the first price auction the weaker bidder bids aggressively and closer to her actual value, thus leaving most of the revenue to the auctioneer. In procurement context the concept is similar (McAfee and McMillan 1989). Therefore, it is possible that the first-price sealed bid auction is more effective in extracting "highest economic value" despite the possibility that a less efficient bidder will win the prize. In such a case, however, there is a danger of the “winner’s curse” where the weaker bidder bids so aggressively that she erodes her profits potentially below zero. Thus, despite winning the project, realistically the development may not come to fruition at all.

Since we are concerned with an almost-common-value auction, analysis by Milgrom (1981) shows that with small asymmetries in common-value auctions, the first-price auction is almost optimal for a revenue-maximizing auctioneer.

3.3.5. Long Term Horizon Considerations

As previously mentioned, realistically governments will wish to issue offshore wind tenders for multiple sites and they may do so through several rounds of tenders. Therefore, we must select an auction mechanism that is most likely to encourage entry and deter collusion in such an environment.

Due to the large scale of offshore wind developments the governments may be hard pressed to find enough bidders that are able to undertake such a substantial development. Therefore, some cases may require for firms to form coalitions and bid for different components of the development. If ascending auction mechanism is utilized, the Nash equilibria appear to be highly collusive, since bidders can divide the project among themselves. Using a first price sealed bid auction design diminishes possibilities for collusion in this case.

Multiple sites up for tender also exacerbate the problem of collusion in ascending auctions. Bidders can signal during the auction which sites they prefer, thus easily dividing the market. Defection is punished by bidding up the price in the designated sites of the defecting bidders. Similarly, sequential auctions also exacerbate the issues with ascending auctions described above. Defecting bidders are simply punished in the subsequent rounds of tenders.

3.3.6. Summary and Conclusions

In discussion above, it becomes clear that first-price sealed bid mechanism is a favored design for the case of offshore-wind competitive tenders. Ascending auctions are very susceptible to collusion and war of attrition while the simultaneous hidden bid nature of first-price auctions avoids this issue. Similarly, in the long term horizon where governments might wish to offer additional sites for tender, first-price auction is preferred for the same reason as above. The question of which design mechanism is better for encouraging entry is not as clear as the collusion arguments. However, generally it has been shown that first-price auctions are better at encouraging entry since they provide opportunities for weaker bidders to win the auction. Due to higher entry and more intense competition the auctioneer may extract higher economic value under first-price auction. To conclude, the selected design mechanism for this analysis is a first price sealed bid auction. The findings of this section are summarized in the table below.

Table 1: Summary

	First-Price Sealed Bid Auction	Ascending Auction
1.Encouraging Entry	• PRO: weaker bidders have a higher probability of winning, thus encouraging entry. • PRO: FPSB have a presence of strategic uncertainty since bidders cannot learn about others' strategies, making the perceived asymmetries less pronounced. In this case, ignorance is bliss for the weaker bidders who have the perception that they can beat the stronger opponents, thus encouraging entry. • PRO: FPSB Auctions allow for less strategic behavior in bidding, discouraging entry deterrence strategies by aggressive bidders. • CON: FPSB is susceptible to the winner's curse, intimidating weaker bidders from entering. The potential embarrassment of overbidding may discourage entry.	• PRO: Winners' curse is less pronounced, encouraging entry. Since bidders can learn from each other, strategic uncertainty (embarrassment about overbidding) decreases, thus encouraging entry. • CON: Even the smallest advantages (cost or reputational advantages) makes the strong bidders win in most cases. This discourages weaker bidders from entering at all. • CON: Strategic behavior may cause stronger bidders to give a high initial bid to intimidate the weaker bidders out of the auction.
2.Discouraging Collusion	• CON: can easily identify divisions in the market • PRO: firms cannot easily agree on divisions because bidding is simultaneous and there are no possibility of signaling • PRO: Detection and punishment of defection are not possible due to the same reason as above. • PRO: Entry is more likely, diminishing success of collusive agreements.	• CON: can easily identify divisions in the market. • CON: can easily agree on divisions by signaling during the auction. • CON: detection and punishment is possible during the progress of the auction. • CON: Entry is not sufficient to deter collusion.
3.Highest Economic Value	• PRO: FPSB Auction maximizes net marginal revenue rather than total value. The weaker bidder bids aggressively (closer to cost/actual value) eroding own surplus and leaving it to the auctioneer. Aggressive bidding from weaker bidders makes stronger bidders (more cost efficient) also bid closer to actual values. • CON: the weaker bidder (less efficient bidder) may win the auction. • CON: the winner's curse is strong since weaker bidders might erode their surplus completely, making the project unprofitable in case of winning. Unprofitable projects are less likely to come to fruition.	• PRO: Ascending Auction induces bidders to bid based on their information. In pure common value auctions where information is affiliated the leading bidders (the ones with better information) send high signals and other bidders learn from those signals bidding up the revenue to the auctioneer. • PRO: The most efficient bidder wins the auction. • CON: If cost asymmetry exists (as in an almost common value auction), entry of weaker bidders is limited, thus weakening competition and diminishing revenues to the auctioneer.
4.Long Term Considerations	• PRO: lack of opportunities to signal during the auction diminishes collusive opportunities and war of attrition in multi-unit and sequential tender scenarios.	• CON: opportunities to signal during the auction increases collusive opportunities and war of attrition in multi-unit and sequential tender scenarios. This is due to the fact that bidders can divide the market more effectively and can effectively detect and punish defection during other rounds of bidding.

3.4. Implementation

Now that we have determined the ideal auction type for the auction, we consider ways to implement the proposed policy. First, we find the optimal result and then we design the auction to replicate that result.

3.4.1. Revelation Principle

In order to implement the optimal policy we need to find a mechanism that reveals the costs of the bidders. As previously mentioned, the bidders can claim to have higher costs and potentially extract an information rent from the government. Myerson (1985) showed that by using transfers and subsidies and then implementing the auction, we can induce bidders to reveal their costs.

The Revelation Principle states through a discriminatory sealed-bid mechanism the government can achieve the same result as if the firms truthfully revealed their costs (Myerson 1985). Through the optimal discrimination function $z(c_1)$ the government can subsidize the less cost efficient firm in order to spur competition with the more cost efficient firm, inducing the firms to bid closer to cost.

3.4.2. Implementation Procedure

To design the auction the government should do the following:

1) Define and clearly segment the firms into two types (near-shore wind and deep offshore wind). It is important to be able to distinguish between the two firms types. Otherwise the mechanism will not lead to efficient outcome.
2) Collect cost information on the two types. This information is necessary to construct cost distributions based on which we can design the discrimination policy.
3) Announce the tender and ask interested firms to submit an application. The number of firms of each type participating in the auction is important for mechanism design.
4) Find the cost discrimination policy that will cause firms to reveal their costs. Analyze the way firms are expected to bid given the cost discrimination policy.
5) Use the optimal bids to find a discrimination rule that replicates the policy.

To implement the mechanism the government should do the following:

1) Announce the tender and ask interested firms to submit proposals.
2) Analyze and announce the discrimination rule. Clarify that during the selection the deep-offshore wind firms will be given a preference, by deflating their bid by a certain percentage.
3) The firms submit their sealed bids.
4) Select the lowest bid based on the discrimination rule.
5) Pay the winner her bid.

4. Auction Mechanism and Policy Implementation

The model to be used in this work is based on McAfee and McMillan (1989). The model presented in the aforementioned paper is used to analyze efficiency of discrimination in government procurement in favor of domestic producers. In their case, the authors consider multiple domestic and foreign bidders who may possess private information about their costs and may utilize this information to increase their payoff. The home country has a higher cost than the foreign counterpart, which constitutes a disadvantage in the auction. The authors show that under certain conditions it is optimal to subsidize the disadvantaged bidder in order to decrease payoffs to private information holders and reveal the true costs.

The parallels between the model above and the situation in this paper are clear. In our case we consider two bidders with different cost distributions: the higher cost deep offshore wind project and a cheaper near shore development. The government can design an optimal auction by exploiting the systematic cost difference between the two technologies. Furthermore, both cases deal with a procurement auction with almost-common value auction type. There is some information that is common to all parties, while other information is private to bidders. In our case we are also looking to reveal private information about costs of offshore wind developments while providing an advantage to the deeper offshore wind firm.

For the purposes of this analysis, I will simplify the model to include only two firms. Also, I will consider world welfare rather than country welfare. In the case of McAfee and McMillan (1989) the government takes into consideration domestic welfare and, therefore, cares which firm (domestic or foreign) wins the project. While the social planner does not specifically care about which project wins the auction, for the purposes of competition the government discriminates in favor of the more expensive firm.

