Bidding Behavior in the Department of Defense's Commercial Activities Competitions

Christopher M. Snyder
Robert P. Trost
R. Derek Trunkey

Abstract

From 1978 to 1994, the Department of Defense conducted more than 2,000 competitions in which private contractors and the government's in-house team bid to provide a service performed in-house before the competition. A three-equation model is constructed, which is used to estimate the in-house bid, the minimum contractor bid, and the in-house team's baseline cost. The model accounts for the fact that the in-house bid is constrained not to exceed its baseline cost. The estimates are used in simulations of the savings from the completed competitions ($1.55 billion annually, 35 percent of the baseline cost) as well as the savings from various alternative policies, including competitively tendering all the functions on the Department of Defense's list of potential candidates ($7.58 billion annually). © 2001 by the Association for Public Policy Analysis and Management.

INTRODUCTION

In 1955, the Office of Management and Budget implemented the Commercial Activities Program. The program was originally designed to reduce government spending simply by privatizing government functions. The program was modified over time so that the in-house team, i.e., the group of government employees that provided the function prior to the competition, was allowed to compete alongside private contractors for contracts in what is termed an A-76 competition. A-76 competitions uniquely combine elements of competition and privatization. If the in-house team submits the winning bid, it continues to provide the function. Though provision is not privatized in this case, the cost of provision may fall due to competitive pressures. On the other hand, if a private contractor wins, the function is privatized.

This paper considers the experience of the Department of Defense with A-76 competitions. The focus is on the cost savings—the reduction in the amount spent by the government to procure the functions—generated by the competitions. The data include all the A-76 competitions that the Department of Defense completed between 1978 and 1994, more than 2,000 in total. A three-equation model is constructed, which is used to estimate separately the in-house team's bid, the minimum contractor bid, and the in-house team's baseline cost (i.e., the cost of providing the function prior to the competition). The model incorporates the fact that the in-house team's bid is

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constrained to be no greater than baseline cost, preventing it from using the competition as an opportunity to fatten its budget.

The estimates are used in simulations which address a number of issues of theoretical and practical interest. First, there is a general concern in the literature regarding the provision of incentives in public enterprise (Rose-Ackerman, 1986). A-76 competitions function as a sort of incentive scheme in that the threat of losing to private contractors in A-76 bidding increases the in-house team's incentives to reduce cost. A measure of the slack in the baseline cost due to weak incentives can be constructed by taking the difference between the in-house team's bid and its estimated baseline cost. By implication, this measure indicates the potential cost savings from using stronger incentives to eliminate what Leibenstein (1966) termed X-inefficiency from the in-house team's performance. The results suggest that X-inefficiency accounts for almost 20 percent of baseline cost.

Second, the literature contains an extensive discussion of the benefits of privatization. A private contractor may be inherently more efficient at providing the service, perhaps because it is better able to solve problems of private information or contractual incompleteness (Laffont and Tirole, 1993, chapter 17; Schmidt, 1996; Hart, Shleifer, and Vishny, 1997), perhaps because it simply receives a better random draw from an underlying technology distribution. An upper bound on the savings from straight privatization is computed by running a simulation excluding the in-house team from the bidding. The results suggest that straight privatization can generate substantial savings, but significantly less than A-76 competitions; so there is an advantage to including the in-house team as a bidder. The results also suggest that the savings from straight privatization would be much higher if the government set a reservation price, maintaining the function in-house if the minimum contractor bid exceeded the in-house team's baseline cost.

Third, a variety of other experiments are performed with the simulations. A simulation is run in which all contracts are awarded using an auction mechanism with secret bidding rather than, as was done in practice, a mix of secret bidding and negotiated sales. Another simulation was run in which functions are bundled together by type at each military installation. This exercise indicates whether any "economies of scale" can be exploited in A-76 competitions, perhaps stemming from greater contractor participation in competitions involving large functions.

Fourth, and perhaps most interesting from a practical standpoint, the model is used to predict savings generated by future competitions. The sample of more than 13,000 functions in the Department of Defense's Commercial Activities Inventory, a list of potential candidates for A-76 competitions, were used for this purpose. The results suggest that the Department of Defense would save an additional $7.58 billion annually if all the functions in the inventory were subjected to A-76 competitions. All of the other simulations described above are also conducted for the inventory.

A growing empirical literature considers the relative efficiency of public versus private firms. Most of the literature considers markets in which demanders are private firms or consumers rather than the government.[1] Three papers have studied the use of A-76 (or similarly structured) competitions to reduce the government's procurement costs. Snyder, Trost, and Trunkey (forthcoming) examined the whole set of more than 3,500 A-76 competitions initiated by the Department of Defense, 40 percent of which were not carried through to completion, to determine whether the pattern of cancellation produced a selection bias. No evidence of selection bias was found. A

[1] Markets that have been studied include water distribution (Teeples and Glyer, 1987; Bhattacharyya, Parker and Raffiee, 1994), natural gas distribution (Hollas and Stansell, 1994), electricity distribution (Kwoka, 1996; Kumbhakar and Hjalmarsson, 1998), telecommunications (Kwoka, 1993; de Boer and Evans, 1996), airlines (Eckel, Eckel, and Singal, 1997; Erlich, Gallais-Hamonno, Liu, and Lutter, 1994), and local busses (Savage, 1993).

reduced-form savings equation was also estimated, but this did not allow for the policy simulations carried out in the present paper. Carrick (1988) analyzed a sample of 1,700 A-76 competitions in other agencies of the U.S. government. His analysis was largely descriptive and again did not allow for the policy simulations and forecasting which are the focus of the present paper. Perhaps closest to the present paper is Domberger, Meadowcroft, and Thompson (1986), who studied garbage collection in 305 localities in the United Kingdom. They estimated an econometric model, which they used to project savings from expanding the outsourcing program to other localities. Their estimate of cost savings was lower than the estimate in the present paper, 22 percent versus 35 percent, but of the same order of magnitude.

DATA

A-76 Competitions

In 1955, the Office of Management and Budget implemented the Commercial Activities Program. This program enables the private sector to compete with government organizations in providing goods and services when it is appropriate and economical to do so. The Commercial Activities Program specifies that government agencies conduct competitions in which outside contractors bid against the agency's in-house team to supply the agency with a good or service. Since the rules for conducting the competitions are given in the OMB Circular A-76 (Office of Management and Budget, 1983), the competitions are referred to as A-76 competitions. As part of its participation in the Commercial Activities Program, the Department of Defense annually constructs a list of functions that could be subject to A-76 competitions. In 1995, this list, called the Commercial Activities Inventory, exceeded 13,000 functions.

