Cost and Efficiency in Government Outsourcing: Evidence from the Dredging Industry

Aaron Barkley [*]

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Abstract

This paper investigates the effect of government outsourcing by considering how outsourcing decisions are determined along two dimensions: (i) cost differences between private firms and government suppliers of public goods and (ii) dynamics arising from cost complementarities and capacity constraints. I formulate and estimate a dynamic binary choice model of government outsourcing using project-level data from the dredging industry. Model estimates indicate substantial cost savings due to outsourcing but also that government presence in the market yields cost reduction. A counterfactual policy featuring direct competition between government and private sector firms finds a total expenditure reduction of 17.1 percent.

1 Introduction

The role of the private sector in the provision of public goods and services is a topic of ongoing debate. Government agencies searching for the lowest-cost providers often leads to outsourcing, or contracting out, projects and tasks to the private sector,

[*]University of Melbourne, Faculty of Business and Economics Building, 3010 VIC, Australia. Email: aaron.barkley@unimelb.edu.au. I would like to thank David P. Byrne, Timothy Moore, Robert A. Miller, Joachim Groeger, Karam Kang, and participants at various conferences and seminars for helpful suggestions. All remaining errors are my own.

counting on productive efficiencies of private firms and the competition generated by procurement mechanisms to secure lower prices.[1] The consequences of these decisions are large. Outsourcing contracts in the United States span education, healthcare, regulatory compliance, public infrastructure, and many other industries, with total expenditures exceeding $400 billion annually.[2]

Given the widespread nature of outsourcing, assessing its costs and benefits is important in evaluating the functions of government. Numerous theories have arisen aimed at clarifying the private sector's role in the provision of government services, with Shleifer and Vishny (1994) illustrating how inefficiencies can arise within government firms while Hart, Shleifer, and Vishny (1997) and Williamson (1999) detail environments in which government provision is optimal. However, existing empirical evidence on government outsourcing is largely descriptive and doesn't assess direct outcomes such as efficiency effects.[3] Measuring the differences in costs faced by government and private sector firms is necessary not only to assess the performance of outsourcing but also to inform how government should participate in these markets.

In this paper, I use data on a history of in-house and outsourced public infrastructure projects as well as procurement auction outcomes to estimate a structural model of outsourcing. A structural approach allows for new empirical insights through disentangling the impacts of productive efficiency, competition, and dynamic effects on outsourcing. This allows me to quantify the extent to which outsourcing is driven by the "cost effect," or efficiency advantages of private sector firms over government, versus by the "competition effect," or the competition between firms generated by the procurement process. When multiple outsourcing decisions are made over time there are often future cost implications from current

[1] Outsourcing is distinct from privatization in that it does not involve the transfer of ownership or control of government assets.

[2] Source: Bloomberg

[3] Examples include Snyder, Trost, and Trunkey (2001), Stevens (1978), and Bel and Rosell (2016).

outsourcing decisions.[4] By estimating a multi-period model in which cost complementarities across projects and capacity restrictions impact future costs, I am able to capture these dynamic effects.

Understanding the interactions between cost, competition, and dynamic effects guides how government should participate in procurement markets. Counterfactual simulations demonstrate how government presence in the market leads to substantial benefits when the level of competition is low. This is due to using government costs, including the impact of in-house provision on future costs, as the outside option of not outsourcing. The ability to credibly threaten to take projects for which there are few competitors and high bids leads to increased allocative efficiency and lower total expenditures. Given the low levels of competition generally present in procurement markets,[5] these results suggest an increased government presence in public service provision may prove beneficial.

The empirical setting used is the United State dredging industry, from which I use data on project-level outsourcing decisions made between 1999 and 2013. Dredging projects are maritime construction projects chiefly aimed at keeping waterways navigable, and are completed by large vessels called dredges. The dredging industry lends itself to the study of outsourcing as each year the US Army Corps of Engineers (USACE) splits the completion of government dredging projects between USACE owned and operated dredges and private sector dredging companies. The USACE operates 12 dredges which complete approximately half of all projects. The remainder are contracted out via procurement auctions whose awards total between $700 million and $1.1 billion annually. Projects often vary considerably in size and scope across sectors.

In addition to the size of a project contributing to the cost of completion, there

[4]For example, a municipality deciding whether to renew a contract for emergency medical services may consider an upcoming contract renewal decision for fire prevention and suppression in its decision, as fixed costs of establishing an in-house ambulatory service might be shared with that of a fire department.

[5]See, for example, Kang and Miller (2017) on US procurement markets.

are two factors that lead to future cost considerations for the government. First, projects may be hundreds of miles apart, and transporting large dredging vessels and other equipment necessary to complete the projects is costly. Second, project dates routinely overlap and dredges themselves must remain on the project site until the work is completed; as such, assignment of a government dredge to work on one project may preclude keeping a future project in-house.

I specify and estimate a dynamic model of government outsourcing decisions that allows for both cost differences between private firms and government that vary with project characteristics and dynamic effects arising from travel distance costs and capacity restrictions. Based on its own expected project cost and dynamic considerations, the government decides each period to keep a project in-house or to outsource via a first-price sealed-bid auction. If a project is outsourced, potential bidding firms play a two-stage auction with entry game in which a first-stage entry game determines auction participants with participating bidders submitting bids in a first-price sealed-bid auction in the second stage.

By focusing attention on the role of cost differences, competition, and dynamics this paper is complementary to much of the existing literature on outsourcing and make-or-buy decisions. Previous empirical work has focused on the role of transaction costs and property rights.[6] The transaction costs economics framework of Williamson (1975, 1979) emphasizes the costs that are incurred by engaging in market transactions, including the well-known hold-up problem.[7] The property rights model of Grossman and Hart (1986) and Hart and Moore (1990) focuses on defining the boundaries of the firm by ownership of assets and the role of asset specificity in determining which tasks are completed within the firm and which are contracted out. I abstract from the asset specificity and ex-post contract renegotia-

[6] Examples dealing with government decisions include Levin and Tadelis (2010) and Warner and Hebdon (2001). Holmstrøm and Roberts (1998) provide a theoretical overview of firm make-or-buy decisions and Lafontaine and Slade (2007) survey empirical work on these models.

[7] An example of the hold-up problem is a situation in which an outside firm contracted to complete one aspect of production obtains the upper-hand in negotiations when the contract is incomplete or has expired and needs to be renewed.

tion that are central to property rights and transaction cost models as these are not a major concern in the dredging industry.[8] This paper also considers the make-or-buy decision within a dynamic context, while the empirical literature to date has focused on the static case.

While the model is agnostic as to the source of cost differences between government in-house work and contracted firms, reasons why private firms may have cost advantages over government agencies for certain tasks include use of high-powered incentives as in Holmstrom and Milgrom (1994), reduction of inefficient bureaucratic policies, and more flexible labor practices. Conversely, a full-time staff of skilled in-house employees may mitigate fixed costs associated with projects.

Identification of the distribution of government costs in a dynamic discrete choice model is complicated by the presence of the future value component in the decision problem and the fact that outsourcing decisions do not directly reveal government cost. Two steps allow these issues to be circumvented: first, non-stationarity of state transitions yields a subset of "temporarily static" periods in which the future value components cancel and so dynamic considerations play no role in the decision of whether or not to outsource the project. Second, heterogeneity in competition across markets generates variation in the expected winning auction bid that identifies quantiles of the government cost distribution. I establish identification of the random, unobserved component of utility in the dynamic model, in contrast to much of the literature on dynamic discrete choice models in which this distribution is assumed to be known.

Results from the structural model indicate substantial cost differences between private firm and government provision, with a government cost advantage for smaller projects while larger projects favor private firms. I estimate that for outsourced projects, which tend to be larger than those kept in-house, average private firm

[8]Dredging typically doesn't require specific investment for any one project, and there is no pattern of higher costs after contract adjustment that would indicate ex-post renegotiation due to incomplete contracting. Appendix B contains additional details.

costs are 23% lower than government costs. However, in-house provision remains cost-efficient for many smaller projects, and government presence in the market remains an important cost reducing force. Counterfactual simulations in which the size of the government fleet is reduced reinforce this, showing that while small reductions would have little impact, substantial cuts to the government's fleet would noticeably increase expenditures.

Using the model estimates, I implement an alternate procurement mechanism in which the government uses the in-house option to impose discipline on private firms in the procurement market. In this mechanism, the government directly participates in the auction by setting a dynamically optimal reserve price that takes into account both current and future costs of in-house completion. I find that total expenditures would be reduced by 17.1% through such a policy, indicating that there is scope for the government to further leverage its own resources in the procurement process to improve outsourcing outcomes. This policy is related to recent empirical work on the performance of procurement auction mechanisms, including Krasnokutskaya and Seim (2011), Lewis and Bajari (2011), and Decarolis (2017). The main innovation of this paper is to identify the government's own in-house completion costs as the outside option of not outsourcing and to use these costs in setting the auction reserve rate to enhance allocative efficiency.

The rest of the paper is structured as follows: Section 1 introduces the empirical setting and data. Section 2 describes the structural model of government outsourcing decisions. Section 3 discusses identification of the model, while estimation and results are given in Section 4. Section 5 gives the results of counterfactual simulations. Section 6 concludes.

2 Empirical Setting and Data

The data analyzed in this paper come from dredging projects overseen by the United States Army Corps of Engineers (USACE). Dredging consists of excavation and transportation of underwater material. Dredging projects are carried out by large vessels known as dredges; a typical dredge has built-in machinery that excavates material from beneath the water as well as a storage container that will hold the dredged material until a disposal area is reached. The primary purpose of most dredging projects is the maintenance of shipping lanes and harbors to insure the safe passage of commercial vessels. Proper care of these passages is crucial to the United States economy as much of US domestic and international trade involves transport of goods along these waterways. Each dredging project occurs in one of 34 USACE districts, which are located along the coasts and inland waterways of the United States.[9]

A series of laws, the first of which passed in 1824, tasked the USACE with maintaining navigable waterways throughout the US. All dredging projects related to these tasks were performed directly by the USACE until 1978 when Congress passed Public Law 95-269, otherwise known as the Minimum Fleet Act. In this act Congress instructed the Corps to contract out to private dredging companies all work that could be done "at reasonable cost." Since that time federal dredging work in the US has been split between projects contracted out and those completed in-house, with the aim of completing all projects at the lowest cost. The role of Corps dredges in the market is thus to minimize government expenditures on dredging projects, and Congress periodically reassesses the level of involvement of Corps dredges in order to insure the lowest cost.[10]

The market operates as follows. Prior to the start of each fiscal year the Corps publishes the schedule of projects to be completed over that year. This schedule includes all projects across all districts. The schedule of projects is made on a yearly basis because (i) the sites that will require dredging work are typically not known more than one year in advance and (ii) the navigation budget issued to

[9] A list of districts and a summary of their dredging activity can be found in Appendix B.

[10] For example, a 2005 report to Congress outlines several options for Corps dredging fleets and evaluates the total costs. The report is available at http://www.aapa-ports.org/files/PDFs/reporto-congress3Junefinal3nov05.pdf

the Corps is decided each year by Congress, and so the total budget available for dredging projects is not known until several months before the start of the fiscal year.[11] Project start dates are determined by a number of regulatory and seasonal factors, including environmental regulations for fish, birds, and sea turtles, weather considerations, and limiting disruption of public land usage such as beaches.

The organization of the market gives the Corps flexibility in assigning projects throughout the year. The advertising schedule often includes language that indicates a project has a certain percentage probability of being contracted out, e.g. the Corps might indicate that there is an 80% chance that a given project will be allocated to the private sector. Furthermore, the Corps has in place a procedure, called "Raise the Flag," which is meant to quickly switch allocation from one sector to another: it either assigns a government dredge to a project originally scheduled to be outsourced prior to the auction being held, or organizes an auction for a project which was initially slated for Corps completion. These features suggest that the Corps intentionally maintains flexibility over the allocation of projects during the course of the year. This is further supported by the observed routes of government dredges, which frequently take paths that would be sub-optimal if the allocation of projects were fixed in advance.[12]

The USACE district in which a project will be completed holds a first price sealed bid auction to contract out the project to a private firm or arranges for the Corps dredge charged with overseeing that district to complete it. Auctions occur on a rolling basis, with the bid opening date typically falling about two months prior to the start of the project while the contract is awarded about three to four weeks prior to the scheduled start date for the project. When a project is allocated to a government dredge, the vessel moves to the district in which the project is located

[11]Emergency dredging work is rare, for example in 2014 emergency dredging accounted for less than 1% of all dredging.