4.1. Model Overview

Consider a model of two bidders, i= 1, 2 for deep-offshore wind and near-shore wind, respectively. Each firm has a constant average cost c_i that is private to the firm. The other firm and the government do not know the value of c_i but perceive it by drawing from a continuously differentiable cumulative probability distribution G_i. The costs for each firm are drawn independently from different distributions. Probability density function g_i is the derivative of G_i.

As perceived by the government, each firm has the highest possible non-zero cost c_i^h and the lowest possible non-zero cost c_i^ℓ. Naturally, $c_i^\ell < c_i < c_i^h$ and $0 < G_i(c_i) < 1$.

As previously mentioned, the government maximizes world welfare, which is essentially maximizing its own value net of the payment: $V(q) - P$. The value of q units of the procured projects is $V(q)$, which is an increasing function ($V' > 0$ and $V'' \leq 0$). For the moment I consider the case where only one project can win the bidding. In Section 8 I discuss the case where more than one project can be selected. P is the payment the government makes for the project. The government seeks to find the best policy to maximize the expected value of $V(q) - P$.

4.2. Virtual Costs and Information Rents

Since firms hold private information about costs, the successful bidder may receive a payoff to that private information. This information rent can be characterized by the inverse hazard ratio, $\frac{G_i(c_i)}{g_i(c_i)}$. Intuitively, the denominator represents the probability that the cost that the government draws is the actual cost of the firm while the numerator represents the probability that the actual cost is lower than the cost perceived by the government. The ratio of the two is the payoff to the private information of the firm since the firm can misrepresent its cost and receive the difference between the virtual cost and the actual cost as profit.

Focusing on the government's desire to minimize payment P we define a function J_i.

(1) $J_i(c_i) = c_i + \frac{G_i(c_i)}{g_i(c_i)}, \quad i = 1{,}2.$[2] (Please see Appendix A.2)

This constitutes a "virtual cost", or the cost the government must pay the firms to prevent them from misrepresenting their true costs. In an optimal auction[3] $J_i(c_i)$ is the expected payment by the government and consists of the actual production cost and the profit from private information. From equation (1) above it is clear that the cost the government is expected to pay increases with the production cost, or $J'_i(c_i) > 0$.

4.3. Discrimination

The government wishes to pay the winner of the auction according to her cost, the concept reminiscent of typical monopoly price discrimination. As a monopsonist, the government wishes to purchase the good at its cost, extracting the entire surplus. Despite purchasing only from one supplier, the government wishes to purchase from the suppliers at discriminatory prices, based on cost. For a monopsonist, the optimal pricing ratio is

(2) $\frac{P_1}{P_2} = \frac{1+1/\eta_2}{1+1/\eta_1}.$

P_1 and P_2 are prices and η_1 and η_2 are price elasticities (in our case we are discussing costs.

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[2] This equation is from Myerson 1981, adjusted for the case where the auctioneer is the buyer.

[3] In an optimal auction the revenue equivalence theorem is satisfied, or the expected revenue is the same between the auction types. Essentially, in an optimal auction the bidders' expected revenue is a function of her signal (Klemperer 1999).

In order to characterize discrimination between near-shore and deep offshore bidders define a function $z(c_i)$. This function allows the government to compare the two bidders and to correct the higher firm's costs in such a way that the lower cost firm's rents are minimized. If $c_1 < c_2$, the deep offshore wind firm (firm 1) can still win the auction if the government discriminates in its favor $z(c_1) < c_2$.

In order to find the optimal discrimination function I look for the case where the government is indifferent between the two bidders.

(3) $J_1(c_1) = J_2(z(c_2))$.

Substituting (2) into (3)

(4) $z(c_1) = c_1 + \frac{G_1(c_1)}{g_1(c_1)} - \frac{G_2(z(c_1))}{g_2(z(c_1))}$.

From this equation the resemblance to a price discriminating monopsonist is clear. Defining optimal discriminatory policy z in terms of probability elasticities $\eta_i(c_i) = c_i \frac{g_i(c_i)}{G_i(c_i)}$ and substituting into (4) I get

(5) $\frac{z(c_1)}{c_1} = \frac{1+1/\eta_1(c_1)}{1+1/\eta_2(z(c_1))}$.

Now look for condition under which it is optimal to discriminate in favor of deep offshore wind Firm 1. The government provides some advantage to Firm 1 when $z(c_1) < c_1$. From formula (5) above this condition is satisfied when $\eta_2\big(z(c_1)\big) < \eta_1(c_1)$.

From equation (3) and (4) it can be seen that condition $z(c_1) < c_1$ is satisfied if

(6) $\frac{d}{dc}\frac{G_2(c_1)}{G_1(c_1)} < 0$ (Appendix A.3).

Condition (6) states that $z(c_1) < c_1$ if and only if $G_2(c_1)/\,G_1(c_1)$ is decreasing in c_1.

It follows that the government should always discriminate, unless the two distributions are related in a proportional way.

4.4. Bidding Equilibrium

As previously discussed, I wish to find a discrimination rule δ which will induce the optimal behavior. In order to do this, I find the respective bids of the firms for the optimal case.

Define the firm equilibrium bidding strategies as B_1 andB_2, which are strictly increasing functions[4]. In a Nash Equilibrium, each firm will bid b_i, provided that the other firm will also bid according to strategy.

(7) $B_1(c_1) = b_1$ and $B_2(c_2) = b_2$.

4.4.1. Probability of winning

Define function $H_i(c_i)$ as a probability that the government accepts the bid from the respective firm. The probability distribution that Firm 1 and 2 win, respectively, is

(8) $H_1(c_1^*) = 1 - G_2(z(c_1^*))$ and$H_2(c_2^*) = 1 - G_1(z^{-1}(c_2^*))$.

Intuitively, the probability of Firm 1's bid being accepted is the probability that the other firm has a cost higher than $z(c_1)$.

Rewrite the probabilities in terms of bids for future purposes.

(9) $H_1(b_1) = 1 - G_2(B_2^{-1}(\delta(b_1))$ and $H_2(b_1) = 1 - G_1\left(B_2^{-1}\,(\delta^{-1}(b_1)\right)$.
(Please see Appendix A.5)

I am attempting to find the discrimination rule δ to induce the firms to bid in such a way that leaves the winner with expected profit of zero. Expected profit is zero when the probability of winning is zero. In order to define a bidding equilibrium, define c_i^m as the highest cost a firm can have and still have a positive probability of winning the auction. As the cost approaches c_i^m the probability of accepted bid approaches zero, so $H_1(c_1^m) = H_2(c_2^m) = 0$. It follows that $c_1^m = \min\{c_1^h, z^{-1}(c_2^h)\}$ and $c_2^m = \min\{c_2^h, z(c_1^h)\}$. Intuitively, the highest cost a firm can have and still have a chance of winning is the lower between own highest possible cost (which could be infinite) and discrimination-adjusted highest cost of the other firm. In equilibrium,

(10) $z(c_1^m) = c_2^m$.

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[4] Please see Maskin and Riley 1996

4.4.2. Expected Profit

Profit of the firm that has won the auction is

(11) $\pi = B_i(c_i^*) - c_i^*.$

The expected profit is

(12) $E(\pi) = \pi H_i(b_i).$

4.4.3. Equilibrium Bid

In summary, to find the equilibrium bid take a derivative of expected profit with respect to cost

(13) $\frac{d}{dc}\pi = B'_i(c_i^*) - 1 = 0.$

Then integrate $B'_i(c_i^*)$ from c_i^* to c_i^m to find the equilibrium bid that results in the expected profit of zero for the winner.

The resulting Nash equilibrium bid is

(14) $B_i(c_i^*) = -H_i^{-1}(c_i^*)\int_{c_i^*}^{c_i^m} c\, H_i'(c_i)dc.$

(Please see Appendix A.6)

Once again we see the resemblance to a discriminating monopolist since the bid is the area under the “marginal revenue” curve discussed in Appendix A.2 divided by the probability of winning the bid.

4.4.4. Bid Discrimination Rule δ

For previous purposes, we defined cost discrimination function in terms of the bid

(15) $$z(c_1) = B_2^{-1}\left(\delta\left(B_i(\mathrm{c}_\mathrm{i}^*)\right)\right).$$

(Please see Appendix a.5.1-a.5.4)

Taking the inverse of both sides of equation (15) I find the bid discrimination function

(16) $$B_2(z(c_1)) = \delta\left(B_1(\mathrm{c}_1^*)\right).$$

Plugging in the equilibrium bids into (16)

(17) $$\delta\left(\int_{c_1^*}^{c_1^m} -c_1 \frac{H'_1(c_1)}{H_1(c_1)} dc\right) = \int_{c_1^*}^{c_1^m} -z(c_1) \frac{H'_2(c_1)}{H_2(c_1)} dc.$$

Equation (17) is the key of implementing the efficient outcome discussed in the previous sections. Using the above function, the government finds the discrimination rule δ that leads to an efficient allocation.