Between 1978 and 1994, the Department of Defense conducted A-76 competitions for 2,195 functions in its Commercial Activities Inventory. The process followed a number of steps. First, the Department of Defense prepared a description of the contract that would be offered to the winning bidder, including the nature of the work required and the length of the contract (usually five years, but with some variation). Second, the in-house team (the Department of Defense employees currently providing the good or service named in the contract description) prepared a bid, called the MEO for "most efficient organization." As part of its bid, the in-house team recorded the number of personnel that it agreed to use for the function if it won. Bids were also solicited from outside contractors. In more than two-thirds of the competitions, bids were submitted secretly in a formal auction; the remainder of the competitions involved negotiated sales. Third, the bids were compared and a winner selected. The in-house team was given a ten-percent advantage, meaning that a contractor must bid at least ten percent below the in-house team to win.[2] Virtually all of the A-76 competitions in the data set were decided on a cost basis, meaning that the bids had only a single dimension, cost, with no allowance for contractor reputation or expectations regarding service quality.

[2] The desirability of providing the incumbent with a bidding advantage is discussed in Williamson (1976): A bidding advantage protects the incumbent's specific investments from expropriation that may occur if the entrant wins the auction. In their formal model, Laffont and Tirole (1993, chapter 8) show the incumbent should receive a bidding advantage if its non-contractible investment can be transfered to the entrant but should receive a bidding disadvantage if its investment is non-transferable. In practice, other reasons for offering an incumbent bidding advantage might include lessening government workers' opposition to the Commercial Activities Program or avoiding transition costs for small savings. Branco (1994) and Vagstad (1995) discuss the optimal design of a procurement auction when one party is favored over others.

Table 1. Descriptive statistics for completed A-76 competitions.

	Number of Functions	Percent In-House Wins	Baseline Personnel Total	Baseline Personnel Per Function	Baseline Personnel Percent Military
By Service Branch					
DoD Agencies	50	42.0	1,034	20.7	0.5
Army	445	50.1	23,588	53.0	14.1
Air Force	732	37.7	26,080	35.6	32.9
Marines	39	53.8	1,264	32.4	12.4
Navy	803	56.8	25,391	31.6	19.0
By Size (number of baseline personnel)					
1-10	833	57.1	4,626	5.6	10.7
11-50	915	41.4	21,081	23.0	11.1
51-100	174	46.0	12,086	69.5	13.6
101-150	52	50.0	6,115	117.6	17.8
151-200	32	50.0	5,605	175.2	12.9
More than 200	63	31.7	27,844	442.0	38.1
By Function Type					
Installation Services	647	52.6	26,806	41.4	9.4
Social Services	230	19.1	4,198	18.3	12.6
Health Services	27	74.1	436	16.1	17.9
Intermediate Maintenance	159	40.9	15,575	98.0	45.7
Depot Maintenance	6	100.0	86	14.3	0.0
Real Property Maintenance	312	44.9	10,493	33.6	8.5
Warehousing	106	52.8	4,151	39.2	22.7
Air Transportation	10	90.0	1,890	189.0	0.5
Research Support	12	25.0	984	82.0	76.2
Training	8	50.0	1,232	154.0	91.9
Data Processing	94	56.4	2,150	22.9	14.3
Audio-visual	81	62.7	2,354	29.1	28.2
Switchboard	90	52.2	1,450	16.1	11.2
Telecommunications	24	54.2	910	37.9	64.6
Administrative Support	147	55.1	1,978	13.5	20.1
Other Nonmanufacturing	116	56.0	2,664	23.0	29.9
Total	2,069	48.2	77,357	37.4	21.8

The data set employed in the remainder of this paper is a cleaned version of the Department of Defense's records of the A-76 competitions conducted between 1978 and 1994.[3] Summary statistics for the 2,069 observations in the final data set are presented in Table 1. The summary statistics by military service reveal that the Navy and the Air Force have been the most active in A-76 competitions, followed by the Army, Marines, Department of Defense Agencies (the assorted agencies within the

[3] Of the 2,195 completed competitions, 119 were missing vital data, two were in unique function classes, and one contained an apparent typographical error. Four observations found in Snyder, Trost, and Trunkey (forthcoming) to be outliers were also dropped, though the results are virtually identical if the outliers are included.

Department of Defense besides the major service branches). More competitions were won by private contractors in the Air Force than in the other branches. The summary statistics by size category—where the size of a competition is the number of baseline personnel (personnel employed in the function before the competition)—show that most competitions were fairly small. On average, 37.4 personnel were employed, 21.8 percent of whom were military. Interestingly, A-76 competitions were not required for competitions of 10 or fewer civilian personnel, but the full A-76 process was often used to justify even these outsourcing decisions. The functions fall into a number of different categories by the type of activity involved. The summary statistics by function type exhibit substantial heterogeneity across the 16 categories. For example, the average function in the air transportation category was 10 times larger and almost five times more likely to be won in-house than in the social services category.

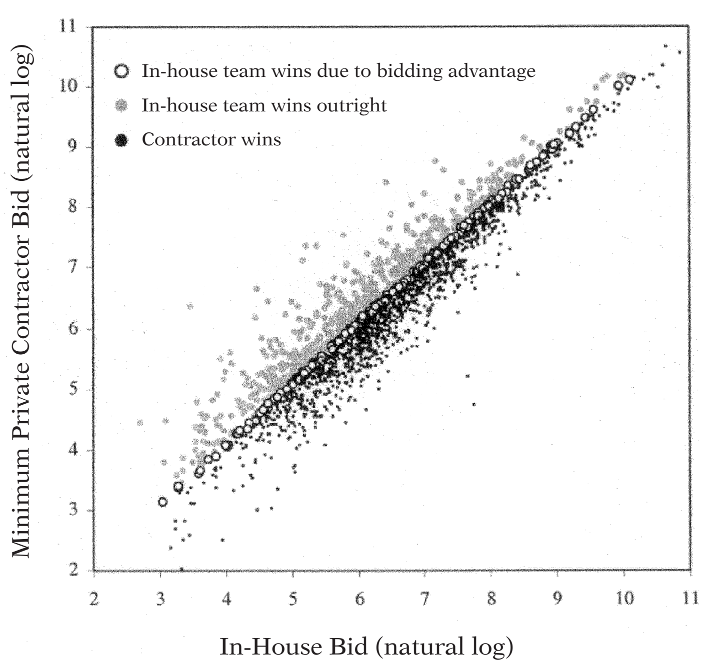
Comparison of Bids

For each competition, the data include the in-house team's bid (denoted c_{gi}) and the minimum of all the private contractors bids (denoted c_{pi}).[4] Since contracts involved in the A-76 competitions were multiyear, bids were divided by contract length to convert them into annual figures. The Department of Defense (1996) price deflator was used to express bids (and all other monetary values throughout the paper) in FY 1996 dollars.

Figure 1 presents a scatter plot of $\ln c_{gi}$ versus $\ln c_{pi}$ for all competitions i in the data set. For competitions indicated by the grey dots in the upper portion of the figure,

[4] Unfortunately, the Department of Defense did not systematically collect information on private contractor bids higher than the minimum.

Figure 1. Comparison of in-house and private contractor bids.