[12]For example, 11% of projects completed by the Corps are situations in which a vessel completes a project in a given district, leaves that district, and returns later in the year to complete another project in the original district. Every such case is a deviation from the solution to a traveling salesman problem of distance minimzation.

and completes the project. Projects completion times range from several days to several months.

The decision to outsource a project is final; only in extreme circumstances will a project be allocated to a Corps dredge after an auction has been held.[13] The USACE also does not use its own dredging resources to participate in the auction. While the Corps does specify an auction reserve price, which is based on an engineering estimate of private sector firms' project completion costs, this is frequently ignored in practice.

The main cost drivers of dredging work are labor and materials, with fuel costs being the major component of the latter. While non-labor inputs costs are similar across USACE dredges and private firms, differences in labor practices represents an important distinction between private and public provision. Corps dredges have strict staffing requirements that are constant across all projects and more stringent requirements for employment.[14] Private firms, in contrast, face no such restrictions and are able to structure labor input use to the specific project and task at hand. This results in highly trained, well-paid crews on USACE dredges compared to private dredges, but also inflexibility in determining crew size over the course of a project.[15] In constrast, private dredging companies often need to assemble and train crew for each individual project, but have the flexibility to vary the use of labor inputs over the course of longer projects. The full-time staffing arrangements of the USACE lessen fixed costs of starting a project relative to the private sector, but result in increased total costs for longer projects due to labor input inflexibility.

Private dredging companies are located throughout the United States and per-

[13]The 2005 USACE report to Congress notes that this happened only twice over the several year period analyzed in the report.

[14]As the USACE is under the Department of Defense dredge operators must be prepared to engage in military operations in the event of an emergency.

[15]For example, an industry report notes that for two similar sized dredging vessels, one in the private sector and one operated by the Corps, the private dredge was manned by 28 crew members on average while the USACE dredge crew was 43. The report also notes that USACE crews are full-time and generally receive higher wages than private crews. Report available at http://www.pnwa.net/new/Articles/MDFOnePager.pdf

form dredging for private firms and individuals, governments and the state and local level, as well as federal dredging contracts through the USACE. While USACE projects represent an important source of demand for dredging services, these projects are a relatively small fraction of the overall number of projects completed in the United States each year.[16]

Completion of dredging work by contracted firms is closely monitored by the USACE through several channels. Many contracts have provisions that the contracted firm supply office space on the project site for USACE engineers to supervise the project. Samples of dredged material are required to be sent for testing at various stages of the project to check compliance with environmental regulations. Images of the completed work are often compared with computer-generated plans to insure the completed work matches contract specifications.[17]

2.1 Data

The main source of data comes from the United States Army Corps of Engineers Navigation Data Center and includes information on all projects contracted out to private dredging companies and daily activities for all dredges operated by the USACE from 1999-2013. Data is collected at the district level and then published on a yearly basis on the Navigation Data Center web page. I supplement this data set with between-port distances obtained from the National Oceanic and Atmosphere Administration (NOAA). Data for the in-house projects consists of the identity of the vessel completing the project, project characteristics such as volume and number of working days, and the district in which the project is completed. Outsourced

[16]Data on permits issued from the USACE ORM Jurisdictional Determinations and Policy Decisions database and Montana Legislative Environmental Policy Office indicate that over 800 dredging permits for non-USACE projects were issued in 2014, more than five times the number of federal contracts issued.

[17]Data on ex-post adjustments to winning bids, summarized in Appendix B, reveals that approximately half of all payment adjustments are negative, i.e. firms receive less than the winning bid for completing the project. As payments are structured in terms of price per cubic yard of material dredged, this is consistent with substantial monitoring and only paying firms for work observed to have been completed.

projects are allocated by first price sealed bid auctions. Auction data consists of the winning bid and identity of the winning bidder, district where work was performed, number of bidders, and project characteristics.

Table 1: Summary Statistics

	In-House Mean (*Std. Dev.*)	Outsourced Mean (*Std. Dev.*)
Projects per Year	123.2 *(28.2)*	118.5 *(22.5)*
Cubic Yards per Project	273.7 *(939.5)*	1177.0 *(1575)*
Working Days per Project	17.9 *(38.7)*	125.8 *(136.0)*
Distance (in-house projects)	136.7 *(314.6)*	
Distance (all projects)	214.5 *(382.7)*	
Cost per project ($, millions)		4.03 *(3.83)*
Number of Bidders		2.46 *(1.32)*

There were 2178 projects awarded to private firms and 1940 projects taken by USACE dredges over the 15 year period in the data. After removing observations for which key data was missing, large, multi-year projects which require resources beyond USACE capabilities, and projects from three districts in which Corps dredges don't operate, the final sample consists of 3,625 observations.[18] Table 1 contains summary statistics for the projects contained in the sample. The distance measured in the table is between each district's USACE headquarters location. There were $477 million dollars worth of contracts issued to private firms each year on average. Although the number of projects completed by the USACE is comparable to the number of projects outsourced, the USACE projects tend to be much smaller; the mean USACE project excavates less than 25% of the material excavated by the mean project completed by a private firm.

Overall 177 firms were awarded at least one contract over the sample period. Most firms are active in a small number of areas: the mean number of districts in

[18] Additional information on the data and sample construction can be found in Appendix B.

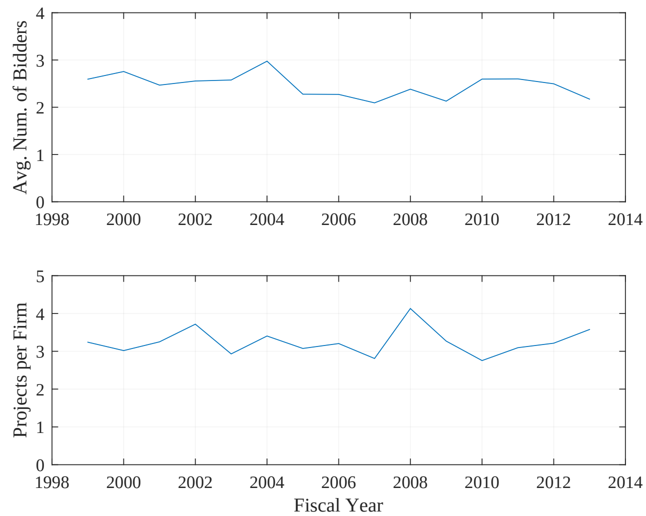
which a firm is active is approximately two, while the median is one. This suggests that most firms confine their dredging operations to their local geographic area. Additionally, private sector dredging capacity far exceeds government dredging resources, with an average of six dredging companies per district. As such, capacity does not appear to be a limiting factor in auction participation: regression results (which can be found in Appendix B) indicate no statistically significant effect of the number of currently ongoing projects in a district on auction participation.

Competition in the auctions is low, with a mean of 2.46 bidders per auction and a median of 3. Auctions with greater that four bidders are rare, while single-bidder auctions are not uncommon. The level of competition varies across districts, with districts in the inland waterways and along the Pacific coast having the fewest competitors while districts in the Gulf and Atlantic coastal regions having higher levels of competition. For example, the auctions in the Galveston district average one full bidder more per auction (3.2) than those held in the Vicksburg district (2.2). This difference in the number of competitors is highly correlated with the number of projects completed in each of these areas, and appears to be more closely related to overall demand for dredging and the importance of commercial shipping in these regions than any particular geographic features.

The private sector dredging industry is stable, with relatively small variation in the number of bids received per auction and project concentration (measured by the average number of projects per firm) across the years in the sample. This is presented graphically in Figure 1. Additional details on firm activity and competition can be found in Appendix B.

In order to examine the importance of project locations and distance traveled on the outsourcing decision, I regress the government's outsourcing decision on observable project variables and distance measures. Table 2 gives coefficient estimates for a linear probability model of in-house government completion. "Project Volume" measures the amount of dredged material for a project in cubic yards,

Figure 1: Level of Competition and Concentration Over Time



"Working Days" gives the number of days required to complete the project, and "Distance" gives the distance to project district in nautical miles. The variable "$t+1$ Distance Saved" gives the reduction in distance to the project in period $t+1$ should the current project be taken; that is, it measures how much closer or farther the vessel will be to the next period's project if the current project is kept in-house.

The estimates are consistent with the summary statistics in that government dredges are less likely to take larger volume projects and those that require more days to complete. Additionally, greater distance to a project decreases the chance that the project is kept in-house while additional distance saved to the next project will increase it. Taken together, these results suggest that travel distance incurs costs to government dredges and that the government is forward-looking with regard to total travel distance.

Table 2: Government Project Selection Probability

Variable	Coef.	Std. err
log(Project Volume (cu. yds.))	-0.095	0.006
log(Working Days)	-0.011	0.001
Distance	-0.015	0.002
$t + 1$ Distance Saved	0.002	0.001
Constant	0.671	0.062
District	Yes	
N	3625.000	

3 Model

Motivated by the empirical facts presented in the previous section, this section presents a model of sequential project allocation in which a government makes outsourcing decisions in each period in order to minimize the expected cost of completing a known schedule of projects.[19] When making the outsourcing decision, the government considers the expected winning bid in a procurement auction and its own cost for the project, which it learns at the beginning of each period. Because vessels must be moved between project sites in order to complete projects and this travel is costly, the impact that vessels locations will have on future travel distances also affects the government decision. Lastly, availability of vessels to complete projects is also considered, as current project allocation decisions may affect the ability to complete future projects in-house. If the project is contracted out, a first-price sealed-bid auction is held in which firms make entry decisions prior to bidding and the contract is awarded to the lowest-bidding firm.

[19]Other models of government preferences assume budget-maximizing objectives (e.g. Niskanen (1968), Niskanen (1971)), in which a "Sponsor" allocates the budget and has an inferior bargaining position relative to the bureau due to an informational disadvantage regarding the social value of the bureau's projects. In my setting, I assume that the "Sponsor" can compare costs of dredging for Corps dredges and private sector dredging and prefers the lower-cost option, even if the total number of dredging projects exceeds the social optimum.

3.1 Model Set-up

A risk-neutral government must complete a known schedule of projects over the course of one year. The schedule of projects is a list, ordered by project start date and containing all the information relevant to each project. There are K districts in which projects must be completed. Time is discrete with a finite horizon T. Each period denotes the start date of a project. The government makes a decision to either outsource the project or keep it in-house. The state variables are denoted $z_t \equiv (\delta_t, x_t, \overline{N}_{k_t}, w_t, y_t)$, where δ_t represents the distance from the government dredge to the current project district and x_t is a vector of project characteristics (e.g. project size). The district in which the project is to be completed is k_t, with $\overline{N}_{k_t} \in \mathcal{N}$ denoting the number of firms in district k_t.

Projects can last for a number of periods and may overlap with other projects; w_t indicates the number of projects whose dates overlap with the project starting in period t. If a dredge is allocated to complete the project in period t, then it will be committed to that project for w_t periods and will be unable to complete other projects during that time. The state variable y_t indicates the availability of the government vessel, with $y_t = 0$ indicates that the vessel is currently available at the start of period t and $y_t = c$ for $c \in \mathbb{N}$ indicating that there are c periods until the vessel is available to take another project.[20]

The timing of the model is as follows: at the start of each period, the government learns its cost for completing the project in that period. It then forms expectations about the winning bid if the project were to be contracted out and makes the outsourcing decision. If the project is kept in-house, the government vessel allocated to the project moves to the project's district and begins the project. If the project is outsourced, a first-price sealed-bid auction is held to determine which firm is awarded the contract.