Upon reflection, it becomes clear from equation (17) that efficient outcome is not possible without discrimination in our case where we can distinguish between the firm times. If the government adopts a policy of no discrimination, $\delta\left(B_1(\mathrm{c}_1^*)\right) = B_1(\mathrm{c}_1^*)$, then the condition above implies that $z(c_1) < c_1$. Previously we discussed that for the efficient outcome we require $z(c_1) = c_1$, where the government pays the firms according to their costs. Conversely, if we impose the efficiency condition $z(c_1) = c_1$, clearly the government will discriminate between bids, or $\delta\left(B_1(\mathrm{c}_1^*)\right) < B_1(\mathrm{c}_1^*)$.

5. Welfare Analysis

Thus far I have assumed that the government can collect funds for the transfer without distortions, thus minimizing its budget by minimizing the profit of firms. However, in practice the government must raise its subsidy through distortive taxes. In this case, I will show that depending on the size of the distortion, the government may place less emphasis on profit of the firms and focus on minimizing costs.

5.1. Government Cost of Public Funds

When raising revenues to finance government spending society incurs a deadweight loss that we will consider in the analysis of welfare. If the market results in an efficient allocation of resources, taxes can distort this efficiency. Taxes alter household consumption decisions, investment and labor supply.

Marginal Cost of Public Funds (MCPF) is a measure for the loss of efficiency. So for every dollar spent on public expenditures results in a dead weight loss of some fraction of that amount. There are various ways that MCPF can be calculated. While the exact number for MCPF is not important for our purposes, it is important to point out that generally the loss is in the 30-45% range for many developed countries. Such a substantial dead weight loss alters our results, as will be discussed below.

5.2. The Model

5.2.1. Reservation Price

It can be shown that the government will purchase some quantity of projects (in our case only one) and the marginal value $V(q)$ should equal the minimum of the two marginal payments.

(18) $V(q) = minJ_i(c_i)$.

In essence, this is the reservation price of the government, because if equation (18) does not hold, the government would reject both bids.

5.2.2. Costless Transfer

In the model presented in the previous sections, the government wishes to minimize the profit to the offshore wind developer.

Welfare objective function consists of summation of consumer surplus (since the government will sell electricity to the consumers who will ultimately bear the burden of the price preference) and producer surplus.

Since consumer surplus is the value of the development to the government minus the payment.

(19) $V(q) - E(J_i(c_i)).$

Producer surplus is the payment from the government minus the cost.

(20) $E(J_i(c_i)) - E(c_i).$

If $J_i(c_i)$ is a costless transfer between producers and consumers, the objective welfare function constitutes

(21) $V(q) - E(c).$

In this case, the government focuses on simply minimizing cost and does not care that the producers receive an information rent.

5.2.3. MCPF Welfare

I now consider a case where the proposed subsidy is not costless and the government must trade-off budgetary efficiency of obtaining the cheapest development and that of avoiding tax distortion.

Define λ as the MCPF where λ < 1.

The producer surplus remains the same and the new consumer surplus is

(22) $$V(q)-E(J_i(c_i))-\lambda \mathrm{E}(J_i(c_i)).$$

The new welfare objective function is then

(23) $$V(q)-\lambda E(J_i(c_i))-E(c_i).$$

Substituting for $J_i(c_i)$ from equation (1) I get

(24) $$V(q)-(1+\lambda)\mathrm{E}(c_i)-\lambda \mathrm{E}\left(\frac{G_i(c_i)}{g_i(c_i)}\right).$$

In the special case where $\lambda=0$ provides us with a welfare function discussed in the previous subsection where the government can costly collect funds and cares only about minimizing costs. The case where $\lambda=1$ is not particularly informative, other than to say that society pays double the cost of the development and wishes to minimize the profit of the developers. In intermediate cases, we see that the government will wish to minimize both cost and the profit of the developers ($\frac{G_i(c_i)}{g_i(c_i)}$) since additional profit results in additional dead weight loss.

Rewriting (24)

(25) $$V(q)-(1+\lambda)\left(\mathrm{E}(c_i)+\left(1-\frac{1}{1+\lambda}\right)\mathrm{E}\left(\frac{G_i(c_i)}{g_i(c_i)}\right)\right).$$

So the new payment function J is

(26) $$J_i(c_i)=c_i+\left(1-\frac{1}{1+\lambda}\right)\frac{G_i(c_i)}{g_i(c_i)}.$$

Substituting in function z and equating the two payments we see that the new cost discrimination function is

(27) $$z(c_1)=c_1+\left(1-\frac{1}{1+\lambda}\right)\left(\frac{G_1(c_1)}{g_1(c_1)}-\frac{G_2(z(c_1))}{g_2(z(c_1))}\right).$$

6. Numerical Example

6.1. The model

Let us consider a numeric example. I assume that $G_1(c_1)$ and $G_2(z(c_1))$ are distributed uniformly.

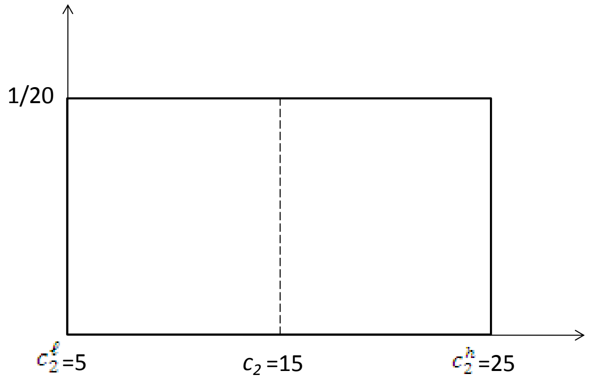
6.1.1. Cost Distributions

Distribution of Deep Offshore Firm 1

$$G_1(c_1) = [13 \quad 31]$$

$$G_1(c_1) = \begin{cases} 0, & c \leq 13 \\ \dfrac{c-13}{31-13}, & 13 < c < 31 \\ 1, & c \geq 31 \end{cases}$$

Distribution of Near-shore Firm 2



$$G_2(z(c_1)) = [5 \quad 25]$$

$$G_2(c_2) = \begin{cases} 0, & c \leq 5 \\ \dfrac{c-5}{25-5}, & 5 < c < 25 \\ 1, & c \geq 25 \end{cases}$$

6.1.2. Virtual Costs and Information Rents

Virtual Cost Function J

From equation (1), I calculate function J for the uniform case.

$$J_1(c_1) = c_1 + \frac{G_1(c_1)}{g_1(c_1)} = c_1 + \frac{\frac{c_1-13}{31-13}}{\frac{1}{31-13}} = 2c_1 - 13. \tag{28}$$

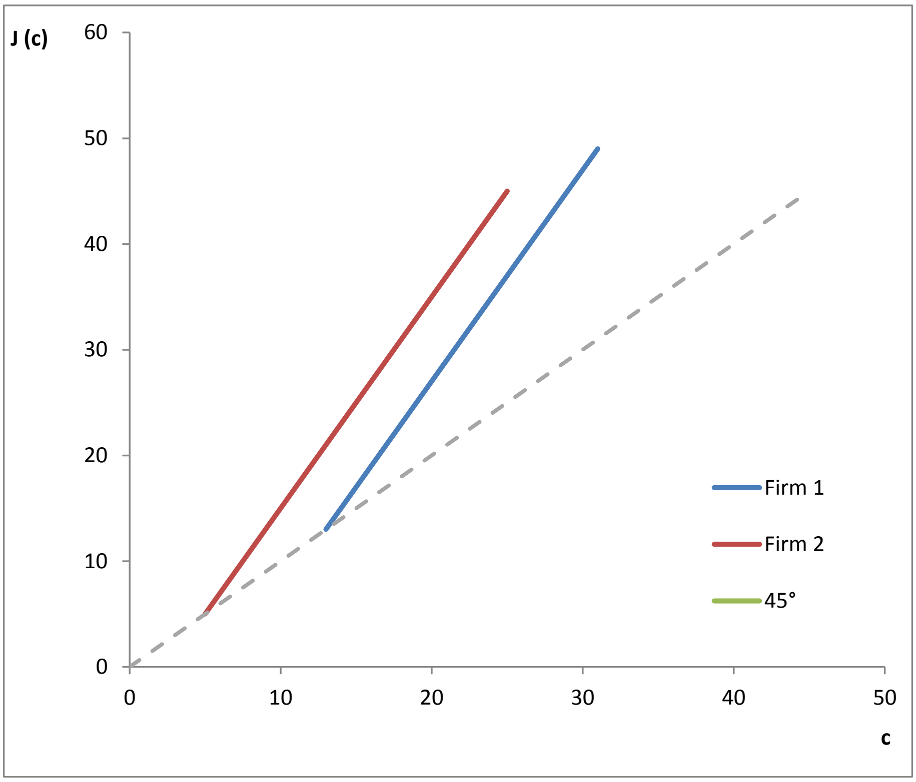
$$J_2(c_2) = c_2 + \frac{G_2(c_2)}{g_2(c_2)} = c_2 + \frac{\frac{c_2-5}{25-5}}{\frac{1}{25-5}} = 2c_2 - 5. \tag{29}$$

In my example, the payments are

$$J_1(22) = 2 * 22 - 13 = 31. \tag{30}$$

$$J_1(15) = 2 * 15 - 5 = 25. \tag{31}$$

These are the payments the government has for consideration. This is the amount the government would need to pay to induce the firms not to misrepresent their costs. Otherwise, firm 1 and firm 2 could report their costs as 31 and 25, respectively.