$c_{gi} \leq c_{pi}$, implying the in-house team won the competitions outright. For those indicated by the black dots in the lower portion of the figure, $c_{gi} > (1+\Delta)c_{pi}$, implying a private contractor won the competitions despite the in-house team's 10 percent bidding advantage, $\Delta = 0.1$. For those indicated by the white circles, $c_{gi} \in [c_{pi}(1+\Delta)c_{pi}]$, implying the competitions were won by the in-house team, though the in-house team would have lost without the bidding advantage.

Commercial Activities Inventory

As noted above, the Commercial Activities Inventory is a list of candidates for future A-76 competitions compiled by the Department of Defense. A forecast of the savings from subjecting all the functions in the 1995 Commercial Activities Inventory to A-76 competitions will be computed in the simulations below. Table 2 lists descriptive statistics for the inventory. Overall, the functions in the inventory are similar to those functions already competed. The main differences are that functions tend to be smaller, involve more military personnel, are more likely to be in a Department of Defense Agency, and are more likely to be in the health services or other non-manufacturing categories.

MODEL

An empirical model of A-76 competitions is derived in this section. The government requires the performances of certain functions, indexed by i. Initially, function i is performed in-house. Let c_{bi} denote baseline cost, i.e., the in-house team's cost of providing function i or equivalently, the cost to the government of having the function performed during this initial stage. Let l_{bi} denote baseline personnel employed during this initial stage.

In the next stage of the model, function i is subjected to an A-76 competition. The in-house team and a number of private contractors bid in a first-price procurement auction for the right to be the sole provider of function i for the government. A private contractor's bid is the price at which it agrees to perform the function; the in-house team's bid is the cost at which it agrees to perform the function. Let $\{j = 1, \ldots, N_i\}$ be the set of private contractors involved in the bidding. Assume that all players know their own cost of performing the function, implying that the competition is a private-values auction.[5]

Let c_{pi} be the lowest of the private contractors' bids. That is $c_{pi} = \min\{c_{pij} | j = 1, \ldots, N_i\}$, where c_{pij} is contractor j's bid. Let c_{gi} denote the in-house team's equilibrium bid. The winning bid, w_i, is selected according to prespecified rules. A simple rule would be to select the lowest bid. Allowing for a more complicated selection rule, possibly providing an incumbency advantage to the in-house team:

$$w_i = \begin{cases} c_{gi} \text{ if } c_{gi} \leq (1+\Delta)\, c_{pi} \\ c_{gi} \text{ if } c_{gi} > (1+\Delta)\, c_{pi}. \end{cases} \quad (1)$$

[5] In practice, the competitions are likely a hybrid of both private- and common-values elements. Equations (4) through (7) can be derived from a common-values-auction model, though the coefficients would be a different function of the underlying structural parameters.

Table 2. Descriptive statistics for commercial activities inventory.

		Baseline Personnel		
	Number of Functions	Total	Per Function	Percent Military
By Service Branch				
DoD Agencies	1,280	52,824	41.3	4.0
Army	3,712	96,277	25.9	27.9
Air Force	3,873	49,089	12.7	55.5
Marines	523	19,082	36.5	56.0
Navy	3,941	162,778	41.3	45.6
By Size (number of baseline personnel)				
1-10	7,897	31,198	4.0	29.8
11-50	3,896	90,947	23.3	34.7
51-100	923	64,560	69.9	38.3
101-150	265	32,544	122.8	38.9
151-200	113	19,378	171.5	59.8
More than 200	235	141,423	601.8	36.4
By Function Type				
Installation Services	3,619	90,950	25.1	30.9
Social Services	2,020	26,774	13.3	13.9
Health Services	1,369	64,852	47.4	63.3
Intermediate Maintenance	1,069	35,334	33.1	73.5
Depot Maintenance	139	43,869	315.6	1.7
Real Property Maintenance	917	18,367	20.0	8.2
Warehousing	114	9,444	82.8	36.0
Air Transportation	11	402	36.5	96.8
Research Support	242	8,748	36.1	27.2
Training	618	24,253	39.2	81.0
Data Processing	706	14,505	20.5	14.7
Audio-visual	236	2,232	9.5	28.3
Switchboard	136	1,278	9.4	31.5
Telecommunications	208	5,695	27.4	79.4
Administrative Support	382	3,648	9.5	30.1
Other Nonmanufacturing	1,543	29,699	19.2	28.9
Total	13,329	380,050	28.5	37.2

According to Equation (1), the in-house team wins the competition as long as its bid is less than a multiple, $1+\Delta$, of the minimum contractor bid. For the A-76 competitions considered in this study, $\Delta = 0.1$. Of course, if $\Delta = 0$, then Equation (1) simply selects the lowest bid. In the last stage of the game, the winning bidder performs the task for the government according to the terms of its bid.

Private contractor j is assumed to choose its bid to maximize its expected profit, defined as the payment from the government minus the cost of performing the task, weighted by the probability of winning the competition. Thus, c_{pij} solves

$$\max_c \left\{ [c - \psi(x_i, \nu_{pij})] \Pr\left(c < \min\left\{ \{c_{pik} \mid k \neq j\}, \frac{c_{gi}}{1+\Delta} \right\} \right) \right\} \quad (2)$$

where ψ is j's cost, a function of observables x_i and unobservables ν_{pij} (such as j's technological efficiency).

The in-house team's decision is similar to the private contractor's. One difference is that it is a nonprofit unit of the government. This difference is addressed by assuming that the in-house team maximizes expected utility, rather than profit, and that its utility is an increasing function of l_{gi}, the number of personnel in the MEO (i.e., the number of personnel the in-house team states in its bid it will use). Intuitively, the manager of the in-house team may find it distasteful to lay off personnel. A second difference is that l_{gi} is constrained to be no greater than l_{bi}, and the in-house team's bid c_{gi} is constrained to be no greater than c_{bi}. This second difference is addressed by treating the in-house team's desired employment, l^*_{gi}, as a latent variable that may differ from actual employment, l_{gi}, because of the constraint $l_{gi} = \min[l^*_{gi}, l_{bi}]$. That is, l^*_{gi} solves

$$\max_l \{ U(l, x_i, \nu_{gi}) \Pr(c_{gi} \leq (1+\Delta) c_{pi}) \}. \quad (3)$$

Utility U, is a function of employment, observables x_i, and unobservables ν_{gi}. The in-house team's utility conditional on losing has been normalized to zero without loss of generality.