[20]If $y_t = 0$ at the start of the period, then a decision to keep the project in-house will mean that $y_{t+1} = w_t$ and it must wait w_t periods before it can be assigned any other projects. If the project is outsourced, $y_{t+1} = 0$.

In describing the model I work backwards from the auction stage, first obtaining an expression for the expected winning bid in the auction conditional on a project being outsourced. I then write the government's payoffs and value function given expectations over the expected winning bids derived in the first section and characterize optimal outsourcing decisions.

3.2 Auction Stage

When a project is outsourced, firms active in the district in which the project is located have the opportunity to bid for the project's contract. I assume that firm bidding behavior is myopic: given that many firms are active in only one or two districts and that the number of ongoing projects does not affect bidder participation, the main two factors driving dynamics in the government decision, distance to project sites and availability of dredges, are unlikely to be a strong factor in firm bidding decisions. As such, participating firms compete in a static first-price sealed bid auction for the contract. The decision to contract the project out is final and precludes assignment to a government vessel.

In the first stage, potential bidders play an entry game to determine who participates in the auction based on the model of Levin and Smith (1994). Prior to learning their private costs for completing the project, bidders receive independent entry cost draws e from a common distribution ζ with support $[\underline{e}, \overline{e}]$. Each potential bidder is aware of his/her own entry costs but not the entry costs of other potential bidders. Entry costs are independent of project completion costs. After learning their entry costs, bidders make entry decisions based on the expected payoff from entering the auction. Bidders that choose to enter the auction then receive their private cost draw from the cost distribution and learn the number of other bidders competing in the auction.

Formally, suppose there are $\overline{N}$ potential bidders. Let e_i indicate the private entry cost drawn from ζ for bidder i,and let $\mathbf{e}_{-i}$ represent the entry costs of the other potential bidders. A pure strategy for player i is defined as a function $\sigma : [\underline{e}, \overline{e}] \rightarrow \{0, 1\}$ that maps each entry cost to an entry decision. Let $\mathbb{E}[u_i|N]$ represent the expected profit for bidder i upon entering an auction with N total bidders. Then there exists a threshold cost level e^* given by

$$e^* = \sum_{n=1}^{\overline{N}} \Pr(N = n \mid e^*)\mathbb{E}[u_i|N = n]$$

where any $e_i < e^*$ leads to entry and $e_i > e^*$ means that bidder i does not enter the auction. This can be re-expressed using the distribution of entry costs as

$$e^* = \sum_{n=1}^{\overline{N}} \binom{\overline{N}}{n} \zeta(e^*)^n (1 - \zeta(e^*))^{\overline{N}-n} \mathbb{E}[u_i|N = n] \tag{1}$$

Since the left side of (1) is increasing in e^* and the right side is decreasing in e^*, as higher entry costs leads to lower entry probabilities, the equilibrium cutoff point e^* exists and is unique.

After bidders have made their entry decisions they draw costs and submit bids in a first-price sealed bid auction. The number of bidders n is assumed known. Each bidder i receives an i.i.d. project cost drawn c_{fi} from a common distribution $F(c_f|x)$ conditional on project characteristics x with positive support on $[\underline{c}_f, \overline{c}_f]$. The independent private values assumption is motivated by the heterogeneity of dredging equipment across firms; each dredge has different specifications and capabilities, and costs will be determined by how a particular dredge fits that project's requirements. I assume that there is no binding reserve price in auctions with two or more bidders. [21] Finally, I assume that bidders play a symmetric, pure strategy Bayesian Nash equilibrium with bids that are increasing in costs.

For ease of notation, I suppress the conditioning on project characteristics x and the time subscript in what follows. Given the above assumptions the bid function

[21] This is motivated by the fact that the stated reserved price is frequently ignored in practice, and it is consistent with the existing literature on procurement auctions (e.g. Li and Zheng (2009)).

can be written as

$$b^*(c_i) = \max_b \Pr(b \le b_j\ \forall j \neq i) \times (b - c_i).$$

which has a closed-form expression given by

$$b(c_{fi}) = c_{fi} + \int_{c_{fi}}^{\infty} \frac{(1 - F(u))^{n-1}}{(1 - F(c_{fi}))^{n-1}} du. \tag{2}$$

The expected winning bid is the auction feature determining government outsourcing decisions. Define $m(c_{fi})$ to be the expected payment received by bidder i. Then $\mathbb{E}[m(c_{fi})|N = n]$ is the ex-ante expected payment received by each bidder when there are n bidders in the auction. For auctions that feature only one bidder, I assume that the firms compete against the government by the government announcing a maximum acceptable contract price, which the firm agrees to provided it is above their cost for the project.[22] Because N is unknown to the government at the time the outsourcing decision is made the government takes the expectation of $\mathbb{E}[m(c_{fi})|N = n]$ over the number of bidders when assessing the expected winning bid. Each district k has $\overline{N}_k$ potential bidders. The probability distribution over the number of bidders is given by η_k, with η_{kn} the probability that there are n bidders in the auction. Defining R to be the expected ex-ante winning bid, we have

$$R = \sum_{n=1}^{\overline{N}_k} \eta_{kn} \cdot n\mathbb{E}[m(c_f)|N = n].$$

3.3 Outsourcing Decision

At the beginning of each period t the government learns its cost c_{gt} for completing the project, which is drawn from a distribution that has conditional cdf $G(\cdot|x_t)$. The distance cost associated with traveling to the project district is given by $\omega(\delta_t)$ and is assumed to be additively separable from the project completion cost. Define

[22] This is similar to the method used in Li and Zheng (2009) and reflects the USACE policy to negotiate with firms in the event that only one bid is received.

$d_t \in \{0, 1\}$ to be the decision variable in period t, where $d_t = 0$ represents that the project has been kept in-house and $d_t = 1$ indicates that the project has been contracted out. Letting $\pi_j(z_t)$ denote the per-period payoff for state z_t when $d_t = j$, the per-period payoffs have a simple expression of the form

$$\pi_0(z_t) = -\omega(\delta_t) - c_{gt} \tag{3}$$

$$\pi_1(z_t) = -R(x_t, \overline{N}_{k_t}) \tag{4}$$

where $R(x_t, \overline{N}_{k_t})$ is the expected winning auction bid. The only random component of the government's payoffs enters through the government's cost draw c_{gt}; hence, this cost should be interpreted as the cost of completing the project relative to the cost of contracting the project out.[23]

The schedule of projects is known for each year, meaning that the project characteristics x_t and district-level competition $\overline{N}_{k_t}$ are known in advance for each project. Distance to future projects is determined by the current location of the government's work crews; when the government sends a vessel to a project location the distance to the subsequent project will be known with certainty. Hence, all state transitions are deterministic, with transitions for two of the states (project characteristics and district characteristics) determined exogenously by the project schedule while the transitions for distance and vessel availability are determined by the government's outsourcing decision and the schedule of projects. While state transitions are deterministic, they are non-stationary as they will depend on the sequence of upcoming projects.

Define $q_{jt}(z_{t+1}|z_t)$ to be the state transitions after making choice j in period t. If we again consider the schedule of projects as a list, ordered by project start date and containing all the information relevant to each project, the state transitions can be thought of as crossing one project off of the list and moving to the next one, updat-

[23] As any pair of choice specific utility shocks that lead to the same differenced distribution are observationally equivalent, normalizing one of the utility shocks to zero is necessary for identification.

ing the locations and availabilities of the government vessels each period. Current choices affect future states through the dependence of the state variables y_t and δ_t on the current period choice. A project that is far away from the remaining projects on the schedule for the fiscal year and has a long completion time will affect future payoffs by both (i) increasing the distance necessary to complete future projects and (ii) potentially rendering the vessel unavailable for the subsequent projects, taking away the potential for the government to save costs by keeping the project in-house.

With these factors in mind, the value function for choice j in period t can be written

$$V_{jt}(z_t) = \pi_j(z_t) + \sum_{\tau=t+1}^{T} \beta^{\tau-t}\mathbb{E}[\pi_{j^*_\tau}(z_\tau)], \tag{5}$$

where j^*_τ is the optimal choice in period j^*_τ. The ex-ante value function is given by

$$\overline{V}(z_t) = p_{0t}(z_t)\mathbb{E}[V_{0t}(z_t)] + p_{1t}(z_t)\mathbb{E}[V_{1t}(z_t)] \tag{6}$$

with $p_{0t}(z_t) = \Pr(V_{0t}(z_t) > V_{1t}(z_t))$. Now define $v_{jt}(z_t)$ to be the value functions conditional on choice j without the random cost c_{gt}; note that removal of this term affects only the in-house payoff. These conditional value functions can be expressed

$$\begin{aligned} v_{0t}(z_t) &= -\omega(\delta_t) + \beta \sum_{z\in\mathcal{Z}} \overline{V}_{t+1} q_{0t}(z|z_t) && (7) \\ v_{1t}(z_t) &= -R(x_t, \overline{N}_{k_t}) + \beta \sum_{z\in\mathcal{Z}} \overline{V}_{t+1}(z) q_{1t}(z|z_t). && (8) \end{aligned}$$

This allows for expression of the conditional choice probability of in-house provision as

$$p_{0t}(z_t) = \Pr(c_{gt} < v_{1t}(z_t) - v_{0t}(z_t)). \tag{9}$$

Capacity affects payoffs through the elimination of the in-house decision option when no dredges are available. In particular, this means that the value function is

$$V_t(z_t) = \begin{cases} \max_{j \in \{0,1\}} \pi_j(z_t) + \beta \sum_{z_{t+1}=1}^{Z} \overline{V}_{t+1}(z_{t+1}) q_{jt}(z_{t+1}|z_t) & \text{if } y_t = 0, \\ \pi_1(z_t) + \beta \sum_{z_{t+1}=1}^{Z} \overline{V}_{t+1}(z_{t+1}) q_{1t}(z_{t+1}|z_t) & \text{otherwise.} \end{cases}$$

If a project would occupy a government dredge for the next $\bar{t}$ periods then the government must trade off potential gains from keeping the project in-house in the current period against the expected losses that might be incurred through the inability to complete projects in-house for the next $\bar{t}$ periods.

4 Identification

This section describes the identification of the model primitives, which are the government cost distribution G, distance costs $\omega(\delta)$, entry cost distribution ζ, and firm cost distribution F, from the observables z_t, d_t, n_t, and the winning auction bids.

4.1 Overview

Identification of the government cost primitives uses the non-stationarity of state transitions to isolate "temporarily static" periods in which all future value terms cancel. This removes the primary obstacle to identification of the distribution of choice shocks in dynamic models, as the future value terms themselves depend on this distribution. I then combine these static periods with an exclusion restriction that government costs are independent of the number of active firms within a district. The full distribution of government costs is identified by variation in the number of active firms using an exclusion restriction in a similar manner to static non-parametric identification of binary choice models (e.g. Lewbel (2000)).

Identification of private sector firm costs uses results from the auction literature for auctions with only winning bids known, for example in Athey and Haile (2002).

Firm costs are then used to identify the expected bidder profit conditional on the number of bidders. Combining this with the empirical distribution over the number of bidders in the auction gives the expected auction profit conditional on entry. This generates an equilibrium cutoff condition for each number of potential bidders $\overline{N}$. Hence, quantiles of the entry cost distribution are identified through variation in the number of potential bidders.

4.2 Government Cost Primitives

Identification of G is established in two steps. The first step is to eliminate the future value component of government choices, as this is the main barrier to identification of the unobserved component of payoffs.

In this setting, such a situation arises when an available dredge is located in the same location as the period t project and the project will conclude before the period $t+1$ project is set to begin. Then regardless of the choice to take the project or not the two factors affecting the future value function, distance to project and availability, are unaffected: the vessel remains in the original district and is available in both cases.

As an example, consider a project in period t located in district k. There is also an available government vessel located in district k at the start of period t; further, suppose that the period t project will conclude prior to the start of the project in period $t+1$. Then the state is $z_t \equiv (\delta_t, x_t, \overline{N}_{k_t}, w_t, y_t) = (0, x_t, \overline{N}_{k_t}, 0, 0)$ and the current decision will not affect availability for the next period project. The project characteristics x and market competition $\overline{N}$ have exogenous transitions that are due to the schedule of projects and hence are unaffected by the choice of the government. The distance to the next project δ_{t+1} will remain fixed regardless of the outsourcing decision, as the vessel has not changed districts. Then the state variables at the start of period $t+1$ are $(\delta_{t+1}, x_{t+1}, \overline{N}_{t+1}, w_{t+1}, 0)$ whether the previous period's project was kept in-house or not.