Information Rent G/g

The information rents to private knowledge about own costs are represented by $\frac{G_i(c_i)}{g_i(c_i)}$.

(32) $$\frac{G_1(c_1)}{g_1(c_1)} = \frac{\frac{22-13}{31-13}}{\frac{1}{31-13}} = 9.$$

(33) $$\frac{G_2(c_2)}{g_2(c_2)} = \frac{\frac{15-5}{25-5}}{\frac{1}{25-5}} = 10.$$

6.1.3. Discrimination

I can show that equation (3) can be rewritten for a uniform distribution as

(34) $z(c) = c - \left(\frac{c_1^\ell - c_2^\ell}{2}\right)$. (Please see Appendix A.4)

So the discrimination function for my example is

(35) $$z(c_1) = c_1 - \left(\frac{13-5}{2}\right) = c_1 - 4.$$

In the uniform case, we see that the government should discriminate. The only case where the government should not discriminate would be if the lowest costs c_i^ℓ in the two distributions were the same.

6.2. Equilibrium Bids

In this section I will find equilibrium bids and the bid discrimination function for my numerical example.

6.2.1. Probability of Winning

I first derive the functions of $H_1(\mathrm{c}_1^*)$ and $H_2(\mathrm{c}_2^*)$. In section 1.4.3 I found function $z(\mathrm{c}_1^*)$

(36) $$z(\mathrm{c}_1^*) = \mathrm{c}_2^* = \mathrm{c}_1^* - 4.$$

Taking the inverse of this function I find

(37) $$\mathrm{z}^{-1}(\mathrm{c}_2^*) = \mathrm{c}_1^* = \mathrm{c}_2^* + 4.$$

Plugging into the probability function, I find the uniform version of the function.

(38) $$H_1(\mathrm{c}_1^*) = 1 - G_2\big(z(\mathrm{c}_1^*)\big) = 1 - \left(\frac{\mathrm{c}_2^*-5}{25-5}\right) = 1 - \left(\frac{\mathrm{c}_1^*-4-5}{25-5}\right) = \frac{29-\mathrm{c}_1^*}{20}.$$

(39) $$H_2(\mathrm{c}_2^*) = 1 - G_1(\mathrm{z}^{-1}(\mathrm{c}_2^*)) = 1 - \left(\frac{\mathrm{c}_1^*-13}{31-13}\right) = 1 - \left(\frac{\mathrm{c}_2^*+4-13}{31-13}\right) = \frac{27-\mathrm{c}_2^*}{18}.$$

Plugging in the values for c_1^* and c_2^* I find probabilities of having the bid accepted to be[5]

(40) $$H_1(\mathrm{c}_1^*) = \frac{7}{20}.$$

(41) $$H_2(\mathrm{c}_2^*) = \frac{2}{3}.$$

For future purposes, I also calculate probability derivatives:

(42) $$H_1'(\mathrm{c}_1^*) = -\frac{1}{20}.$$

(43) $$H'_2(\mathrm{c}_2^*) = -\frac{1}{18}.$$

---

[5] Please note that the probabilities of being accepted do not add up to unity because we did not pick the same values for c_i^h. It is, however, very close.
$$\frac{21}{60} + \frac{40}{60} \approx 1$$

6.2.2. Zero Probability of Winning

I now find the costs $c_1^m$and c_2^mat which the probability of winning is zero

(44) $$H_1(c_1^m) = H_2(c_2^m) = 0.$$

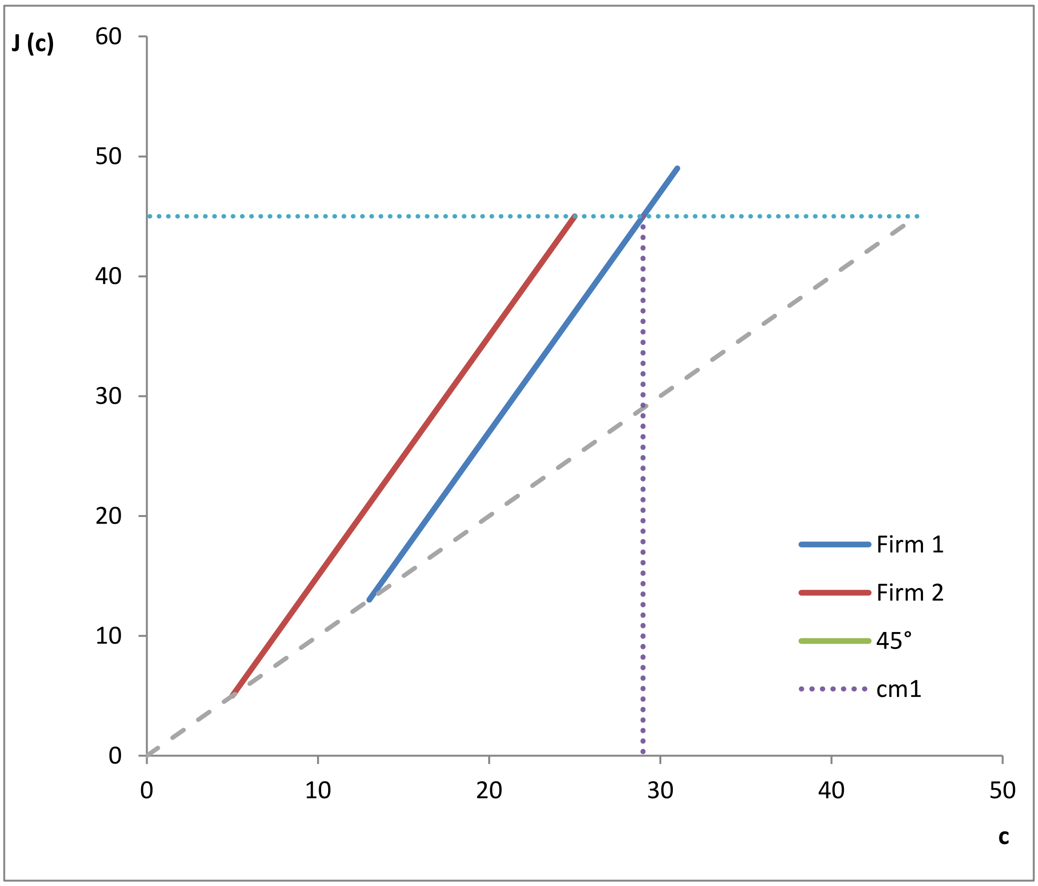
(45) $$c_1^m = \min\{c_1^h, z^{-1}(c_2^h)\} = \min\{31, 29\} = 29\ .$$

(46) $$c_2^m = \min\{c_2^h, z(c_1^h)\} = \min\{25, 27\} = 25.$$

So in equilibrium,

(47) $$z(29) = 29 - 4 = 25 = c_2^m.$$

Plugging in the value c_1^m into the probability formula, I find that the probability of having your bid accepted is zero. Although the value c_2^m does not lead to probability function to be zero, clearly the government will never accept the bid that lists a cost higher than the highest possible cost of the firm. So any cost higher than 25 will lead to zero probability of being accepted.



From the graphing of the J function above we can see that the government will not accept any bids that are higher than the J value corresponding to cm1.

6.2.3. Equilibrium Bid

Firm 1 Bid

First define the bid functions for uniform distribution.