In addition to being an argument of U, MEO employment l_{gi} implicitly enters (3) as a determinant of c_{gi}. This follows from interpreting c_{gi} as the in-house team's cost of production conditional on winning the bid. In fact, the stronger assumption will be made that MEO employment is the sole endogenous determinant of c_{gi}. Other, exogenous, determinants include observables z_i, unobservables ϵ_{gi}, and parameters β_g. Under the assumption that including MEO employment captures all relevant scale effects, it is proper to exclude l_{bi} from the determinants of c_{gi}; so z_i will be taken to be the set of all variables in x_i except l_{bi}. Written formally,

$$\ln c_{gi} = G(l_{gi}, z_i, \beta_g) + \epsilon_{gi}. \quad (4)$$

Taking the first-order conditions associated with Equations (2) and (3), integrating over the unobservables, taking the minimum of the private-contractors' bids, and solving simultaneously yields the equilibrium values of the decision variables. Expressing these as a log-linear function of the observables yields the following reduced-form expressions:

$$\ln c_{pi} = P(l_{bi}, z_i, \beta_p) + \epsilon_{pi} \quad (5)$$

$$\ln l^*_{gi} = L(l_{bi}, z_i, \beta_l) + \epsilon_{li} \tag{6}$$

with

$$l_{gi} = \min\{l^*_{gi}, l_{bi}\} \tag{7}$$

Error terms ϵ_{pi} and ϵ_{li} are functions of the parameters characterizing the distribution of unobservable variables $\{v_{pij} \mid j = 1,\ldots,N_i\}$ and v_{gi}. For estimation purposes, ϵ_{gi}, ϵ_{pi}, and ϵ_{li} are assumed to be jointly normally distributed with covariance matrix

$$\Sigma = \begin{pmatrix} \sigma^2_g & \sigma_{gp} & \sigma_{gl} \\ \sigma_{gp} & \sigma^2_p & \sigma_{pl} \\ \sigma_{gl} & \sigma_{pl} & \sigma^2_l \end{pmatrix} \tag{8}$$

The expected savings from A-76 competition i can be written

$$\int_{\mathbf{R}^3} [c_{bi} - c_{pi}\mathbf{1}\{w_i = c_{pi}\} - c_{gi}\mathbf{1}\{w_i = c_{gi}\}]\, dF(e_{gi}, e_{pi}, e_{li}) \tag{9}$$

where $\mathbf{1}\{\cdot\}$ is an indicator function that selects winning bid w_i according to Equation (1) and where F is a trivariate normal distribution function. The integrand in Equation (9) is a highly nonlinear function of the errors, necessitating the simulation methodology for estimating savings adopted below.

ESTIMATION METHOD AND RESULTS

The empirical model is contained in the system of Equations (4) through (7). One complication in estimating the model is that Equations (6) and (7) imply that the dependent variable, l_{gi}, is censored from the right by l_{bi}, an observable exogenous variable. A generalized Tobit procedure (Amemiya, 1985, section 10.2) will be employed, which is consistent in this setting.

A second complication is that Equations (4) through (7) form a recursive system in that l_{gi} appears on the right-hand side of Equation (4) but is a dependent variable in Equations (6) and (7). Consistent estimation of Equation (4) requires the use of instrumental variables if and only if the errors ϵ_{gi} and ϵ_{li} are correlated. Hausman (1978) tests turned out to provide ambiguous evidence on this issue. On the one hand, comparing the ordinary least squares estimates of Equation (4) with the two-stage least squares estimates using l_{bi} as an instrument for l_{gi} produced a Hausman test statistic of $\chi^2_{24} = 25.3$, with an insignificant p-value of 0.39. On the other hand, if Equations (4) and (5) are estimated as a system, so that the Hausman test involves comparing the seemingly unrelated regression estimates with the three-stage least squares estimates, the resulting test statistic is $\chi^2_{24} = 233.3$, significant at better than the 1 percent level. To gain efficiency, Equations (4) and (5) were estimated as a system using three-stage least squares.

The set of regressors in all three equations include two powers of the log of the number of personnel: $\ln l_{gi}$ and $(\ln l_{gi})^2$ in the case of Equation (4), l_{bi} and $(\ln_{bi})^2$ in the case of Equations (5) and (6). Other regressors, z_i, include the percentage of baseline personnel who are military (as opposed to civilian), a linear time trend, and a series of dummy variables for service branch and function type. The dummy variables are constructed so that the comparison case is an A-76 competition conducted by the Navy of the installation services type.

The model of the previous section assumed that competitions are auctions with secret bidding. In practice, about one-third of the competitions involved some negotiations and thus were not strict auctions. To account for any divergence of these competitions from the predictions of the model, a secret bidding dummy was included;

Table 3. Model estimates.

	In-House Bid Equation		Contractor Bid Equation		MEO Personnel Equation	
Independent Variables	Coefficient	(Std. Err.)	Coefficient	(Std. Err.)	Coefficient	(Std. Err.)
Constant	4.106 ***	(0.057)	4.562 ***	(0.075)	0.707 ***	(0.054)
ln(Baseline Personnel)	—	—	0.800 ***	(0.039)	0.759 ***	(0.027)
ln(Baseline Personnel)^2	—	—	0.012 *	(0.006)	0.024 ***	(0.004)
ln(MEO Personnel)	1.021 ***	(0.031)	—	—	—	—
ln(MEO Personnel)^2	-0.008	(0.005)	—	—	—	—
Percent Military Personnel	-0.091 *	(0.048)	-0.396 ***	(0.064)	-0.308 ***	(0.035)
Time Trend	-0.017 ***	(0.004)	-0.034 ***	(0.005)	-0.031 ***	(0.003)
Secret Bidding Dummy	-0.056 **	(0.026)	-0.171 ***	(0.034)	-0.029	(0.019)
Service Dummies						
DoD Agencies	0.159 **	(0.078)	0.299 ***	(0.102)	-0.072	(0.058)
Army	0.162 ***	(0.041)	0.195 ***	(0.041)	-0.048 **	(0.024)
Air Force	0.201 ***	(0.029)	0.166 ***	(0.037)	0.019	(0.022)
Marines	0.000	(0.082)	-0.019	(0.107)	-0.067	(0.054)
Function-Type Dummies						
Social Services	-0.416 ***	(0.041)	-0.823 ***	(0.053)	0.101 ***	(0.033)
Health Services	-0.096	(0.098)	0.147	(0.128)	0.140 *	(0.078)
Intermediate Maintenance	0.069	(0.045)	0.063	(0.060)	0.003	(0.034)
Depot Maintenance	-0.092	(0.203)	0.059	(0.265)	-0.114	(0.149)
Real Property Maintenance	0.073 **	(0.037)	0.048	(0.048)	-0.005	(0.028)
Warehousing	-0.200 ***	(0.053)	-0.192 ***	(0.069)	-0.029	(0.044)
Air Transportation	0.679 ***	(0.159)	0.925 ***	(0.207)	0.015	(0.116)
Research Support	0.034	(0.146)	0.109	(0.191)	0.052	(0.102)
Training	-0.175	(0.177)	-0.129	(0.231)	0.056	(0.131)
Data Processing	-0.421 ***	(0.056)	-0.428 ***	(0.073)	0.030	(0.044)
Audio-visual	-0.125 **	(0.059)	-0.093	(0.077)	-0.152 ***	(0.043)
Switchboard	-0.611 ***	(0.057)	-0.747 ***	(0.074)	-0.195 ***	(0.041)
Telecommunications	-0.183 *	(0.106)	-0.262 *	(0.138)	0.005	(0.075)
Administrative Support	-0.581 ***	(0.047)	-0.605 ***	(0.061)	-0.084 **	(0.035)
Other Nonmanufacturing	-0.036	(0.050)	0.071	(0.066)	-0.103 ***	(0.038)
Pseudo R^2	0.868		0.776		0.585	

Notes: First and second regressions estimated jointly using three-stage least squares with two powers of the natural log of baseline personnel as instruments for the two powers of the natural log of MEO personnel. Third estimated as a censored normal (i.e., tobit type) regression. In each, 2,069 observations used. Dependent variable in first regression is the natural log of the in-house bid; in the second is the natural log of the minimum contractor bid; and in the third is the natural log of MEO personnel. Omitted service dummy is Navy; omitted function-type dummy is Installation Sevices. Service dummies are jointly significant better than the 5 percent level, and funtion-type dummies at better than the 1 percent level, in all regressions. Time trend ranges from 1 (for 1978) to 17 (for 1994). Pseudo R^2 is the percent of variance explained by the predictors. *Significant at the 10 percent level; ** 5 percent level; ***1 percent level.

it equals one for competitions involving auctions with secret bidding and zero for competitions involving some negotiations.