It is straightforward to demonstrate that these circumstances result in static decisions:

$$\begin{aligned} v_{1t}(z_t) - v_{0t}(z_t) &= \pi_1(z_t) - \pi_0(z_t) + \beta \sum_{z \in \mathcal{Z}} \left(\overline{V}_{t+1}(z) q_{1t}(z|z_t) - \overline{V}_{t+1}(z) q_{0t}(z|z_t) \right) \\ &= \pi_1(z_t) - \pi_0(z_t), \end{aligned}$$

since $q_{1t}(z|z_t) = q_{0t}(z|z_t)$. Hence, when the state transitions are the same for both choices, the ex-ante value function terms for the next period cancel and the differenced conditional value function can be expressed solely in terms of the current period flow utilities.

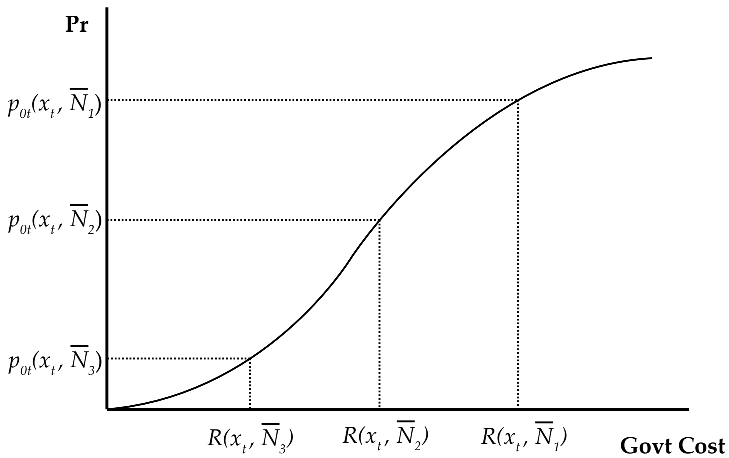
After obtaining a set of temporarily static observations using the method above, the distribution of G is identified using an exclusion restriction. Specifically, I assume that $\overline{N}$ affects the expected winning bid, and hence the probability of the outcome variable d, but is independent of C_g after conditioning on characteristics x. This allows variation in $\overline{N}$ to change the probability that $d_t = 1$ in a way that identifies the distribution of C_g. This is illustrated for fixed project charateristics x in Figure 2.

After identification of G is complete, identifying $\omega(\delta)$ follows from the representation results of Arcidiacono and Miller (2011) after a normalization of $\omega(\delta)$ for one value of the state δ. These results are formalized in the proposition below.

Proposition 4.1 *Suppose the following assumptions hold:*

1. $G(c|x, \overline{N}) = G(c|x)$ *for all* $x \in \mathcal{X}$.
2. *There exists a set of periods* $\mathcal{T}$ *such that for each* $\tau \in \mathcal{T}$ *there exists a subset* $Z_\tau \subset \mathcal{Z}$ *for which the state transitions do not depend on the government's choice:* $q_{1,\tau}(z_{\tau+1}|z_\tau) = q_{0,\tau}(z_{\tau+1}|z_\tau)$ *for all* $\tau \in \mathcal{T}$ *and* $z_\tau \in Z_\tau$.
3. $G(c|x)$ *is strictly increasing for all* $x \in \mathcal{X}$.
4. *For each fixed* x, $R(x, n)$ *is strictly decreasing in* n *so that* $R^{-1}(n; x)$ *exists.*

Figure 2: Identification of Government Cost Distribution



Note: Holding the contract characteristics x_t fixed, the distribution function of government costs evaluated at the expected contract price for each level of competition n maps exactly to the conditional choice probability for that state.

5. *$\omega(\delta_0) = 0$ for some $\delta_0 \in \Delta$ and the discount factor β is known.*

Then $G(c \mid x)$ and $\omega(\delta)$ are identified for all $x \in \mathcal{X}$ and $\delta \in \Delta$.

Assumption 1 is the exclusion restriction which allows for variation in $\overline{N}$ to identify quantiles of the government cost distribution. Assumption 2 is the assumption that ensures a set of periods and states for which all future value terms cancel. Assumption 3 is required to apply the inversion theorem of Hotz and Miller (1993). Assumption 4 guarantees a one-to-one mapping between $\overline{N}$ and expected winning bids for a given x. Finally, Assumption 5 is a normalization that enables identification of $\omega(\delta)$ for all $\delta \neq \delta_0$.

4.3 Auction Game

Identification for the distribution of firm costs follows the arguments of Guerre, Perrigne, and Vuong (2000) and Athey and Haile (2002) applied to auctions in which bidders have independent private costs and only the winning bid is observed. The number of bidders n is known. Let $W(\cdot)$ denote the distribution of winning bids. The costs for winning bidders can be expressed in terms of the submitted bid and winning bid distribution as $c_f^W = b - \frac{n[1-W(b)]}{(n-1)w(b)}$, where $w(\cdot)$ is the density associated with the distribution $W(\cdot)$. This gives the distribution of winning costs $F_W(c_f)$, and an order statistic transformation yields the distribution of all firms' costs.

Identification of the entry cost distribution follows a similar argument to that of the identification of the government cost distribution. For a fixed vector of project characteristics x in market k with the number of potential bidders denoted $\overline{N}_k$, the equilibrium entry cutoff $e_k^*(x)$ can be obtained by using the observed participation decisions for the probability distribution over the number of bidders in (1):

$$e_k^*(x) = \sum_{j=1}^{\overline{N}_k} \eta_{jk}(x)\mathbb{E}[u_i|n=j,x] \tag{10}$$

where $\eta_{jk}(x)$ is the observed probability of j bidders in an auction with characteristics x in market k. Variation in the number of potential bidders across districts generates different values for $e^*(x)$.[24] This means that

$$\sum_{j=1}^{\overline{N}_k} \zeta(e_k^*(x))^j(1-\zeta(e_k^*(x))^{\overline{N}_k - j}\mathbb{E}[u_i \mid n=j,x] = e_k^*(x) \tag{11}$$

holds for each market $k \in \mathcal{K}$. Then the quantiles of the distribution ζ associated with each value of $e_k^*(x)$ are identified from (11).

5 Estimation and Results

Estimation of the model primitives proceeds in three stages. In the first stage, nonparametric estimators for the number of potential bidders in each district and the

[24]Specifically, a lower number of potential bidders increases the expected profit and raises the equilibrium entry cutoff, while a higher number of potential bidders has the opposite effect.

expected auction price are obtained. These are then used to estimate the government cost distribution and distance costs following the strategy laid out in the previous section. Finally, the observed distribution over the number of bidders is used with the estimated number of potential bidders to estimate the entry cost distribution, and firm costs are estimated from the auction data.

While the identification results from the previous section are non-parametric, in practice the number of observations and the size of the state space make non-parametric estimation impractical. Hence, I make the following parametric assumptions in estimation: government costs are assumed to be drawn from a Weibull(α, ρ) distribution, the winning bids distribution is parameterized as Log-Normal(μ, γ), and entry costs are drawn from Exponential(λ). All parameters are log linear in the project characteristics (and the number of bidders in the case of μ and γ). Travel distance costs are assumed to be linear: $\omega(\delta) = \theta\delta$. Finally, I fix the yearly discount factor $\beta = 0.94$.

Estimation is done via maximum likelihood. The winning bid distribution parameters (λ, γ) are estimated directly from the winning bid observations for auctions with two or more bidders. This winning bid distribution is then used to estimate the cost distribution. The government cost distribution is estimated by maximizing likelihood of the observed outsourcing decisions over the temporarily static periods, where the likelihood for each observation is a Bernoulli likelihood in which the probability of keeping a project in-house is determined by the government cost parameters (α, ρ) and the expected winning bid $R(x_t, \overline{N}_{k_t})$. Similarly, firms' entry likelihood is a binomial likelihood in which the entry probability is determined by the probability of being below the equilibrium entry cutoff, which is computed using the firm cost distributions and empirical probabilities over the number of bidders. Finally, the travel cost parameter is estimated by backwards induction of the value function using the estimated government cost distribution. Confidence intervals are obtained via subsampling following the procedure of Politis, Romano, and

Wolf (1999). Additional details on estimation can be found in Appendix B.

5.1 Estimates

The estimates for the government cost distribution and the distance cost are contained in Table 3. Larger projects and projects that take longer to complete increase expected cost, while also increasing the expected winning bid in the auction market. Results from the dynamic model demonstrate that distance costs are substantial, with each additional 100 miles adding $23,400 to total costs. The average contribution of travel costs for projects taken by the government is 3% for all projects and 7% for projects that involve changing districts.

Simulated results using the model estimates are listed in Table 4. To obtain the model predictions the model was simulated 500 times using the estimated values. The model matches the percentage of government projects outsourced and the total contract costs from outsourcing well. Total accumulated distance by government vessels is slightly overestimated by the model. Average project characteristics for both in-house projects and outsourced projects also fit model predictions well.

5.2 Comparing Government and Firm Costs

Using the estimates from the structural model I analyze the relative effects that competition and costs have on project allocation. Figure 3 displays the cost distribution for the government plotted against the winning bid distribution for auctions with three bidders and the distribution of firm costs for three levels of project size quantiles. The quantiles are for both project volume and length: the 0.25 quantile corresponds to a project with the 0.25 percentile for cubic yards of material dredged and the 0.25 percentile for working days. As can be seen from the top three graphs in Figure 3, the mean government cost of project completion is lower than the expected winning bid for the 0.25 project size quantile, while being approximately even at the median project size and substantially greater than the winning bid at

Table 3: Estimates

	Estimate	95% C.I.
Government Costs		
α		
Constant	0.8189	[0.6878, 1.2892]
Project Size	0.0019	[-0.006, 0.0023]
Working Days	0.4665	[0.4532, 0.7376]
ρ		
Constant	3.3371	[2.9715, 5.0990]
Project Size	0.0001	[-0.003,0.0002]
Working Days	-0.0320	[-0.0907, -0.0278]
θ		
Distance (100's of miles)	0.0234	[0.0102, 0.0535]
Entry Costs		
λ		
Constant	-3.9215	[-4.9163, -2.8764]
Project Volume	0.3386	[0.2680, 0.4297]
Working Days	-0.1009	[-0.2762, 0.0388]
Winning Bid Distribution		
μ		
Constant	2.3525	[2.3259,2.3777]
Project Size	0.0267	[0.0250,0.0285]
Working Days	0.0009	[0.0006,0.0012]
Number of Bidders	-0.0035	[-0.0054,-0.0016]
γ		
Constant	0.7364	[0.4465,1.0197]
Project Size	-0.0870	[-0.1077,-0.0667]
Working Days	0.0018	[-0.0009,0.0057]
Number of Bidders	0.0122	[-0.0145,0.0411]

the 0.75 quantile.