(48) $$B_1(\mathrm{c}_1^*) = -\mathrm{H}_1^{-1}(\mathrm{c}_1^*)\int_{c_1^*}^{c_1^m} \mathrm{c}\, H_1'(c_1)dc = -\frac{1}{\frac{29-\mathrm{c}_1^*}{20}}\int_{c_1^*}^{c_1^m} c\left(-\frac{1}{20}\right)dc = \frac{1}{29-\mathrm{c}_1^*}\left(\frac{(c_1^m)^2-(c_1^*)^2}{2}\right).$$

(49) $$B_1(\mathrm{c}_1^*) = \frac{1}{7}\left[\frac{c^2}{2}\right]_{22}^{29} = \frac{51}{2} = 25.5.$$

Firm 2 Bid

(50) $$B_2(\mathrm{c}_2^*) = -\mathrm{H}_2^{-1}(\mathrm{c}_1^*)\int_{c_1^*}^{c_1^m} z(c)H_2'(c)dc = -\frac{1}{\frac{31-\mathrm{c}_1^*}{18}}\int_{c_1^*}^{c_1^m}(c-4)\left(-\frac{1}{18}\right)dc = \frac{1}{31-\mathrm{c}_1^*}\left[\frac{c^2}{2}-4c\right]_{c_1^*}^{c_1^m}.$$

(51) $$B_2(\mathrm{c}_2^*) = \frac{1}{9}\left[\frac{c^2}{2}-4c\right]_{22}^{29} = \frac{301}{18} = 16.7\overline{2}.$$

6.2.4. Bid Discrimination Rule δ

Now that I found the equilibrium bids, I can find the δ discrimination function that will result in the optimal outcome.

(52) $B_2(z(c_1)) = \delta\big(B_1(\mathrm{c}_1^*)\big).$

Plugging in values of equilibrium bid I get

(53) $\delta(25.5) = 16.7\overline{2}.$

A discrimination rule that can be adopted to implement the auction is

(54) $\delta(b) = .656b.$

The reason why the discrimination rule appears to be so high is due to a high cost differential, where Firm 1 is about 60% more expensive than Firm 2.

6.2.5. Profit

The profit of the firm that wins the auction is simply

(55) $\pi = B_i(\mathrm{c}_\mathrm{i}^*) - \mathrm{c}_\mathrm{i}^*.$

Profits of Firm 1 and 2, if they win are

(56) $\pi_1 = 25.5 - 22 = 3.5.$

(57) $\pi_2 = 16.7\overline{2} - 15 = 1.7\overline{2}.$

Comparing this to information rents found in Section 1.4.2 of 9 for Firm 1 and 10 for Firm 2, clearly the discrimination policy has achieved its purpose.

Expected profits are 1.225 and 1.148 for Firm 1 and Firm 2, respectively.

6.3. Welfare Analysis

6.3.1. Reservation Price

I find the reservation price $V(1)$

Costless Transfer Reservation Price

(58) $V(q) = minJ_i(c_i) = \min(25, 31) = 25.$

MCPF Reservation Price

From equation (1), I calculate function J for the uniform case. Please note that in this case the function J represents not the payment made to the firms but the total payment by the government. The uniform cases of the new J functions are as follows.

(59) $J_1(c_1) = c_1 + \left(1 - \frac{1}{1+\lambda}\right)(c_1 - 13) = c_1 * 2.4 - 18.2 = 34.6.$

(60) $J_2(c_2) = c_2 + \left(1 - \frac{1}{1+\lambda}\right)(c_2 - 5) = c_2 * 2.4 - 7 = 29.$

So the reservation price in the MCPF case is as follows.

(61) $V(q) = minJ_i(c_i) = \min(29, 34.6) = 29.$

6.3.2. Costless Transfer Numerical Example

For the case of the costless transfer, I find expected welfare by substituting in the probabilities of winning the auction.

(62) $V(q) - E(c) = 25 - \left(\frac{7}{20} * 22 + \frac{2}{3} * 15\right) = \frac{73}{10} = 7.3.$

I can compare this outcome to the case where the firms collect the full information rent and bid accordingly. If there was no discrimination and the companies just collected their payment $J_i(c_i)$, then welfare would be zero since cheaper firm would win the auction and collect its respective payment (the more expensive firm's probability of winning is zero. Its bid is rejected because it is higher than the reservation price).

6.3.3. MCPF Welfare

Let the government cost of public funds $\lambda = .40 = \frac{2}{5}$.

I also find the uniform version of the cost discrimination function z

(63) $$z(c_1) = c_1 + \left(1 - \frac{1}{1+\lambda}\right)\left(\frac{G_1(c_1)}{g_1(c_1)} - \frac{G_2(z(c_1))}{g_2(z(c_1))}\right) = c_1 - \frac{2}{7}\left(\frac{13-5}{2}\right) = c_1 - \frac{8}{7}.$$

Comparing the new cost discrimination function to the previous one, it is clear that the "subsidy" to the deep offshore wind firm has decreased.

We also define the new probabilities of winning based on the new cost discrimination function.

(64) $$H_1(\mathrm{c}_1^*) = 1 - G_2\big(z(\mathrm{c}_1^*)\big) = 1 - \left(\frac{\mathrm{c}_2^* - 5}{25-5}\right) = 1 - \left(\frac{\mathrm{c}_1^* - \frac{8}{7} - 5}{25-5}\right) = \frac{26 - \mathrm{c}_1^*}{20} \approx .21.$$

(65) $$H_2(\mathrm{c}_2^*) = 1 - G_1(\mathrm{z}^{-1}(\mathrm{c}_2^*)) = 1 - \left(\frac{\mathrm{c}_1^* - 13}{31-13}\right) = 1 - \left(\frac{\mathrm{c}_2^* + 1 - 13}{31-13}\right) = \frac{30 - \mathrm{c}_2^*}{18} \approx .79.$$

(66) $$V(q) - (1+\lambda)\mathrm{E}(c_i) - \lambda\mathrm{E}\left(\frac{G_i(c_i)}{g_i(c_i)}\right) = 29 - 1.4(.21 * 22 + .79 * 15) - .4(.21 * 7.58 + .79 * 2.92 \approx 4.38.$$

As can be seen from the example, the welfare decreases if we include the marginal cost of public funds. Intuitively, the government is becoming more concerned about minimizing the budget rather than extracting the profit from the firms. Of course, a lower profit also indicates a lower deadweight loss. So the government optimizes between efficiency and budget minimization.

7. Auctioning Renewable Energy in Practice

In this section I discuss the realities of auctioning renewable energy. As previously discussed, there are several downsides of using an auction method over other available policy options. First I discuss the practical advantages and shortfalls of applying the auction method. Then I discuss other practical nuances that must be considered. In the final section I propose future extensions of the model to address these cases.

7.1. Success of Renewable Energy Promotion Schemes

The increasing relevance of offshore wind as a solution to climate change problem as well as an important economic stimulant necessitates an overview of the deployment mechanisms which are used to promote market penetration. There are several policy support mechanisms which have been utilized to hasten the advent of renewable energy, including competitive tendering, feed-in tariffs and quotas.

While several popular policy mechanisms have been found effective in deploying on-shore wind, the offshore developers respond to a more traditional approach to deployment—tendering, due to the large scale and significant geospatial, technical and infrastructural requirements of the projects.

Compared to the feed-in tariff systems which typically bring a lot of transparency and equality between projects (essentially if the developer fulfills the economic and technical conditions, they can proceed with development of the project), tendering mechanisms typically require a lot more interaction with the authorities. This is ideal for offshore wind since there are relatively few feasible sites for development, and therefore relatively few tender opportunities. Furthermore, it would be difficult to streamline offshore wind developments using a "one price" feed-in tariff mechanism due to significant differences in technologies between near-shore and deep-offshore wind. Actually, it is the discernable differences, or "types" that allow for implementation of the auction mechanism from previous sections.

Due to the nascence of the technology, there are relatively few companies in the world with sufficient scale and capabilities to develop large offshore wind projects. In this case, the tendering mechanism provides a customized relationship between the potential developers and the authorities. This allows for a more effective "fine-tuning" of the agreements and support from the government.

While there are clear advantages to using an auction method over feed-in tariffs, particularly in the first stages of deployment, research shows that average on-shore wind prices were lower in countries that used feed-in tariffs. Butler and Neuhoff (2008) confirmed this when they compared the prices from Germany's StreG feed-in scheme and U.K.'s Non-Fossil Fuel Obligation (NFFO, quotas achieved through competitive tenders) and U.K.'s subsequent Renewable Obligation Certificates (ROCs, auctioned certificates). The authors point out that while the U.K. NFFO system drove down the prices of wind energy significantly (from 12.34p.kWh in 1990 to 3.99p/kWh in 1998), not many projects came to fruition. One of the reasons for this is the “winner’s curse” where the bidders agreed on a price too low to be profitable. This impacted the ability of firms to finance the projects.

Wind projects received a subsidy under the NFFO. However, this subsidy did not yield the result we developed in our model of reducing profits. On the contrary, on-shore wind developers continued to reduce costs, expecting the sunsetting clause of the subsidies. Subsidies were extended, however, providing developers with unexpected profits! Clearly, the auction mechanism was designed with emphasis on high deployment rather than profit minimization. Despite the efforts, feed-in tariffs in Germany resulted in a higher absolute capacity and capacity relative to goals than the U.K. system.

Other institutional factors play a role in determining success of the policy scheme. For example, the fact that Germany’s developers had access to cheap financing and were not penalized for intermittency on the balancing markets played a large role on successful deployment.