The estimation results are presented in Table 3. In the two bidding equations, the coefficient on the first power of the log of personnel is positive and significant, implying that larger tasks—where size is measured in terms of the number of employees—are more costly to provide. The coefficient on the squared personnel term is positive and significant for the contractor bidding equation, implying that their bids increase faster than the size of the task. Over most of the range of sizes within the sample, this term is not economically significant, however; so the elasticity of the bids with respect to the size can be taken to be roughly constant. The coefficients on percent military personnel imply that the bids were lower the greater the proportion of military used in the baseline. One explanation is that civilian employees are more efficient than military on average, perhaps because civilian employees are left to develop specialized skills whereas military employees often switch jobs in the military rotation, perhaps because military personnel have weekly training obligations that occupy some of their time. In either event, the greater the percentage military, the greater the cost savings bidders could expect from replacing military with civilian employees. The time trend is negative in all three cases, suggestive of productivity gains over time.[6] The secret bidding dummy is negative and significant, suggesting that bidding is more competitive when a formal auction is used than when negotiated sales are allowed. An alternative explanation based on a spurious selection effect cannot be ruled out, however: More complex, and thus more expensive, tasks might require negotiations between the government and potential suppliers.

Considering the service dummies, there is little difference between the Marines and the Navy, as would be expected from their close ties. The rest of the branches had higher baseline costs and bids on average than the Navy. This difference could be due to a number of factors, including more complex tasks or weaker cost controls in Department of Defense Agencies, the Army, and the Air Force relative to the Navy.

Considering the function dummies, the results accord with the intuition that capital-intensive functions will have a higher cost per employee than labor-intensive functions. Capital-intensive functions—such as intermediate maintenance, real property maintenance, and air transportation—have positive coefficients, while labor-intensive functions—such as social services, training, data processing, and administrative support—have negative coefficients. The coefficients on warehousing, audio-visual, switchboard, and telecommunications seem counterintuitive until it is noted that they reflect the operation of capital equipment owned by the government rather than the provision of capital equipment. For example, warehousing involves the administration of government-owned warehouses rather than the construction of new warehouses.

Competitions within the Air Force provide a rich set of data which can be used to test this intuition formally. The Air Force is the sole service branch that maintained a record of the in-house team's bid broken down into labor costs and other (capital, materials, and overhead) costs. These data were used to compute *LSHARE*, labor's average share of total cost in the in-house bid, for each function type. Then *FUNCOEF*, the estimated coefficients on the function-type dummies from the in-house bid equation reported in Table 3, was regressed on *LSHARE*:[7]

$$\underset{}{FUNCOEF} = \underset{(0.55)}{0.81} - \underset{(0.62)}{1.14}\ LSHARE \quad (N = 14,\ R^2 = 0.22) \tag{10}$$

[6] See Lyon (1998) for a formal test of productivity gains due to learning effects using panel data on the procurement of missile systems.

[7] Weighted lease squares was used, with the weights given by the inverse of the standard errors of the coefficients in Table 3. The results from unweighted least squares were similar. Though there are 16 function categories in the main data set, two had to be dropped because there was no Air Force data to compute *LSHARE* for them, yielding 14 observations in regressions (10) and (11).

where standard errors are reported in parentheses below coefficient estimates. The raw correlation between *FUNCOEF* and *LSHARE* is -0.45. The analogous regression in which *FUNCOEF* is instead defined to be the estimated coefficients on the function-type dummies from the contractor bid equation is

$$\underset{}{FUNCOEF} = \underset{(0.80)}{1.11} - \underset{(0.90)}{1.49}\, LSHARE \quad (N = 14,\ R^2 = 0.19) \tag{11}$$

with a raw correlation between *FUNCOEF* and *LSHARE* of -0.41. The negative coefficient on *LSHARE* is significant at better than the 5 percent level in a one-tailed test in Equation (10) and at better than the 10 percent level in Equation (11). Though the results should not be viewed as conclusive because of the small number of observations, they are at least consistent with the hypothesis from the previous paragraph regarding the relationship between labor intensiveness and bids.

POLICY SIMULATIONS

Although there is some independent interest in examining the estimates $\hat{\beta}_g$, $\hat{\beta}_p$, $\hat{\beta}_l$, from Table 3, their main use is as an input for the simulations in the present section. (The appendix contains a detailed description of our simulation methodology.) The methodology involves taking a series of random draws from the distribution of error terms ($\hat{\epsilon}_{gi}$, $\hat{\epsilon}_{pi}$, $\hat{\epsilon}_{li}$). These errors can be substituted, along with the estimated coefficients ($\hat{\beta}_g$, $\hat{\beta}_p$, $\hat{\beta}_l$), into Equations (4) through (7) to simulate baseline cost and parties' bids under various policies.

Table 4. Simulation results.

	Completed A-76 Competitions			Commercial Activities Inventory		
		Annual Savings			Annual Savings	
Policy	Percent In-House Wins	Billion FY 1996 $ Annually	Percent of Policy (A) Savings	Percent In-House Wins	Billion FY 1996 $ Annually	Percent of Policy (A) Savings
(A) Basic Conditions	51.9	1.55	100.0	59.2	7.58	100.0
(B) Without Outside Contractors	100.0	0.88	57.1	100.0	6.13	80.9
(C) Without In-House Team (Reservation Price)	0.0	1.34	86.4	0.0	5.96	78.7
(D) Without In-House Team (No Reservation Price)	0.0	0.98	63.6	0.0	5.15	68.0
(E) In-House Team Allowed to Exceed Baseline Cost	40.7	1.44	93.3	54.0	7.50	99.0
(F) Secret Bidding	48.8	1.58	102.4	54.9	7.59	100.2
(G) Bundled Functions	51.7	1.57	101.6	59.5	7.62	100.6

Table 4 summarizes the simulation results for seven different policies, labeled (A) through (G). Consider the first three columns, which contain the simulation results for the sample of 2,069 completed A-76 competitions. The basic case, and the standard for comparison, is (A); in this case, simulations are performed under the standard A-76 rules. Under (A), 51.9 percent of the A-76 competitions are won by the in-house team, and the competitions generated an annual savings of $1.55 billion (this and the rest of the savings figures below are in FY 1996 dollars on an annual basis).