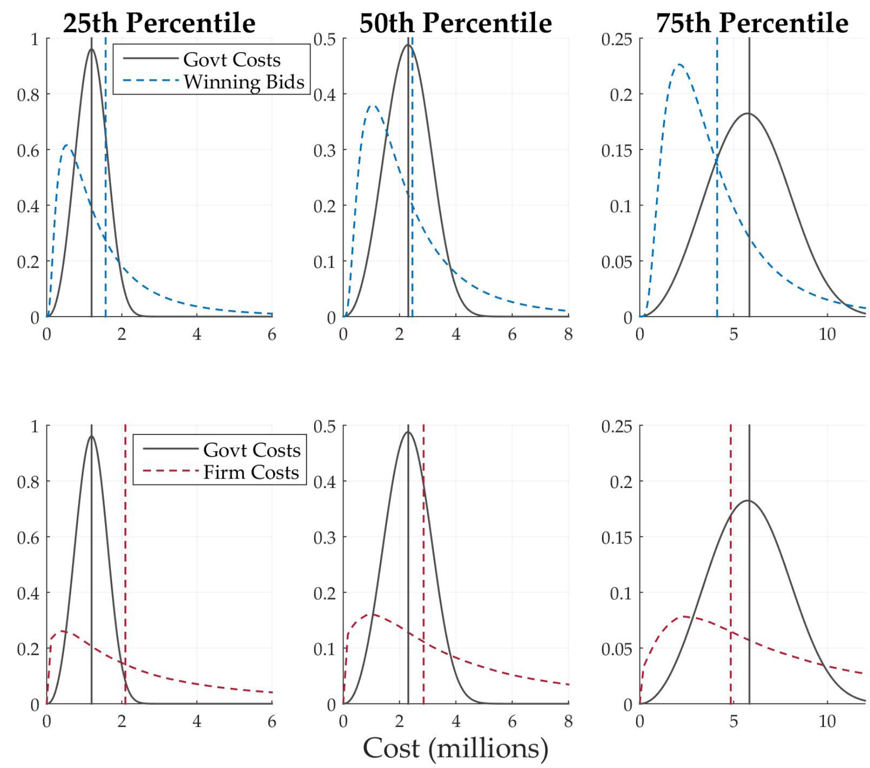
The relationship between firm costs and government costs is similar, although as is to be expected the firm cost distribution has both a higher mean and variance than the winning bid distribution. This leads to a government cost advantage on average for median-sized projects, while the expected winning bid is almost exactly equal to government costs. The high variance in firm costs and the two-stage nature of the outsourcing process can lead to inefficient allocation of projects; I will quantify the extent to which this occurs in the following section.

Table 4: Model Fit

	Data	Predicted
In-house projects (pct.)	50.98	49.46
Annual Contract Costs (millions)	$472.7	$492.0
Govt. distance traveled per project	136.6	132.4
Govt. cu. yds. per project (thousands)	273.7	274.7
Firm cu. yds. per project (thousands	1,177	1,166
Working days per project (govt.)	17.95	15.28
Working days per project (firms)	125.8	125.4

These results suggest that the role of government in this market varies with the type of project being considered. For smaller projects that require less time and use of capital resources, government vessels act as the main source for project completion. Indeed, most of the projects that are smaller in scope are kept in-house. In contrast, for larger projects the government acts essentially as a fringe competitor: given the large difference in average costs for projects above the 75th percentile, a cost draw that would lead the government to forgo contracting the project out to a private firm would be rare.

Figure 3: Distributions of Government Costs, Winning Bids, and Firm Costs



Note: This figure compares the distribution of government costs with winning bid and firm cost distributions for the 0.25, 0.50, and 0.75 quantiles of project size. The three graphs in the top panel display government costs distributions plotted with the winning bid distributions for auctions with 3 bidders, while the bottom three graphs shows firm cost distributions. Means associated with each distribution are displayed as vertical lines.

5.3 Cost vs. Competition Effect in Outsourcing

Previous reduced form studies (e.g. Stevens (1978), Snyder, Trost, and Trunkey (2001)) have aimed to quantify the extent to which government outsourcing decisions are driven by differences in cost between public sector provision and private firms and to what extent they are driven by outsourcing decisions inducing competition amongst firms. I estimate the cost and competition effects by comparing the estimated government cost against the expected outsourcing cost when there is one bidder and the expected outsourcing cost for the standard competition level. I define the competition effect to be the difference in costs between the one-firm case and the baseline competition, while the cost effect is the difference between the government's cost and the cost in the one-firm case.

I find that 79 percent of the cost savings between government and private sector firms for outsourced projects is due to the cost effect, while 21 percent is due to the competition effect. This result is intuitive given the relatively low level of competition and the large cost differences between public vs. private provision for large projects. It should be noted that the cost effect varies substantially for outsourced projects according to project size. In general a mixed-delivery approach is likely to be most beneficial when the competition effect is small and there is variability in the cost effect, so that the government can take (or at least credibly threaten to take) projects which might otherwise only have a single competitor.

6 Counterfactual Simulations

This section presents the results of two counterfactual policy simulations. First, I investigate the effect of reductions to the government's dredging fleet in order to determine the importance of government dredging on total expenditures. Second, I implement an alternate procurement mechanism. In this mechanism the government directly participates in the auction by setting a dynamically optimal reserve price that takes into account both current and future costs of in-house completion.

6.1 Reduction in Government Capacity

In order to investigate the effect that government presence in the market has on total expenditures I perform a counterfactual policy simulation in which I reduce the government's capacity. Lessening the ability to complete projects in-house will indicate how important direct public sector involvement in project completion is for minimizing government expenditures. Additionally, fixed costs of maintaining dredges are high; the USACE estimates that annual costs for keeping a dredge operational run in excess of $2 million. Retiring under-utilized dredges may thus save costs through eliminating their associated fixed costs.

The counterfactual is run by simulating the model a sequence of times. For each iteration the vessel that was active for the fewest working days is removed from the government's fleet. The simulations track the number of projects kept in-house as well as total expenditures on dredging projects.

The results of the simulations are summarized in Figure 4. Small reductions in government fleet size have little effect on expenditures: reducing the fleet size by one increases annual outsourcing costs by $0.32 million and a reduction of 2 vessels increases annual outsourcing costs by $ 1.38 million. However, further reductions are more impactful. When four vessels are removed, annual government costs increase by over $9 million per year, and a four vessel reduction corresponds to a $15 million per year increase. These results suggest that while government may be slightly over-invested in dredging capacity, government dredges nevertheless remain important in lowering total expenditures.

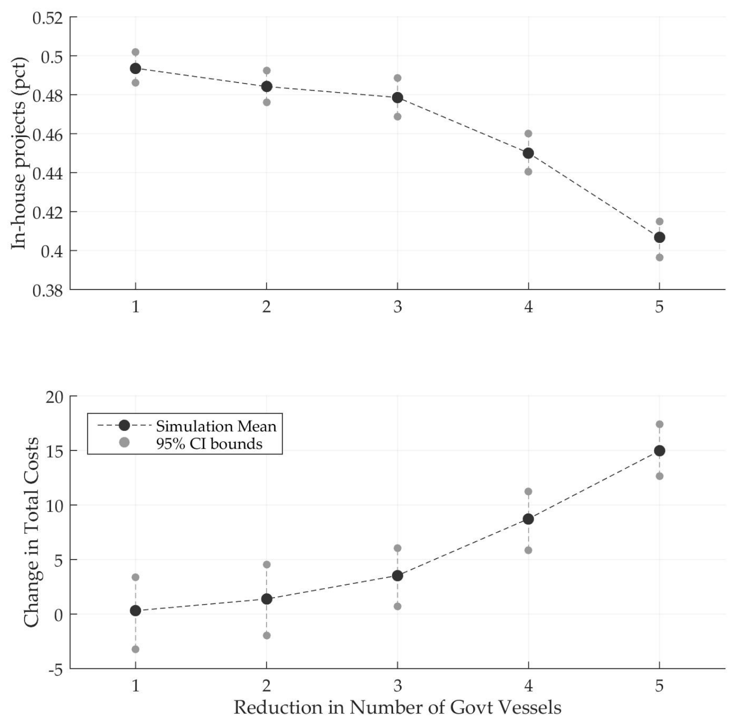
6.2 Direct Government Competition

I perform a counterfactual policy experiment which features direct competition between the government and private sector firms for each project that uses government costs as the outside option of not outsourcing to the private sector.[25]In this new mechanism, the government holds a second price auction for every project with a reserve rate set by the government's cost for doing the project and the future value components.[26] This reserve rate ensures that the project is allocated to

[25]This is a similar concept to the privatization competitions used in other situations by the Department of Defense; Snyder, Trost, and Trunkey (2001) empirically investigates these competitions.

[26]A publicly announced reserve price results in lower expected cost to the government than a secret reserve that would be the case if the government were to submit a bid in the auction; see Elyakime,

Figure 4: Vessel Reduction Simulation Results



Note: Summary of the results of the capacity reduction counterfactual simulation. On the x-axis is the number of vessels subtracted from the baseline model. The y-axis on the two figures correspond to the percentage of projects kept in-house and the annual project costs (in millions of dollars), respectively.

the supplier in the auction with the lowest cost, whether that is government or a private firm.[27]

If no bids are placed below the government's reserve rate, the project is kept in-house. Otherwise, the project is contracted out to the lowest-bidding firm, with the contract price determined by the second lowest cost (which may be the government's reserve price). Because bidder entry into the auctions may be affected by the presence of a reserve price, the entry equilibrium is recalculated for each auction and this is used to compute the government's value function. The procedure is described briefly below, and full details of the simulation can be found in Appendix A.

In the auction stage for a project in period t, the government has drawn a project cost c_{gt} with distance cost $\theta\delta_t$ and has expected future value terms $\overline{V}_{t+1}(z)$ for each $z \in \mathcal{Z}$. Then the maximum bid that the government is willing to accept in order to contract the project out is

$$r_t^* = c_{gt} + \theta\delta_t + \beta \sum_{z \in \mathcal{Z}} \left[\overline{V}_{t+1}(z_{t+1})(q_{1t}(z|z_t) - q_{0t}(z|z_t)) \right]. \tag{12}$$

Hence, the value in (12) gives the reserve price set by the government in each auction. The reserve price will also affect bidder entry, as the presence of a reserve price changes the expected profit obtainable by potential entrants. Modifying equation (1) to account for a reserve price r yields the new equilibrium cutoff condition:

$$e_r^* = \sum_{j=1}^{\overline{N}} \binom{\overline{N}}{j} \zeta(e_r^*)^j (1 - \zeta(e_r^*))^{\overline{N}-j} \mathbb{E}[\tilde{u}_i | r, n = j], \tag{13}$$

where $\mathbb{E}[\tilde{u}_i \mid r, n]$ is the payoff for player i in a second price auction with n total bidders and a reserve price r. In order to account for the effect that the reserve price policy has on entry decisions into the auctions, I re-compute the equilibrium

Laffont, Loisel, and Vuong (1994).

[27] This policy is motivated by efficient allocation. Alternative approaches could also be considered, such as a reserve price that minimizes total expected costs.

entry cutoff for each auction. The timing is as follows: each period, the government draws its cost c_{gt} and sets the reserve price according to (12). Next, entry costs for each firm are drawn from ζ. Using the new equilibrium cutoff $\tilde{e}_{k_t}(x_t)$, firms with entry costs lower than $\tilde{e}_{k_t}(x_t)$ enter the auction. Auction entrants then learn their private costs c_f and bid in a second-price auction for the project contract. If no firm's bid is lower than the government reserve, the project is kept in-house. Otherwise, the project is awarded to the lowest bidder who receives the minimum of the reserve price and the second-lowest bid.

The results of the counterfactual policy experiment, obtained from 500 simulations of the model, are contained in Table 5. Direct competition of government vessels against private sector firms lowers total expenditures by 17.1%. One of the key reasons for this is that the reserve price binds in many cases when the project would otherwise have been issued at a higher cost: a low-cost bidder may submit a bid greater than the government's cost of completing a project and still win the auction if the level of competition is low. The government reserve caps the amount awarded to the winning firm for these auctions, and in many such cases the project would have been kept in-house under the baseline model of choosing to outsource before the auction result was known. The "wait and see" approach of the direct competition model allows the government to opportunistically outsource projects after seeing how bidding unfolds, facilitating lower total expenditures.

Table 5: Results of Direct Government Competition Counterfactual Simulation

	Predicted Costs (millions)	% Change from Baseline Model
Government	$101.9	-38.26%
Outsourcing	$442.8	-10.0 %
Total	$544.7	-17.1 %

Note: Results of the counterfactual policy experiment of government reserve prices.

7 Conclusion

This paper studied the outsourcing of dredging projects by the US Army Corps of Engineers. A dynamic binary choice model of outsourcing decisions is formulated and estimated using a novel identification strategy to identify the full distribution of the random component of government payoffs. I supply evidence of cost differences between the government and private firms that varies by project type, with in-house project allocation often proving optimal for smaller projects while larger projects are more likely to be contracted out. I find substantial private sector firm cost advantages for outsourced projects, averaging 23% lower costs than government provision, and also that government in-house provision remains optimal for a large share of projects.