Furthermore, under the competitive tender scheme, the competition seemed to be for the best sites, resulting in difficulties with planning consent and land rights for those particular sites. The feed-in tariffs in Germany, however, were adjusted for wind speed, allowing developers more flexibility on the location. This is not, however, an intrinsic flaw in the auction scheme. An auction can be designed to provide flexibility on location within certain constraints (appropriate sea-beds are not available everywhere). This approach was successful in the Netherlands.

Under the auction schemes competition is severe during the bidding process, resulting in lower rents to developers. With feed-in tariffs there is no price competition since the feed-in tariff is the same for everyone. However, there is competition for quality sites.

Finally, in addition to competition during the tendering stage, the market conditions in the upstream manufacturing of turbines plays a large role in the success of the tendering mechanism. For example, lower prices in Germany may be attributable to cheaper procurement (stronger competition between suppliers) rather than competition at the development stage.

To conclude, there are many factors that determine the success of promotion schemes in terms of producing lower prices and higher deployment. However, if properly designed, auction schemes can successfully spur competition and result in low prices. Furthermore, tenders will remain relevant even when the policy shifts to feed-in tariffs since most feed-in tariffs are designed based on tendering experiences. In fact, it is possible to implement both policies at the same time, where the government can first hold an auction and set a feed-in rate based on the bids.

7.2. Offshore Wind Auctions in Practice

The two popular approaches for tendering for offshore wind are the model used in the Netherlands and the Danish model. The outcomes of the two approaches provide a different mechanism for locating the sites for offshore wind developments. The tendering schemes in the UK and France mirror the two approaches.

Netherlands

Under the Dutch model, the tariffs are not announced in advance and are determined through the auction mechanism. The distinction is that a certain amount of capacity is being put up for auction and developers are responsible for selecting the ideal site and technology, while competing on the final price. This way, the developers can apply for one or several sites while taking into account the behavior of competitors.

Denmark

The Danish model leaves much of the power of site selection and desired technological characteristics to the tendering authority. The authority defines the location, capacity and technical specifications while various companies offer bids for those particular specifications.

France

Although France switched away from tendering through the Eole 2005 program to feed-in tariffs, much of the tendering principles remain in the implementation of the feed-in tariff policy. The tendering scheme was launched in 1996 with a goal to reach 250-500MW of capacity by 2005. This scheme brought about 55 projects totaling in 361MW in capacity. The key features of the French approach is that the selection of projects was based not only on cost-efficiency of the installations but long term benefits of the technology chosen, economic benefits, reliability and environmental impacts. Also, diversity in location and technology was one of the criteria emphasized in determining the winners.

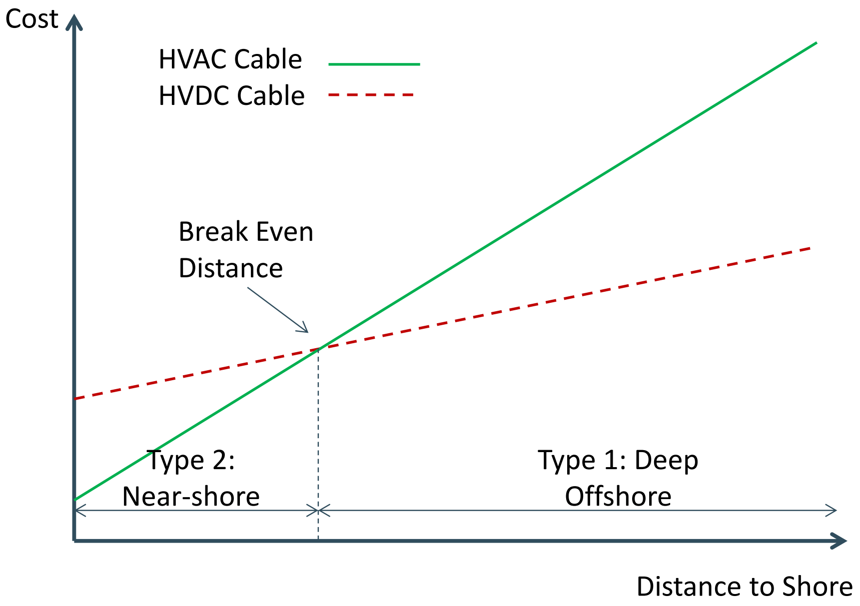
The United Kingdom

The United Kingdom is also considering implementing feed-in tariffs instead of the renewable obligations scheme (based on competitive tendering). For offshore wind, however, the tendering mechanism will continue to be implemented due to the scale and expense of the projects and the need to coordinate transmission developments. The UK essentially set up quotas with a requirement of producing 10% of electricity through renewable sources. Quotas would be detailed by technology. The tender also specifies the capacity. The government evaluated the bids and defined a reservation price, or "strike price." All bids below that price were accepted and the government ensured compliance with the contract through penalties for defaults.

7.3. Transmission Cost as a Competitive Vehicle

One of the reasons why competitive tender process might not have resulted in cheaper prices and higher deployment of on-shore wind may be due to the fact that the auctioneers could not distinguish between efficient and inefficient producers. The natural advantage of offshore wind is that we can distinguish between more cost-effective near-shore wind and more expensive deep offshore wind relying on the measurement of distance to shore. The cost of additional transmission and transmission infrastructure increases with this distance. There may be other cost differences due to technology differences (longer stalls, larger turbines, more expensive sea-bed foundation, more expensive transportation, operation and maintenance). The wind speeds, however, are greater offshore than near-shore, and with the correct technology offshore wind can be competitive with near shore projects. Thus, it is useful to focus on transmission costs as both a discriminant between firm types and a subject of the subsidy.

From the technical perspective, there is a threshold distance to shore that can be defined at which transmission becomes a lot more expensive. At a certain distance more expensive HVDC LCC (High Voltage DC Cable with Line Commutated Converters) or HVDC VSC (with Voltage Source Converters) are needed. With these cables both offshore and onshore substations are required as well as significant additional investment. The government can analyze these cost differences and determine a distance to the shore at which developments become a Type 1 Firm. To illustrate this distinction please refer to the graph below.



According to some calculations, this threshold is around 50km for HVDC LCC and HVAC Cable intersection and approximately 85km for HVDC VSC and HVAC intersection.

7.4. Bidding in Practice

In practice, the bid price is determined through a complex accounting formula where transmission costs impact several different components of this formula. The "profit" is expressed as a "markup" on the capital investment rather than an information rent. And during the tendering process the bidders compete based on this markup (equity return).

There are four essential components of the bid: 1) Capital costs and Operation and Maintenance, 2) Depreciation 3) Taxes and 4) Return on Investment. Expected predicted capacity is also a key determinant of the bid price since it allows the companies and their investors to recover the costs and collect a reasonable return. The markup reflects the level of risk incurred by the investors in the form of Return on Investment.

Revenue requirement can be calculated using the following formula:

$$Revenue\ Requirement = O + T + d + r(I - D)$$

O — Operating Expenses (O&M)

T — Taxes (Corporate taxes and other)

d — Annual Depreciation Expense

I — Gross Investment

D — Accumulated Depreciation

R — Rate of Return

Operating Expenses, Taxes and annual depreciation constitute the expenses that the offshore wind developer must recover while collecting interest on the investment net of depreciation.

$$Profit\ (Gross\ of\ Corporate\ Tax) = Revenue\ Requirement - O - T - d - interest$$

Profit of the offshore wind developer essentially depends on the remaining Rate of Return collected on the Rate Base, or the investment, after servicing the debt.

Transmission makes up a significant component of price. This asset touches on every component of the rate. Deep offshore wind may incur larger O&M expenses since at greater distances transmission is more likely to be damaged during storms. More significant maintenance requires the construction of platforms and the use of submarine cable laying ships. Taxes are paid on the equipment and purchase of the transmission assets. Transmission assets may depreciate faster at greater distances, increasing depreciation expense. The value of the asset itself is costly relative to the total investment in the project and therefore constitutes a significant portion of the rate base.

Finally, transmission assets are directly and indirectly related to the generation capacity of the offshore wind assets. Transmission is an essential component of producing and transporting electricity to the shore and sufficient transmission capacity is required for full utilization of the resource. On shore there are also transmission capacity constraints due to congestion on the lines which can impact the amount of electricity that is actually sold. Furthermore, transmission investment increases with distance to the shore, but so do the capacity factors and quantities produced.

Profit is expressed through the rate of return on investment, which reflects the risks faced by investors. Typically the return to debt can be eliminated if the government "guarantees" the loans. Similar guarantees are difficult with equity. This is why in reality bidders bid multiples of their costs rather than arbitrary functions of their estimates.

7.5. Other Practical Considerations

There are other realistic divergences from our model that should be considered.