Scenario (B) excludes outside contractors from the bidding process, leaving the in-house team as the sole bidder. It is important to note that the simulation implicitly assumes that the in-house team bids as if the private contractors were present. This is true since the estimates on which the simulation is based come from reduced-form Equations (4) and (6); these equations implicitly assume equilibrium bidding behavior on the part of private contractors conditional on the observables. In practice, if the in-house team knew that private contractors were excluded and that it would always win the competition, it would alter its strategy: Specifically, it would have no incentive to bid below baseline cost, and no savings would be realized from the competition. Scenario (B) is useful for revealing the amount of slack—Leibenstein's (1966) X-inefficiency—in the in-house team's performance before the competition. Before the competitions, there may have been little incentive for the in-house teams to trim budgets, cut personnel, or innovate. The competitions often had the effect of strong incentive schemes: The threat of losing the competition often led the in-house team to submit a bid substantially lower than its baseline cost. The savings figure in scenario (B) of $880 million is precisely the cost reduction that results from the incentive effect of the A-76 competitions. It is a lower bound on the total slack inherent in baseline cost since the competitive pressures of the competition may not have been sufficient to wring all the slack out of the in-house team's bid. For example, if only a few private contractors were involved in the bidding or if the in-house team had inside information that the contractors were high-cost, the in-house team may not need to bid much below baseline cost to maintain a high probability of winning the competition. In sum, these simulations suggest that at least $800 million—19.9 percent of baseline cost—was slack in the in-house team's performance before the competition.

Scenarios (C) and (D) bear on the question of the savings that could be realized if the A-76 competitions were restructured—removing the in-house team as a bidder—so that they involved straight privatization. Ideally, it would be desirable to have a measure of the savings generated if the in-house team were excluded from the bidding, and the private contractors took this fact into account in their bidding strategies. Since the simulations are based on reduced-form parameter estimates, scenarios (C) and (D) do not exactly perform this thought experiment. Instead, they show the savings that would be realized if the in-house team were excluded from the bidding but the private contractors bid as if they still faced the competitive pressures of the in-house team. These simulations likely overstate the savings from straight privatization since private contractors' bids would likely be higher in the absence of competitive pressures from the in-house team.[8] Thus, the figures in (C) and (D) should be regarded as upper bounds on the true savings from privatization. Two scenarios excluding the in-house team are investigated because the government can run the procurement auction in two ways. The government can use the in-house team as a sort of outside option (or secret reservation value): If no private contractor bids lower than baseline cost, the function is not privatized and the in-house team continues to provide it at its current

[8] The prospect of softer competition in the absence of the in-house team may attract additional private bidders, partially offsetting the softening of competition.

cost.[9] This is scenario (C). Alternatively, the government can remove the in-house team from the process entirely and privatize the function even if the lowest contractor bid exceeds baseline cost. In other words, the government has no reservation value. This is scenario (D). The upper bound on the privatization savings is $1.34 billion with scenario (C) and falls to $980 million with scenario (D). Both figures are large, suggesting that straight privatization has the potential to generate considerable savings. Both figures fall well short of the savings from A-76 competitions, however; and this is true even though the figures are upper bounds. Thus, A-76 competitions, by including the in-house team as a bidder, improve upon straight privatization as a procurement mechanism.

As indicated by the $360 million drop in savings from scenario (C) to (D), the in-house team's participation should, at a minimum, involve its baseline cost being used as a reservation price and the function maintained in-house if no private contractor betters it.[10] In a calculation not presented in the table, private contractors' simulated bids were found to exceed baseline cost in 31 percent of the cases. In scenario (C), the function would fall back to provision by the in-house team, and zero savings would be generated, in these cases. In scenario (D), negative savings would be generated in these cases. This accounts for the much lower figure for savings in (D) compared to (C).

Scenario (E) examines the effect of removing the constraint that the in-house team bid below baseline cost. The simulation effectively allows the in-house team to employ its unconstrained level of labor, l^*_{gi}, rather than the constrained level, l_{gi}, and submit an unconstrained bid $c^*_{gi} = G(l^*_{gi}, z_i, \beta_{gi}) + \epsilon_{gi}$ rather than the constrained bid, c_{gi}. The simulation is an overestimate of the true savings because it implicitly assumes that the private contractors bid as if they faced an in-house team constrained to bid no higher than baseline cost. The in-house team's bid would be higher on average if it were not constrained to bid baseline cost; in response, private contractors would likely shade their bids up on average. This would generate a series of feeback effects from the private contractors to the in-house team and vice versa, all tending to raise equilibrium bids and reduce the savings generated by the competititon. The simulations show that savings would be no more than $1.44 billion, or 93.3 percent of the original $1.55 billion. These results show that the baseline-cost constraint contributes at least a small amount to savings in the A-76 process.

Scenario (F) examines the effect of using a formal auction mechanism with secret bidding in all competitions, replacing negotiations that were used in practice in about a third of the competitions. Savings rise slightly, to $1.58 billion. The probability of an in-house win falls. The finding that auctions perform no worse than negotiated sales contrasts some findings in other settings. For example, in the real estate economics literature, Mayer (1995, 1998) finds that there is a price discount for houses sold at auction relative to negotiated sales. He finds that the benefit of auctions is in reducing the average time needed to sell the house. One explanation for the contrasting findings is that the "arrival" process for bidders is likely to be more sporadic in the housing market than in the procurement market. One should also keep in mind the caveat above that more complex tasks might require negotiations, biasing the estimated savings from negotiations downward.

The last scenario, (G), examines the savings that would arise if similar functions were bundled together and subjected to an A-76 competition as a single unit. The