The model estimates are used to perform two counterfactuals. In the first, the total capacity of the government is reduced in order to investigate the effect of government presence in the dredging market. I find that a reduction of up to one sixth to government capacity would have little effect on total expenditures, while larger reductions prove more consequential. In the second counterfactual I feature direct competition of government against private firms through a dynamically optimal reserve price determined by government costs. The result is a 17.1% decrease in total government expenditures. These results are primarily due to the fact that private firms and government face different cost structures that vary based on project characteristics and competition is low, suggesting that in markets facing similar conditions there is scope for government involvement in the market, combined with a procurement mechanism aimed at taking full advantage of government presence, to enhance efficiency and lower costs of public good provision.

References

Arcidiacono, P., and R. A. Miller (2011): "Conditional Choice Probability Estimation of Dynamic Discrete Choice Models with Unobserved Heterogeneity," *Econometrica*, 79(6), 1823–1867.

Athey, S., and P. A. Haile (2002): "Identification of Standard Auction Models," *Econometrica*, 70(6), 2107–2140.

Bel, G., and J. Rosell (2016): "Public and Private Production in a Mixed Delivery System: Regulation, Competition and Costs," *Journal of Policy Analysis and Management*, 35(3), 533–558.

Decarolis, F. (2017): "Comparing Procurement Auctions," *International Economic Review*, Forthcoming.

Elyakime, B., J. J. Laffont, P. Loisel, and Q. Vuong (1994): "First-price sealed-bid auctions with secret reservation prices," *Annales d'Economie et de Statistique*, pp. 115–141.

Grossman, S. J., and O. D. Hart (1986): "The Costs and Benefits of Ownership: A Theory of Vertical and Lateral Integration," *Journal of Political Economy*, pp. 691–719.

Guerre, E., I. Perrigne, and Q. Vuong (2000): "Optimal Nonparametric Estimation of First-Price Auctions," *Econometrica*, 68(3), 525–574.

Hart, O., and J. Moore (1990): "Property Rights and the Nature of the Firm," *Journal of Political Economy*, pp. 1119–1158.

Hart, O., A. Shleifer, and R. W. Vishny (1997): "The Proper Scope of Government: Theory and an Application to Prisons," *Quarterly Journal of Economics*, 112(4), 1127–1161.

Holmstrom, B., and P. Milgrom (1994): "The Firm as an Incentive System," *American Economic Review*, pp. 972–991.

Holmstrøm, B., and J. Roberts (1998): "The Boundaries of the Firm Revisited," *Journal of Economic Perspectives*, 12(4), 73–94.

Hotz, V. J., and R. A. Miller (1993): "Conditional Choice Probabilities and the Estimation of Dynamic Models," *Review of Economic Studies*, 60(3), 497–529.

Kang, K., and R. A. Miller (2017): "Winning by Default: Why is there so little competition in government procurement?," Discussion paper.

Krasnokutskaya, E., and K. Seim (2011): "Bid Preference Programs and Participation in Highway Procurement Auctions," *American Economic Review*, 101(6), 2653–2686.

Lafontaine, F., and M. Slade (2007): "Vertical Integration and Firm Boundaries: The Evidence," *Journal of Economic Literature*, pp. 629–685.

Levin, D., and J. L. Smith (1994): "Equilibrium in Auctions with Entry," *American Economic Review*, pp. 585–599.

Levin, J., and S. Tadelis (2010): "Contracting for Government Services: Theory and Evidence from U.S. Cities," *Journal of Industrial Economics*, 58(3), 507–541.

Lewbel, A. (2000): "Semiparametric qualitative response model estimation with unknown heteroscedasticity or instrumental variables," *Journal of Econometrics*, 97(1), 145–177.

Lewis, G., and P. Bajari (2011): "Procurement contracting with time incentives: Theory and evidence," *The Quarterly Journal of Economics*, 126(3), 1173–1211.

Li, T., and X. Zheng (2009): "Entry and Competition Effects in First-Price Auctions: Theory and Evidence from Procurement Auctions," *Review of Economic Studies*, 76(4), 1397–1429.

Niskanen, W. A. (1968): "The Peculiar Economics of Bureaucracy," *American Economic Review*, pp. 293–305.

——— (1971): *Bureaucracy and representative government*. Transaction Publishers.

Politis, D. N., J. P. Romano, and M. Wolf (1999): *Subsampling*. Springer, New York.

Shleifer, A., and R. W. Vishny (1994): "Politicians and Firms," *Quarterly Journal of Economics*, pp. 995–1025.

Snyder, C. M., R. P. Trost, and R. D. Trunkey (2001): "Reducing Government Spending with Privatization Competitions: A Study of the Department of Defense Experience," *Review of Economics and Statistics*, 83(1), 108–117.

Stevens, B. J. (1978): "Scale, Market Structure, and the Cost of Refuse Collection," *The Review of Economics and Statistics*, pp. 438–448.

Warner, M., and R. Hebdon (2001): "Local Government Restructuring: Privatization and its Alternatives," *Journal of Policy Analysis and Management*, 20(2), 315–336.

Williamson, O. E. (1975): "Markets and Hierarchies," *New York*, pp. 26–30.

——— (1979): "Transaction-cost Economics: the Governance of Contractual Relations," *Journal of Law and Economics*, pp. 233–261.

——— (1999): "Public and Private Bureaucracies: A Transaction Cost Economics Perspectives," *Journal of Law, Economics, and Organization*, 15(1), 306–342.

A Appendix A: Proofs and Simulation Details

A.1 Identification of Government Cost Primitives

Proof of Proposition 1. The proof proceeds in three stages. First, the identification of G from the static observations is shown. Next, an expression for the value function that makes use of the distribution estimated in the first stage is derived. Finally, identification of $\omega(\delta)$ is established by using techniques similar to Arcidiacono and Miller (2011).

First, take $\tau \in \mathcal{T}$. The conditional choice probability $p_{0\tau}(z_\tau)$ is

$$\begin{aligned} p_{0\tau}(z_\tau) &= \Pr\left(-c_{g\tau} - \omega(\delta_0) + \beta \sum_{z \in \mathcal{Z}} \overline{V}_{\tau+1}(z) q_{0\tau}(z|z_\tau) \geq -R(x_\tau, \overline{N}_{k_\tau}) + \beta \sum_{z \in \mathcal{Z}} \overline{V}_{\tau+1}(z) q_{1\tau}(z|z_\tau)\right) \\ &= G(R(x_\tau, \overline{N}_{k_\tau})|x_\tau) \end{aligned}$$

where the equality follows from the assumption that $\omega(\delta_0) = 0$ and $q_{0\tau}(z|z_\tau) = q_{1\tau}(z|z_\tau)$ for all $z \in \mathcal{Z}$ and $\tau \in \mathcal{T}$. Then all choices in the set $\mathcal{T}$ are effectively static and depend only on $(x_\tau, \overline{N}_{k_\tau})$, so that $p_{0\tau}(z_\tau) \equiv p_{0\tau}(x_\tau, \overline{N}_{k_\tau})\ \forall \tau \in \mathcal{T}$. By assumption, $R^{-1}(x_\tau, c) : \mathcal{X} \times [\underline{c}, \overline{c}] \to \mathcal{H}$ exists. Hence,

$$G(c|x_\tau) = p_{0\tau}(x_\tau, R^{-1}(x_\tau, c)) \tag{14}$$

completing identification of G.

Identification of $\omega(\delta)$ proceeds by expressing the future value function in terms of observables. The first step is to use the inversion theorem of Hotz and Miller (1993) to establish the existence of a function $\phi(p_{0t}(z_t)) = v_{0t}(z_t) - v_{1t}(z_t)$. Because G is continuous and strictly increasing and $p_{0t} = \Pr(-c_{gt} + v_{0t}(z_t) \geq v_{1t}(z_t))$ it follows that $\phi(p_{0t}(z_t)) = G^{-1}(p_{0t}(z_t)|x_t)$.

Next we establish an expression for the expected government conditional on keeping a project in house:

$$\begin{aligned} \mathbb{E}[c_{gt}| - c_{gt} + v_{1t}(z_t) \geq v_{0t}(z_t)] &= \mathbb{E}[c_{gt}|c_{gt} \leq v_{1t}(z_t) - v_{0t}(z_t)] \\ &= \mathbb{E}[c_{gt}|c_{gt} \leq -\phi(p_{1t}(z_t))] \end{aligned}$$

As the distribution of c_{gt} is known and ϕ is given by the inversion theorem, this expression is known. Let $\xi(p_{1t}(z_t))$ denote this term. Following Arcidiacono and

Miller (2011), we can write the value function as follows:

$$V_t(z_t) = \sum_{j=0}^{1} p_{jt}(z_t) v_{jt}(z_t) + p_{1t}(z_t)\xi(p_{1t}(z_t)).$$

Subtracting $v_{1t}(z_t)$ from each side yields

$$\begin{aligned}
V_t(z_t) - v_{1t}(z_t) &= \sum_{j=0}^{1} p_{jt}(z_t) v_{jt}(z_t) + p_{1t}(z_t) \cdot \xi(p_{1t}(z_t)) - v_{1t}(z_t) \\
&= \sum_{j=0}^{1} p_{jt}(z_t)(v_{jt}(z_t) - v_{1t}(z_t)) + p_{1t}(z_t) \cdot \xi(p_{1t}(z_t)) \\
&= p_{0t} \cdot \phi(p_{1t}(z_t)) + p_{1t}(z_t) \cdot \xi(p_{1t}(z_t)) \\
&\equiv \psi_1(p_t(z_t)) \qquad (15)
\end{aligned}$$

Using a similar procedure, we define $\psi_0(p_t(z_t)) \equiv p_{1t} \cdot \phi(p_{1t}(z_t)) + p_{1t}(z_t) \cdot \xi(p_{1t}(z_t))$. Now that expressions for the ψ_j terms have been derived we can appeal directly to the results of Arcidiacono and Miller (2011) for the remainder of the proof. Specifically, let $\{d'_\tau\}_{\tau=t+1}^{T}$ be any sequence of decisions from τ until T. Using the definition of $\psi_j(p_\tau(z_\tau))$ we can write the conditional value function for choice $d_t = 0$ as

$$v_{0t}(z_t) = \pi_{0t}(z_t) + \sum_{\tau=t+1}^{T} \sum_{z_\tau \in \mathcal{Z}} \beta^{\tau-t}[\pi_{d'_\tau \tau}(z_\tau) + \psi_{d'_\tau}(p_{d'_\tau \tau}(z_\tau))]\kappa_{\tau-1}(z_\tau | z_t, d'_t = 1) \quad (16)$$

with a similar expression for $v_{1t}(z_t)$. Noting that

$$v_{1t}(z_t) - v_{0t}(z_t) = \psi_0(p_t(z_t)) - \psi_1(p_t(z_t))$$

we can insert plug in the expressions for $v_{1t}(z_t)$ and $v_{0t}(z_t)$ and set $d'_\tau = 1$ for all

$\tau > t$ to obtain, upon rearrangement

$$\begin{aligned}\omega(\delta_t) &= R(x_t, \overline{N}_{k_t}) - \psi_0(p_t(z_t)) + \psi_1(p_t(z_t)) \\ &\quad - \sum_{\tau=t+1}^{T} \beta^{\tau-t} \sum_{z_\tau \in \mathcal{Z}} [-R(x_\tau, \overline{N}_{k_\tau}) + \psi_0(p_\tau(z_\tau))](\kappa_{\tau-1}(z_\tau|z_t, 0) - \kappa_{\tau-1}(z_\tau|z_t, 1)).\end{aligned}$$

This yields an expression for $\omega(\delta_t)$ in terms of functions of state variables which are known from normalizations ($R(x_\tau, \overline{N}_{k_\tau})$, the distribution of the unobserved term identified in the first stage ($\psi(p_\tau(z_\tau))$), or observed in the data ($\kappa_{\tau-1}(z_\tau \mid z_{\tau-1}, d_t)$), completing identification of $\omega(\delta_t)$. ■