Realistically, there can be more than one bidder of each Type. Additional competitors would change probabilities of winning the auction.

The government may wish to accept more than one project at a time. This may change the effectiveness of the subsidy.

As previously discussed, there may be multiple rounds of competitive tenders that the government wishes to run (In the U.K, for example, there are two rounds of bidding that are currently planned). The challenges of multiple rounds and formation of consortiums have been discussed in previous sections.

Some governments currently provide transmission subsidies that are proportional to distance to shore rather than an optimal estimate, as presented in our model. Such a subsidy may not result in a desired outcome.

Finally, the government may have a technology preference in their desire to promote innovation and deployment of deep offshore technology. Therefore, it may attach additional value to this particular technology, which will impact the auction mechanism design.

These extensions will briefly be considered in the next chapter.

8. Extensions for Further Study

In this chapter I propose topics for future study, relying on practical considerations that were not included in the core model due to scope.

8.1. Multiple Competing Firms

Realistically, there may be more than one firm of each type competing in the auction for an offshore wind site. McAfee and McMillan (1989) consider this for a number of firms n_1 and n_2 for type 1 and type 2, respectively.

The authors show that the optimal cost correction function z is independent of number of firms. However, probabilities of winning and bidding strategies are derived based on an adjusted formula.

Thus, the probability of an accepted bid for multiple firms of the two types is as follows.

$$H_1(c_1^*) = \left[1 - G_2\left(z(c_1^*)\right)\right]^{n_2}[1 - G_1(c_1^*)]^{n_1 - 1}. \tag{67}$$

$$H_2(c_2^*) = [1 - G_1(z^{-1}(c_2^*))]^{n_1}[1 - G_2(c_2^*)]^{n_2 - 1}. \tag{68}$$

So probability of winning is dependent not only on probability that own cost is less than that of competitors of the other type, but also less than the other own type competitors.

Using these probabilities it is possible to derive the new bid discrimination function.

8.2. Proportional Subsidies

From the previous discussion we saw that countries, in an attempt to promote innovation in offshore wind technology provide proportional transmission subsidies (e.g. EUR/kWh for every additional kilometer offshore). Depending on how these subsidies were calculated, they may or may not lead to efficient outcome.

From the discrimination condition below, the optimal discrimination policy, or “subsidy”, is a function of cost distribution differences.

$$z(c_1) = c_1 + \frac{G_1(c_1)}{g_1(c_1)} - \frac{G_2(z(c_1))}{g_2(z(c_1))}. \tag{69}$$

As previously discussed, the discrimination function considers the information rents firms may receive due to information asymmetry between the principle (the government) and the agent (the bidders).

In this case, the government discriminates based on costs directly (not through bids) since a direct subsidy for transmission assets is considered. Previously we saw that if there is discrimination in costs, the policy of discriminating between bids is not optimal and vice versa.

The government, when providing the transmission subsidy, provides a certain amount of subsidy per additional kilometer of transmission. So the “subsidy” takes on the following form

$$z(c) = (1-\alpha)c. \tag{70}$$

This is suboptimal, since the cost correction function is proportional to cost rather than a function of cost and elasticity differences.

In order to be efficient α must take on a very particular value that represents the distributional differences in cost we discussed above.

$$(1-\alpha)c = c + \frac{G_1(c_1)}{g_1(c_1)} - \frac{G_2(z(c_2))}{g_2(z(c_2))}. \tag{71}$$

In the uniform case:

$$(1-\alpha)c = c + \frac{c_2^l - c_1^l}{2}. \tag{72}$$

$$\alpha = \frac{c_1^l - c_2^l}{2}. \tag{73}$$

Other possible values for α will lead to a sub-optimal outcome.

This subsidy is more costly to consumers and leads to a lesser welfare than the optimal outcome.

Despite this conclusion, the government often faces a more complex case of multiple bidders and multiple sites and for administrative reasons and for reasons of fairness and transparency must have a simple discrimination rule. Whenever possible, however, the government should opt for the efficient subsidy discussed previously.

8.1. Technology Preference

Just because proportional subsidies do not provide an optimal outcome (except in a certain case), it does not mean that the government cannot continue to support a particular technology for its own sake. While policy-makers do not wish to admit it, the country’s renewables portfolio is essentially a testament to certain technology preferences. Examples of this are goals such as “20% Wind by 2020” in the U.S. and “50 Wind by 2050” in Germany. To achieve such goals for a particular technology, the government may wish to discriminate based on objectives other than cost.

To incorporate this extension into our model I add an additional term β to represent the value the government attaches to achievement of goals.

According to McAfee and McMillan (1985), the new cost discrimination function satisfies

$$(74) \qquad z(c_1) = c_1 + \frac{G_1(c_1)}{g_1(c_1)} - \frac{G_2(z(c_1))}{g_2(z(c_1))} + \beta.$$

Designing the bid discrimination mechanism using this function the government can achieve both its cost reduction objectives and social objectives.

8.2. Multiple Accepted Projects

The tendering process requires a lot of administrative effort on the part of the government. That is why the government may wish to accept multiple projects at each bidding phase. McAfee and McMillan (1989) prove that the government may purchase multiple quantities of projects.

$$(75) \qquad V'(q) = min J_i(c_i).$$

Define the firm’s expected profit for a price p_i and reported cost $\check{c}_i$.

$$(76) \qquad \pi_i = E_{-i}(p_i(\check{c}_i, c_{-i}).$$

It can be shown that the number of projects q that the government purchases is as follows.

$$(77) \qquad q_i = \begin{cases} V'^{-1}(J_i(c_i)), & min J_i(c_i) \\ 0, & otherwise. \end{cases}$$

8.3. Multiplicative Strategies

In order to stay close to realistic bidding behavior of firms, it may be useful to consider using “multiplicative strategies” in the future, where the firms bid multiples of their cost. Intuitively, this constitutes a “markup” or “Return on Investment” discussed in the previous chapter.

Generally, it is difficult to find equilibrium in a sealed bid auction, particularly when considering multiplicative strategies. Rothkope, Harstad and Fu (2003) present a model (not equilibrium) that applies multiplicative strategies. Similar to McAfee and McMillan model, the authors show that the government may reduce procurement cost if “disadvantaged” (e.g, minority-owned, women-owned businesses) bidders are subsidized.

While the actual used by Rothkope, et al is out of scope for this discussion, it should be mentioned that the authors rely on a special “Weibull distribution” to define the markup.

9. Conclusion

Efficient deployment of offshore wind is a pertinent concern of energy policy-makers. Despite substantial experience in on-shore wind, offshore wind faces some significant barriers to deployment. In particular, deep offshore wind faces higher costs relative to its near-shore counterparts. The government is concerned with successful and cost-efficient deployment of this technology.

Among various policy options, competitive tendering process appears to be a viable option for successful deployment of offshore wind. Relying on economic, energy and auction literature, I find that the government can minimize its procurement cost by discriminating in favor of the more expensive deep-offshore wind. I rely on a model by McAfee and McMillan (1989) to find the optimal discrimination rule that implements the truthful-revelation principle. Furthermore, I show that the implementation of the optimal discrimination rule results in positive welfare. I also show that the policy is welfare enhancing even in the case where the government faces a positive marginal cost of public funds. Finally, I illustrate the model through a numerical example.

In addition to theoretical considerations, I examine renewable energy auctions in practice and propose extensions for further study.

Appendix

A.1 Auction Types

First Price Sealed Bid

In a first-price sealed-bid auction the bids are submitted independently, without seeing other bidders' offers. The winner with the highest bid (or lowest bid in the case of procurement auction) wins and pays her bid. Such an auction is typically used to sell oil field leases and mineral extraction rights.

Second Price Sealed Bid

In a second-price sealed bid auction, the bids are submitted independently, without seeing other bidders' offers. The winner with the highest bid (or lowest bid in procurement auctions) wins, but pays the price equal to the second highest bid. Second-price sealed bid auctions are not typical in practice despite important theoretical conclusions.

Ascending

In an ascending (English) auction the bids are oral. The auctioneer begins the bidding at some price and continues to raise it until only one bidder remains. Once no other bidder is willing to pay a higher price, the highest bidder wins the auction and pays the price equal to her bid. This type of auction is typically used to sell art and used cars.

Descending

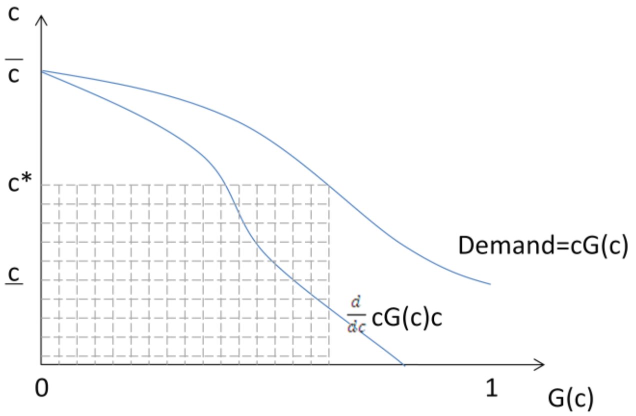
In a descending (Dutch) auction, the price declines until some bidder agrees to pay that price. The first bidder to stop the price decline wins the auction and pays that price. This type of auction is used to sell flowers and fish.