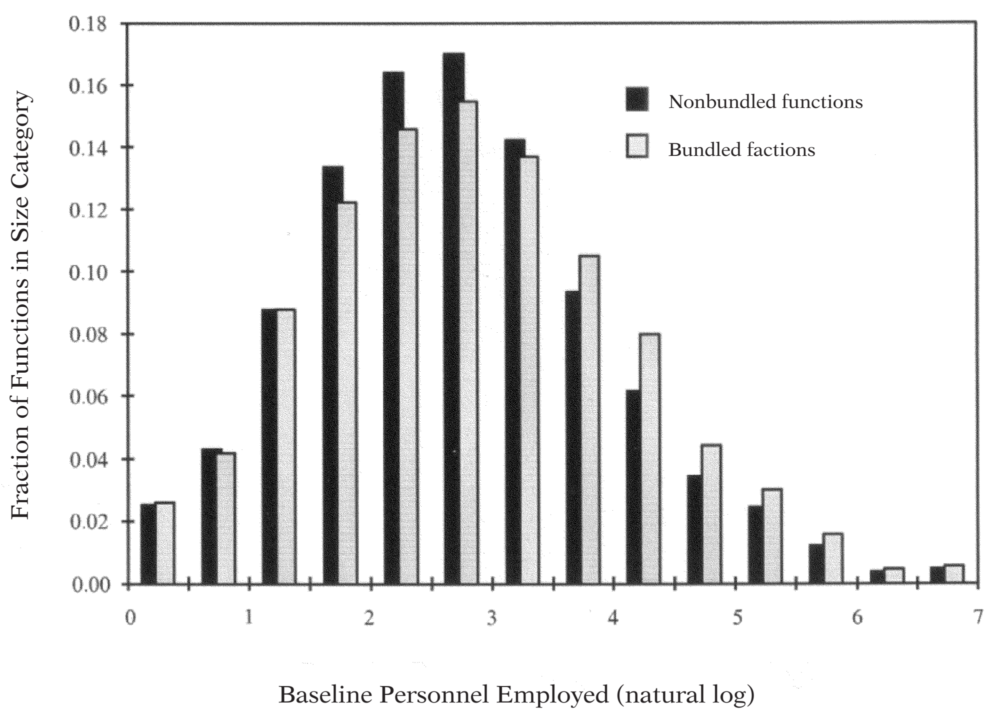
[9] There is no incumbency advantage assumed in this scenario. A private contractor wins if $c_{pi} < c_{bi}$; it is not necessary that $(1 + \Delta)\, c_{pi} < c_{bi}$.

[10] Whether the reservation price should be secret, and whether the price should be greater or less than baseline cost are interesting questions beyond the scope of the present study.

Department of Defense has issued a recommendation that service branches begin developing larger competitions (see Marcus, Seamans, and Coast, 1999), so bundling is a question of current policy interest. For each location (usually corresponding to a single military installation) and each function type (see the list in the last group of rows in Table 1), all the functions were taken that were competed from 1978 to 1994 and treated as a single function, essentially by aggregating the baseline personnel employed.[11] Bundling reduces the number of functions from 2,069 to 1,793. Figure 2 compares the size distribution (measured by employment) of the original and bundled samples. A slightly higher proportion of the bundled sample is in the larger-size classes and a slightly lower proportion is in the moderate-size classes compared with the original, nonbundled sample. Note that bundling does not create functions whose size lies outside of the range of the original sample, so the parameter estimates should provide reliable predictions concerning the bundled functions. The simulation shows that bundling increases savings slightly to $1.57 billion. Given that the bundled sample is not radically different from the original, it is not surprising that this figure is close to the savings without bundling. The result implies that there are positive "economies of scale" in the Department of Defense's A-76 competitions. One explanation is that larger competitions attract more private contractors as bidders, generating lower

[11] The employment-weighted value for the time trend and the secret bidding dummy were used, though different treatments of these variables made little difference.

Figure 2. Size distributions of bundled and nonbundled functions.



bids. The fact that the in-house winning percentage falls slightly with bundling is consistent with this hypothesis.[12]

An issue of substantial policy interest regards the savings that will be realized from the Department of Defense's recent initiative to conduct a new round of A-76 competitions. This issue is addressed by simulating the savings that would be realized if the 13,329 functions in the Department of Defense's 1995 Commercial Activities Inventory (described in the data section above) were subjected to A-76 competition according to the rules in each scenario (A) through (G). The results are presented in the last three columns of Table 4. A minor complication in the inventory simulations regards the value to use for the time trend. Based on the notion that a restarted A-76 program would resemble the past program at its height rather than at the time it was winding down to a halt, we set the time trend at 1983, the mean for completed A-76 competitions. The simulations were also run fixing the time trend at 1996. In these simulations, savings and the in-house winning percentage were slightly higher than reported in Table 4.[13]

Under the standard rules, the simulations imply that $7.58 billion could be saved annually if the functions in the Commercial Activities Inventory were subjected to A-76 competitions, a savings of about 40 percent of baseline cost. One of the striking differences between the results for the inventory and for the sample of completed A-76 competitions is that the in-house winning percentage is predicted to be significantly higher for functions in the inventory. Indeed, relative to the functions involved in the completed A-76 competitions, the characteristics of the Commercial Activities Inventory functions seem to make them better suited, on average, for in-house performance. As noted, the in-house team wins a larger percentage of competitions under standard rules. Eliminating private contractors in scenario (B) does not cause savings to fall as much as with completed A-76 competitions; and eliminating the in-house team in scenario (C) causes savings to fall more. The constraint on bids provided by baseline cost matters less for functions in the Commercial Activities Inventory than for completed A-76 competitions, whether one considers baseline cost as a reservation value for contractor bids, as in (D); or whether one considers baseline cost as a constraint on the in-house team's bid, as in (E).

For the Commercial Activities Inventory, the remaining two scenarios—moving completely to secret bids (F) and bundling functions (G)—increase savings slightly relative to scenario (A).

One caveat regarding the savings figures for the Commercial Activities Inventory is that they are based on the maintained assumption that the same model applies to inventory functions as to completed A-76 competitions. In practice, this maintained assumption may not hold. There may be a selection effect due to "cherry picking"—functions that were subjected to A-76 competitions may have been better candidates, in the sense of producing greater savings, than those remaining in the inventory—causing the inventory savings figures to be overestimates. The scarce evidence that bears on the question of "cherry picking" suggests that it may not be a significant factor. Tighe *et al*. (1996) found that many functions in the Navy's inventory are similar to those that have already been subject to A-76 competitions; the only difference is the inventory functions are located at installations that have experienced little A-76

[12] Analyzing a small subset of the data for which number of bidders was reported, Marcus, Seamans, and Coast (1999) found a strong positive correlation between competition size and number of bidders. The authors also find—consistent with our results—"economies of scale" in A-76 competitions.

[13] Another minor complication regards the value to use for the secret bidding dummy. A value for each observation, was randomly simulated, maintaining the same expected value, 0.67, as in the sample of completed A-76 competitions.

activity. Tighe *et al*. concluded, "Overall, about 10 percent of the Navy shore establishment is outsourced. Many opportunities remain."

CONCLUSIONS

The Department of Defense saved an estimated $1.55 billion annually (FY 1996 dollars), 35 percent of baseline cost, by subjecting commercial functions to A-76 competitions. It could save $7.58 billion more annually if it subjected its broader list of commercial activities to similar competitions. The present value of the combined streams of savings would exceed $90 billion assuming a 10 percent discount rate. The savings come not just from privatization but also from the competitive pressures brought to bear on the in-house team, causing it to produce more efficiently even if the function is not privatized. This last finding is not merely of theoretical interest: It suggests that the A-76 process—with the special feature that the in-house team bids along with private contractors—may be more efficient than straight privatization. If it is impractical in a particular application to have the in-house team bid along with private contractors, the government should at least consider having a reservation value; i.e., it should have the in-house team continue producing unless a private contractor submits a bid below the in-house team's current cost.