A.2 Government Reserve Price Simulation

To perform the counterfactual policy in which government sets a reserve price for each auction, it is necessary to re-compute the value function for each state as auction entry and bidding (and therefore expected winning bid) are affected by the establishment of a reserve price policy. Ex-ante value functions for each state are computed using the following sequence of steps, which is run for each fiscal year-region pair:

1. Starting in period T, government draws cost c_{gT}, sets $r^*(c_{gT})$ to be $r^*(c_{gT}) = c_{gT} + \theta\delta_t$.
2. Expected profit conditional on reserve price $r^*(c_{gT})$ and j bidders for each $j \in \{1, .., \overline{N}_{k_t}\}$ is calculated by simulating the auction 200 times.
3. For each $n = 1, ..., \overline{N}_{k_t}$, the expected profit for each bidder conditional on entry is calculated by simulating auction outcomes 200 times for each number of bidders.

$$\mathbb{E}[\tilde{u}_i|n, x_T, r^*] = \Pr(c_i < c_j \forall j \neq i) \cdot \mathbb{E}[b(c_i) - c_i|c_i < c_j \forall j \neq i, c_i \leq r^*(c_{gT})]$$

4. The expected profit and entry cost distribution are used to solve for the equi-

librium entry cutoff $\tilde{e}_k(x_T)$:

$$\tilde{e}_k(x_T; r^*(c_{gT})) =$$

$$\sum_{j=1}^{\overline{N}_{k_t}} \Big(\zeta(\tilde{e}_k(x_T; r^*(c_{gT})))^j [1-\zeta(\tilde{e}_k(x_T; r^*(c_{gT})))]^{\overline{N}_{k_t}-j}\Big) \cdot \mathbb{E}[\tilde{u}_i \mid j, x_T, r^*(c_{gT})]$$

5. Using the entry cost cutoff $\tilde{e}_k(x_T)$, the distribution over the number of bidders can be expressed

$$\Pr(n = j|\tilde{e}_k(x_T; r^*(c_{gT}))) = \zeta(\tilde{e}_k(x_T; r^*(c_{gT})))^j [1-\zeta(\tilde{e}_k(x_T; r^*(c_{gT})))]^{\overline{N}_{k_t}-j}$$

6. Draw from the number of bidders distribution and simulate the auction outcome.

7. Average over simulations s to obtain CCPs and conditional payoffs: $\tilde{p}_{0T}(z_T) = \frac{1}{200}\sum_{s=1}^{200} \mathbb{1}\{d_{sT} = 0\}$, $\mathbb{E}[\tilde{V}_{0T}(z_T)|d_T = 0] = -\frac{\sum_{s=1}^{200} \mathbb{1}\{d_{sT}=0\}(c_{gsT}+\theta\delta_t)}{\sum_{s=1}^{200} \mathbb{1}\{d_{sT}=0\}}$, and $\mathbb{E}[\tilde{V}_{1T}(z_T)|d_T = 1] = -\frac{\sum_{s=1}^{200} \mathbb{1}\{d_{sT}=1\}b_s^1}{\sum_{s=1}^{200} \mathbb{1}\{d_{sT}=1\}}$ where b_s^1 is the winning bid in auction s.

8. Ex-ante value function computed as $\tilde{V}_T(z_T) = \tilde{p}_{0T}(z_T)\mathbb{E}[\tilde{V}_T|d_T = 0] + (1-\tilde{p}_{0T}(z_T))\mathbb{E}[\tilde{V}_T|d_T = 1]$.

9. Iterating backwards from $t = T-1, .., 1$, draw 200 government costs c_{gst} for each t and z_t from $G(\cdot|x_t)$. Set reserve price $r^*(c_{gst}) = c_{gst}+\theta\delta_t+\beta\sum_{z\in\mathcal{Z}}\tilde{V}_{t+1}(z_t)(q_{0t}(z|z_t)-q_{1t}(z|z_t))$.

10 . Repeat steps 1 through 8, with $\mathbb{E}[\tilde{V}_{0T}(z_T)|d_T = 0] = -\frac{\sum_{s=1}^{200} \mathbb{1}\{d_{st}=0\}(c_{gst}+\theta\delta_t-\beta\sum_{z\in\mathcal{Z}}\tilde{V}_{t+1}(z)q_{0t}(z|z_t))}{\sum_{s=1}^{200} \mathbb{1}\{d_{st}=0\}}$, and $\mathbb{E}[\tilde{V}_{1T}(z_T)|d_T = 1] = -\frac{\sum_{s=1}^{200} \mathbb{1}\{d_{sT}=1\}b_s^1-\beta\sum_{z\in\mathcal{Z}}\tilde{V}_{t+1}(z)q_{1t}(z|z_t)}{\sum_{s=1}^{200} \mathbb{1}\{d_{sT}=1\}}$.

The simulation is run by beginning at the first project for each region and fiscal year, drawing cost c_{gt} and setting the reserve price using the simulated value functions, and simulating the entry process and auction outcome. If the lowest cost for private sector firms in the auction is lower than the reserve price, the project is outsourced. Otherwise, the project is kept in-house. Then the state variables are updated and the simulation proceeds to the next stage. The simulation is run 500 times for each fiscal year-region pair.

B Appendix B: Data and Estimation

B.1 Sample Construction

The original sample consists of 2487 contracted-out projects and 1945 projects completed by the Corps. Any projects that were missing bid information, project size, start date, or the number of working days were removed. There are three Corps districts that contract out dredging work on the Great Lakes: Chicago, Buffalo, and Detroit. These contracts were also removed, as there are no Corps-owned dredges that are active in the Great Lakes region. Lastly, extremely large projects (expected contract price exceeding $20M) were removed, as projects of this size are never observed to be taken by Corps dredges and they often require multiple large dredges working on the project at once, which is not something the Corps is equipped to accommodate. 77 Corps projects that had overlapping dates in the same district were combined. Additionally, 29 projects involving emergency dredging after the Deepwater Horizon oil spill in the Gulf region were removed. This leaves a final sample of 3625 observations across 31 districts.

Table 6 gives a list of USACE districts and provides a breakdown of how many of the total projects in each district are Corps projects and how many are contracted out. It also lists the average volume of dredged material for projects in each district. Table 7 lists the total dredging projects each year and indicates how many were Corps projects and how many were contracted out.

Table 6: USACE Districts

District	**Total Projects**	**Corps Projects**	**Contracted Projects**	**Mean Project Size** (cu. yds. in thousands)
Alaska	51	2	49	401
Baltimore	112	112	73	537
Buffalo	78	0	78	206
Charleston	79	25	54	1,099
Chicago	33	0	33	94
Detroit	232	0	232	54
Galveston	215	0	215	1,747
Honolulu	8	2	6	94
Huntington	31	0	31	86
Jacksonville	189	17	172	624
Kansas City	2	2	0	47
Little Rock	4	0	4	1,251
Los Angeles	48	12	36	827
Louisville	16	1	15	945
Memphis	24	17	7	6,555
Mobile	127	16	111	1,296
New England	96	62	34	114
New Orleans	562	235	327	1,763
New York	138	26	112	524
Norfolk	203	80	123	270
Philadelphia	270	152	118	433
Pittsburgh	14	0	14	10
Portland	380	310	70	414
Rock Island	18	11	7	269
Sacramento	8	0	8	258
San Francisco	104	67	37	454
Savannah	43	0	43	2,798
Seattle	72	28	44	491
St. Louis	190	186	4	273
St. Paul	66	46	20	312
Tulsa	1	0	1	530
Vicksburg	86	68	18	765
Walla Walla	1	0	1	11
Wilmington	654	541	113	240

Table 7: Projects by Year

Fiscal Year	Total Projects	Corps Projects	Contracted Projects
1999	251	125	126
2000	232	114	118
2001	232	99	133
2002	263	141	122
2003	323	177	146
2004	275	145	130
2005	236	124	112
2006	248	156	92
2007	216	115	101
2008	218	118	100
2009	220	109	111
2010	283	132	151
2011	259	158	101
2012	251	145	106
2013	192	86	106

B.2 Estimation

B.3 Expected Contract Price

Expected winning bids are estimated directly from the data non-parametrically. First, the distribution over the number of bidders is estimated. This is done non-parametrically by counting the number of observations with each number of bidders after smoothing over contract characteristics. The maximum number of bidders in each district k is $\overline{N}_k$. This is estimated by taking the maximum number of bidders observed in the market over the sample period. Let $\eta_{kn}(x_t)$ be the probability that n bidders are observed in an auction with project characteristics x_t. Next the expected winning bid conditional on the number of bidders is with a Nadaraya-Watson estimator. Let $\mathcal{A}_n$ denote the set of auctions in which there are n bidders. Then the expected winning bid for an auction with characteristics x in market k is given by averaging over the expected winning bid for each number of bidders:

$$\hat{R}(x, \widehat{\overline{N}_{k_t}}) = \sum_{n=1}^{\widehat{\overline{N}_{k_t}}} \hat{\eta}_{kn}(x_t) \left(\frac{\sum_{t \in \mathcal{A}_n} K\left(\frac{x - x_t}{h_x}\right) b_t}{\sum_{t \in \mathcal{A}_n} K\left(\frac{(x - x_t)}{h_x}\right)} \right).$$

The kernel function K is a multiplicative normal kernel, and the bandwidth parameter h_x is obtained using Silverman's rule of thumb.

B.4 Government Cost Distribution

The government cost distribution is estimated from periods in which the available project is located in the same district as the assigned government dredge and the next available project in the dredge's region will begin after the current project has ended. There are 1086 such observations in the data.

Estimation of the parameters in (α, ρ) takes place by linking the observed choices for the static periods to the conditional distribution function of government costs. The each government choice observation is a draw from a Bernoulli distribution with probability parameter given by the distribution of government costs evaluated at the expected contract price. Recalling that G denotes the cdf of C_{gt}, we have that

$$\Pr(d_t = 0 | z_t) = G(R(x_t, \overline{N}_{k_t})).$$

We obtain the estimator for (α, ρ) by gathering all static observations and maximizing the joint two-step likelihood after plugging in the first-stage estimates for $R(z_t)$ obtained in the previous section. More formally, let $\mathcal{T}$ represent the set of periods in which the future value components of utility cancel. Then the estimator is

$$(\hat{\alpha}, \hat{\rho}) = \arg\max_{\alpha, \rho} \prod_{\tau \in \mathcal{T}} G(\hat{R}(x_t, \widehat{\overline{N}}_{k_t}); \alpha, \rho)^{1-d_t} \times [1 - G(\hat{R}(x_t, \widehat{\overline{N}}_{k_t}); \alpha, \rho)]^{d_t} \tag{17}$$

With the estimate for the government cost distribution we can proceed to the estimation of the dynamic model and recover the distance cost parameter.

B.5 Distance Parameter θ

In the data, several districts have multiple dredges that perform projects in the district. This complicates dynamic considerations, as the availability of both dredges must be accounted for when considering the future value component. For these regions, I consider all dredges that are linked by the overlapping district(s) simultaneously; this results in a state variable consisting of distances and locations for each of the dredges in that set of districts. In such cases I assume that an in-house decision to send the closest available dredge to the project. This assumption is empirically motivated: for over 97% of in-house projects the closest available dredge is selected to complete it.[28] This result of this grouping is a set of five non-overlapping regions $I_1, ..., I_5$, in which no vessel operating in any one of the regions takes projects in any of the others, that operate in parallel. There are also fifteen fiscal years Y spanning 1999-2013. Hence, the value function is generated via backwards induction for each region-year pair, and estimates are obtained by maximizing the likelihood across all such region-year pairs. For notational simplicity I drop the dependence on the regions I and fiscal year Y in much of what follows.