Combination Auction

This type of auction combines ascending and descending auctions. First proposed by Klemperer (1998) this auction begins with the "English" stage where price increases continuously until a certain number of bidders remain. Then in the Dutch stage, the surviving bidders from the first stage make sealed bids that cannot be lower than the first stage price level. The top bidders win, but pay the last winners' price. This type of auction was used in the UK to auction four third generation mobile-phone licenses (Klemperer 2002).

A.2 Virtual Cost

Function $J_i(c_i)$ is in accordance with "marginal revenue" approach to auctions (Klemperer 2000a), adjusted for procurement case where the auctioneer is the buyer.



a.2.1 $\frac{d}{dc} c\, G(c) = 0.$

a.2.2 $Payment = c * g(c) + G(c).$

a.2.3 $J(c) = c + \frac{G(c)}{g(c)}.$

A.3 Equation 6

a.3.1 $c_1 + \frac{G_1(c_1)}{g_1(c_1)} = z(c_1) + \frac{G_2(z(c_1))}{g_2(z(c_1))}.$

a.3.2 $z(c_1) < c_1.$

a.3.3 $c_1 + \frac{G_2(c_1)}{g_2(c_1)} < c_1 + \frac{G_1(c_1)}{g_1(c_1)}.$

a.3.4 $\frac{G_2(c_1)}{g_2(c_1)} < \frac{G_1(c_1)}{g_1(c_1)}.$

a.3.5 $\frac{G_i(c_i)}{g_i(c_i)} = 1/\frac{d}{dc} lnG_i(c_i).$

a.3.6 $\frac{d}{dc} lnG_2(c_1) < \frac{d}{dc} lnG_1(c_1).$

a.3.7 $\frac{d}{dc}\frac{G_2(c_1)}{G_1(c_1)} < 0.$

A.4 Equation 34

a.4.1 $z(c_1) = c_1 + \frac{G_1(c_1)}{g_1(c_1)} - \frac{G_2(z(c_1))}{g_2(z(c_1))}.$

a.4.2 $z(c_1) = c_1 + \left(\frac{\frac{c_1 - c_1^{\ell}}{c_1^h - c_1^{\ell}}}{\frac{1}{c_1^h - c_1^{\ell}}}\right) - \left(\frac{\frac{z(c_1) - c_2^{\ell}}{c_2^h - c_2^{\ell}}}{\frac{1}{c_2^h - c_2^{\ell}}}\right).$

a.4.3 $z(c) = c - (\frac{c_1^{\ell} - c_2^{\ell}}{2}).$

A.5 Equation 9

Given

a.5.1 $B_1(c_1) = b_1.$

a.5.2 $B_2(c_2) = b_2.$

a.5.3 $\delta(b_1) = b_{2.}$

a.5.4 $z(c_1) = c_2\,.$

Relating the cost discrimination function z to bids:

a.5.5 $B_2(c_2) = b_2.$

a.5.6 $B_2(z(c_1)) = b_2.$

a.5.7 $z(c_1) = B_2^{-1}(b_2).$

a.5.8 $z(c_1) = B_2^{-1}\big(\delta(b_1)\big).$

Plugging in, I find

a.5.9 $H_1(b_1) = 1 - G_2(B_2^{-1}(\delta(b_1)).$

a.5.10 $H_2(b_1) = 1 - G_1\left(B_2^{-1}\ (\delta^{-1}(b_1)\right).$

A.6 Equation 14

First I find a derivative of profit and expected profit:

a.6.1 $\pi = B_i(\mathrm{c}_\mathrm{i}^*) - \mathrm{c}_\mathrm{i}^*$.

a.6.2 $\frac{\mathrm{d}}{\mathrm{dc}}\pi = B'_i(\mathrm{c}_\mathrm{i}^*) - 1 = 0.$

a.6.3 $E(\pi) = \pi H_i(b_i).$

a.6.4 $\frac{\mathrm{d}}{\mathrm{dc}}\mathrm{E}(\pi) = 1 + \frac{\pi\frac{\partial H_i(b_i)}{\partial\, b_i}}{H_i(b_i)} = 0.$

a.6.5 $B'_i(\mathrm{c}_\mathrm{i}^*) = -\,\pi\frac{H_i'(b_i)}{H_i(b_i)}.$

To write a.6.5 in terms of costs, I evaluate a.6.4. Begin by evaluating $\frac{\frac{\partial\, H_1}{\partial\, b_1}}{H_1}$:

a.6.6 $H_1(b_1) = 1 - G_2(B_2^{-1}\left(\delta(b_1)\right)\!.$

a.6.7 $\frac{\frac{\partial\, H_1}{\partial\, b_1}}{H_1} = \frac{-g_2\left(B_2^{-1}\,(\delta(b_1))\right)B_2'^{-1}\,(\delta(b_1))\delta'(b_1)}{1-G_2(z(\mathrm{c}_1^*))} = -\frac{g_2(z(c_1))z\prime(c_1)}{1-G_2\left(z(\mathrm{c}_1^*)\right)B'_1(\mathrm{c}_1^*)}.$

From a.5.4 and a.5.1 I can find $z(\mathrm{c}_1^*)$ in terms of equilibrium strategy:

a.6.8 $z(\mathrm{c}_1^*) = B_2^{-1}(\delta(B(b_1))).$

a.6.9 $z'(\mathrm{c}_1^*) = \ B'^{-1}_2(B_1(\mathrm{c}_1^*)) * \ \delta'(B_1(\mathrm{c}_1^*)) * B'_1(\mathrm{c}_1^*).$

Plugging in $z'(\mathrm{c}_1^*)$ into a.6.7 I find

a.6.10 $\frac{\frac{\partial\, H_1}{\partial\, b_1}}{H_1} = \frac{-g_2(z(\mathrm{c}_1^*))*z\prime(\mathrm{c}_1^*)}{1-G_2\left(z(\mathrm{c}_1^*)\right)B'_1(\mathrm{c}_1^*)}.$

Previously I found

a.6.11 $H_1(\mathrm{c}_1^*) = 1 - G_2\left(z(\mathrm{c}_1^*)\right).$

a.6.12 $H_1'(\mathrm{c}_1^*) \quad = -g_2(z(\mathrm{c}_1^*)) * z'(\mathrm{c}_1^*).$

Plugging a.6.12 into a.6.10 I find

a.6.13 $$\frac{\frac{\partial H_1}{\partial b_1}}{H_1} = \frac{\frac{H'_1(c_1)}{H_1(c_1)}}{B'_1\,(c)}.$$

Plugging a.6.13 into a.6.4 I found the derivative of the equilibrium strategy in terms of probabilities based on cost as needed.

a.6.14 $$B'_1(\mathrm{c}_1^*) = -\,\pi\frac{H'_1(\mathrm{c}_1^*)}{H_1(\mathrm{c}_1^*)}.$$

By symmetry,

a.6.15 $$B'_2(\mathrm{c}_1^*) = -\,\pi\frac{H'_2(\mathrm{c}_1^*)}{H_2(\mathrm{c}_1^*)}.$$

Integrating a.6.14 and a.6.15 by parts we find the profit for some constant K

a.6.16 $$\pi = \mathrm{H}_\mathrm{i}^{-1}(\mathrm{c})(\mathrm{K} - \int_{c_i^l}^{c_1^*} H_i(\mathrm{c})dc) = 0.$$

I wish to find a K such that the profit is 0.

a.6.17 $$\mathrm{K} = \int_{c_i^l}^{\mathrm{c}_\mathrm{i}^\mathrm{m}} H_i(c)dc.$$

Plugging in a.6.16 I find expected profit

a.6.18 $$\mathrm{E}(\pi) = \mathrm{H}_\mathrm{i}^{-1}(\mathrm{c}_\mathrm{i}^*)\int_{c_i^*}^{\mathrm{c}_\mathrm{i}^\mathrm{m}} H_i(c)dc.$$

Integrating a.6.18 by parts I find the equilibrium bid, as needed.

a.6.19 $$B_i(\mathrm{c}_\mathrm{i}^*) = \mathrm{H}_\mathrm{i}^{-1}(\mathrm{c}_\mathrm{i}^*)\int_{c_i^*}^{\mathrm{c}_\mathrm{i}^\mathrm{m}} cH'_i(c)dc.$$

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