The last step in the estimation of the model primitives relating to government cost is to use the results of the first two stages to write an expression for the value function that allows for estimation of the distance cost parameter θ. Specifically, the estimator for θ will be a two-stage maximum likelihood estimator in which the first-stage estimates are plugged into the likelihood function for government decisions. The per-period discount factor is $\beta^{1/T_{IY}}$ where T_{IY} is the number of projects in region I for fiscal year Y. Construction of the value function is done through backwards induction; beginning in the last period T we have that the probability

[28]This can be understood by thinking of the network of districts as approximately linear, with most regions consisting of locations along the coast or within the inland waterway system. For these networks there is no distance reduction from sending any vessel that isn't already the closest to the project.

that the project is kept in-house $p_{0T}(z_t)$ is

$$\begin{aligned} p_{0T}(z_T) &= \mathbb{1}_{\{y_T=0\}} \Pr(C_{gT} + \theta\delta_T < R(x_T, \overline{N}_{k_T})) \\ &= \mathbb{1}_{\{y_T=0\}} G(R(x_T, \overline{N}_{k_T}) - \theta\delta_T \mid x_T) \end{aligned}$$

and $p_{1T}(z_T) = 1 - p_{0T}(z_T)$. Then the ex-ante value function in period T and state z_T is

$$\overline{V}_T(z_T) = p_{0T}(z_T)\mathbb{E}[\pi_0(z_T)|d_T = 0] + p_{1T}(z_T)\pi_1(z_T)$$

which can be expressed as

$$\overline{V}_T(z_T) = p_{0T}(z_T)\left[\theta\delta_T + \frac{\int_0^{R(x_T,\overline{N}_{k_t})-\theta\delta_T} u\hat{g}(u)du}{\hat{G}(R(x_T, \overline{N}_{k_T}) - \theta\delta_T)}\right] + p_{1T}(z_T)R(x_T, \overline{N}_{k_T}).$$

For $t = 1, ..., T - 1$ we have that

$$\begin{aligned} p_{1t}(z_t) &= \mathbb{1}_{\{y_t=0\}} \Pr\Bigg(C_{gt} + \theta\delta_t + \beta \sum_{z_{t+1}\in\mathcal{Z}} \overline{V}_{t+1}(z_{t+1})q_{0t}(z_{t+1}|z_t) < R(x_t, \overline{N}_{k_t}) \\ &\quad +\beta \sum_{z_{t+1}\in\mathcal{Z}} \overline{V}_{t+1}(z_{t+1})q_{1t}(z_{t+1}|z_t)\Bigg). \end{aligned}$$

Recalling that

$$\begin{aligned} v_{0t}(z_t) &= \theta\delta_t + \beta \sum_{z_{t+1}\in\mathcal{Z}} \overline{V}_{t+1}(z_{t+1})q_{0t}(z_{t+1}|z_t), \\ v_{1t}(z_t) &= R(x_t, \overline{N}_{k_t}) + \beta \sum_{z_{t+1}\in\mathcal{Z}} \overline{V}_{t+1}(z_{t+1})q_{1t}(z_{t+1}|z_t). \end{aligned}$$

then the ex-ante value function in period t and state z_t is

$$\overline{V}_t(z_t) = p_{0t}(z_t)\left[v_{0t}(z_t) + \frac{\int_0^{v_{0t}(z_t)-v_{1t}(z_t)} u\hat{g}(u)du}{\hat{G}(v_{0t}(z_t) - v_{1t}(z_t))}\right] + p_{1t}(z_t)v_{1t}(z_t).$$

Then we can express the conditional choice probability of keeping a project in-house as

$$\hat{p}_{0t}(z_t) = \hat{G}(v_{0t}(z_t) - v_{1t}(z_t)).$$

Recalling that there are five non-overlapping regions I and fifteen fiscal years Y, this gives the estimator for θ as

$$\hat{\theta} = \arg\max_{\theta} \prod_{I=1}^{5} \prod_{Y=1}^{15} \prod_{t \in T_{IY}} (\hat{p}_{1t})^{d_t} \times (1 - \hat{p}_{1t})^{1-d_t}. \tag{18}$$

where T_{IY} is the set of projects in region I during fiscal year Y. Since the estimates from the first stage are consistent estimates for the estimated winning bid and the distribution of government costs, (18) yields a consistent estimate for θ.

B.6 Entry Cost Distribution

Estimation of the entry cost parameters proceeds in two steps. First estimates for the equilibrium entry cutoff values $\hat{e}_k^*(x)$ are generated from equation (10) using the empirical distributions over the number of bidders $\hat{\eta}_{kn}$. Then for each λ, $\zeta(\hat{e}_k^*(x))$ gives the probability for an individual bidder's entry into an auction in market k with project characteristics x. The estimate $\hat{\lambda}$ is generated by maximizing the likelihood of the observed number of bidders in each auction.

B.7 Firm Cost Distribution

The winning bid distribution is estimated parametrically, with the parameterization given by

$$b_{it} \sim \text{Log-normal}(\mu_t, \gamma_t),$$

where

$$\log(\mu_t) = \mu_{0t} + \mu_{1t}x_{1t} + \mu_{2t}x_{2t} + \mu_3 N_t, \quad \log(\gamma_t) = \gamma_0 + \gamma_1 x_{1t} + \gamma_2 x_{2t} + \gamma_3 N_t.$$

Once estimates of the winning bid distribution parameters have been obtained, firm costs can be expressed as

$$\hat{c} = b - \frac{N[1 - \hat{W}(b)]}{(N-1)\hat{w}(b)}. \tag{19}$$

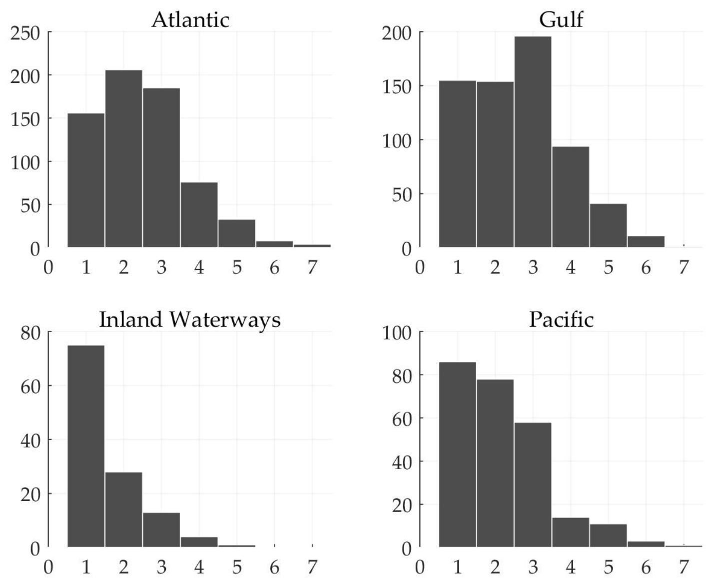
where b is a submitted bid. Hence for any bid, the associated cost can be found by applying (19) using the estimated winning bid distribution. To generate the cost distributions, bids are randomly sampled from the bid distribution obtained via the order statistic transformation $\hat{H}(b) = 1 - [1 - \hat{W}(b)]^{1/N}$ and these sampled bid values are used to generate firm costs $\hat{c}$.

B.8 Other Figures and Tables

This section gives additional figures and tables. Figure 5 shows the heterogeneity in competition across geographic regions. Table 8 shows results for a regression of number of variables that includes a measure of private sector capacity, "Ongoing Projects," as a dependent variable. The coefficient on this variable is not significant, indicating that private sector dredging companies do not face large capacity restrictions.

The final two figures, Figures 6 and 7, display information on the changes made to contractor payments after completion of the project. Both of these figures indicate that ex-post adjustments to payments are as likely to be negative as positive, with a mean payment change of -0.03% of the original winning bid. Figure 6 also suggests that there is no pattern of larger contracts being more susceptible to incomplete contracting or hold-up problems, as these do not display the pattern of high ex-post payment adjustments that would normally be associated with these occurring.

Figure 5: Histogram of Auction Participants by Region



Note: Histogram of the number of bidders in project auctions separated by region. Districts located on the Atlantic and Gulf coasts have comparatively higher numbers of bidders, while the Inland Waterways and Pacific regions have lower competition overall and a greater chance of having a single bidder.

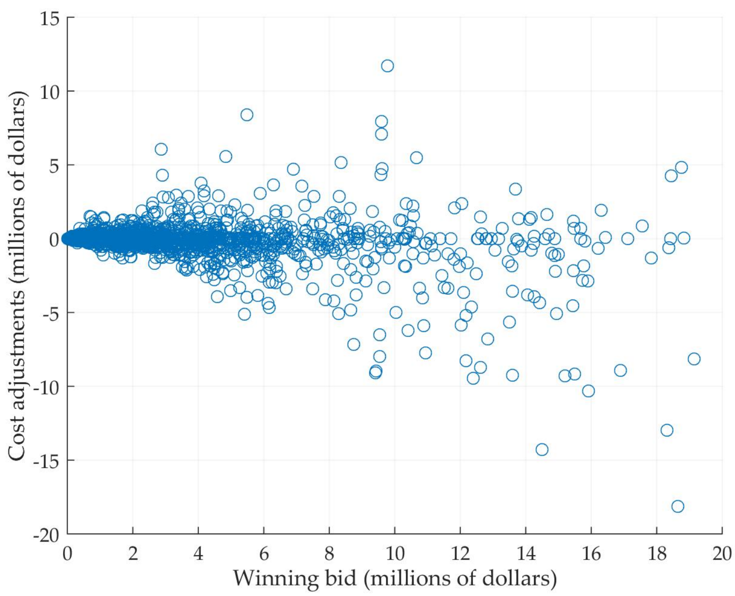
Table 8: Regressions of variables on number of bidders

Variable	**Coef.**	**Std. err**	**Coef.**	**Std. err**
log(Working Days)	0.009***	0.002	0.008***	0.002
log(Project Volume (cu. yds.))	-0.039	0.029	-0.079*	0.039
Ongoing Projects	-0.028	0.015	-0.025	0.016
Govt. Estimate			0.079	0.048
Consant	1.656***	0.205	0.737	0.577
District	Yes		Yes	
N	1777.000		1777.000	

* $p < 0.05$, ** $p < 0.01$, ***$p < 0.001$

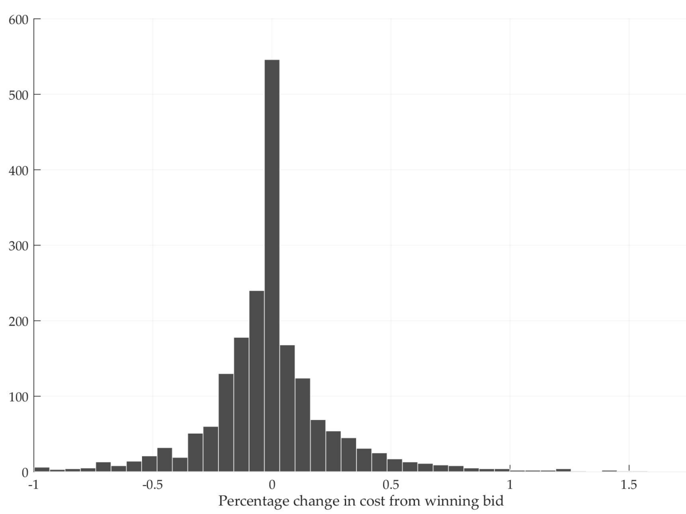
Note: This table contains regression results for the effect of observable characteristics on the number of bidders. The variable "Ongoing Projects" represents the number of projects underway in the district at the time the current project is set to begin. That this variable has a statistically insignificant effect on the number of bidders in the auction, suggesting that the number of currently ongoing projects does not impact bidder participation in auctions.

Figure 6: Winning Bids against Ex-post Payment Changes



Note: Plot of winning bids against the ex-post changes in payment to the contracted firm. There is no readily observable pattern that suggests cost adjustments correlate more strongly with smaller or larger projects; if anything, very large projects are more likely to have reductions made to the initial bid.

Figure 7: Histogram of Changes to Winning Bid



Note: This figure is a histogram of ex-post changes to contract price as a percentage of the winning auction bid. While nearly all contracts feature changes to the winning bid, the mean change is almost exactly zero.