The savings figures come with two main caveats. First, only costs are considered and not the quality of the functions provided. Quality may fall as a result of A-76 competitions. In a case study of 30 A-76 competitions won by private contractors, Marcus (1993) found that the the base commanders rated the private contractors' performance as satisfactory in all but three cases; the three exceptions involved outright contractor default.[14] In the absence of a broader study of the effects of A-76 competitions on quality, work presented here can be thought of as a partial picture of the value of the A-76 program—a picture of the cost side. Second, the analysis is partial equilibrium in the sense that it does not consider what happens to members of in-house teams displaced as a result of privatization. If these personnel are retained within agencies reluctant to cut staff, simply being switched to less productive jobs, the savings figures will be overestimates.

The broader literature finds mixed evidence on the relative efficiency of public versus private firms. For example, Kwoka (1996) finds that cost levels are lower with municipally-owned than investor-owned electric utilities. Teeples and Glyer (1987) find no significant cost differences beteween public and private systems for water delivery and suggest that the preferred ownership type may depend on regional characteristics. Erlich et al. (1994) find evidence in favor of private firms in the form of faster productivity growth. The unambiguous finding of large savings from A-76 competitions presented here is due in part to the fact that an A-76 competition is not simply a mechanism for changing a supplier's ownership; it also involves a competitive bidding process that enhances incentives for cost reduction. The literature tends to find that competitive outsourcing leads to cost savings: More than 90 percent of the 203 studies (which include surveys, quantitative analyses, and case studies) found that competitive outsourcing produced positive savings, according to the meta-analysis reported in Domberger and Jensen (1997).

The results presented here have implications for government agencies beyond the Department of Defense. While the Department of Defense has conducted more A-76

[14] Domberger, Hall, and Li (1995) compare the quality of publicly-provided cleaning services to recently privatized ones and conclude that privatization actually improves performance on average. See also the survey by Domberger and Jensen (1997).

Table 5. Size of commercial activities inventories for other government agencies.

Government Agency	Personnel in Commercial Activities Inventory
Agriculture Department	48,421
Veterans Affairs Department	19,377
NASA	7,957
General Services Administration	4,556
Transportation Department	3,827
Interior Department	2,749
Federal Emergency Management Agency	2,324
Justice Department	1,980
Labor Department	1,167
Health and Human Services Department	1,109
Commerce Department	947
Treasury Department	894
Social Security Administration	766
All Others	5,364
Total	101,438

Source: Author's calculations based on data from current Commercial Activities Inventories as of April 12, 2000, reported in the *Fair Act Report* (2000).
Note: Figures exclude functions in inventory that were in the process of being competed or were labelled "core," "inherently governmental" or "status under consideration."

competitions and has a larger Commercial Activities Inventory than any other agency, other agencies have conducted competitions in the past (see Carrick, 1988), and many agencies have recently begun to expand their Commercial Activities Inventories in response to the Federal Activities Inventory Reform (FAIR) Act of 1998. Table 5 ranks agencies aside from the Department of Defense according to the size of their current Commercial Activities Inventories. Over 100,000 personnel are involved in total, a substantial figure, though less than a third the size of the Department of Defense's inventory. The true scope of commercial activities is likely much larger than 100,000 personnel, however: Reluctant to comply with the FAIR Act, agencies have excluded many times this number of personnel from their inventories by classifying their associated functions as "core" or "inherently governmental," sometimes with dubious justification (FAIR Act Report, 2000). Though there are some specialized functions (e.g., nuclear waste removal in the Department of Energy) on which the model would have little bearing, most of the functions in these other agencies' Commercial Activities Inventories are similar enough to the ones in the present study for the model to be of some value in projecting savings for them.

APPENDIX

For a given function i, let $(\hat{\epsilon}_{gir}, \hat{\epsilon}_{pir}, \hat{\epsilon}_{lir})$ be the rth draw from a trivariate normal distribution with mean zero and covariance matrix $\hat{\Sigma}$. In total, R draws are made, indexed by $r = 1, \ldots, R$. In practice, $R = 1{,}000$. Bids were simulated by substituting the randomly-drawn errors, observable data l_{bi} and z_i, and the estimated coefficients into Equations (4) through (7), yielding

$$\hat{c}_{gir} = G(\hat{l}_{gir}, z_i, \hat{\beta}_g) + \hat{\epsilon}_{gir}$$

$$\hat{c}_{pir} = P(l_{bi}, z_i, \hat{\beta}_p) + \hat{\epsilon}_{pir}$$

$$\hat{c}_{bir} = P(l_{bi}, z_i, \hat{\beta}_g) + \hat{\epsilon}_{pir}$$

where

$$\hat{l}_{gir} = \min\{\hat{l}^*_{gir}, l_{bi}\}$$

$$\hat{l}^*_{gir} = L(l_{bi}, z_i, \hat{\beta}_l) + \hat{\epsilon}_{lir}$$

In addition, define the simulated unconstrained in-house bid:

$$\hat{c}^*_{gir} = G(\hat{l}^*_{gi}, z_i, \hat{\beta}_g) + \hat{\epsilon}_{gir} .$$

To simulate the in-house bid $\hat{c}_{gir}$, actual MEO employment $\hat{l}_{gir}$ was first simulated (which in turn requires simulating desired MEO employment $\hat{l}^*_{gir}$), substituting it along with the estimated coefficients $\hat{\beta}_g$, observable data z_i, and error $\hat{\epsilon}_{gir}$ and error into G(•). Baseline cost $\hat{c}_{bir}$ is simulated similarly except that baseline personnel l_{bi} is substituted rather than $\hat{l}_{gir}$. Simulating the minimum contractor bid is straightforward.

Expected savings from a single A-76 competition, i, is

$$\frac{1}{R} \sum_{r=1}^{R} (\hat{c}_{bir} - \hat{w}_{ir})$$

where $\hat{w}_{ir}$ is the simulated winning bid, which depends on the rules of the particular policy scenario as described below. This process can be repeated for each of the completed A-76 competitions, and the resulting figures summed to produce total savings. It can also be repeated for out-of-sample functions (for example, functions in the Commercial Activities Inventory) as long as there is data for l_{bi} and z_i to be substituted into the simulation formulae. With baseline cost and the bids simulated, it is possible to compute the expectation of savings or indeed any other function of these variables. In particular, the simulations were also used to compute the expected percentage of competitions won by the in-house team.

The winning bid, $\hat{w}_{ir}$, takes on the following values in each of the different scenarios from Table 4:

$$\text{(A)} \quad \hat{w}_{ir} = \begin{cases} \hat{c}_{gir} \text{ if } \hat{c}_{gir} \leq (1+\Delta)\, \hat{c}_{pir} \\ \hat{c}_{pir} \text{ else} \end{cases}$$

$$\text{(B)} \quad \hat{w}_{ir} = \hat{c}_{gir}$$

$$\text{(C)} \quad \hat{w}_{ir} = \min\{\hat{c}_{bir}, \hat{c}_{pir}\}$$

$$\text{(D)} \quad \hat{w}_{ir} = \hat{c}_{pir}$$

$$\text{(E)} \quad \hat{w}_{ir} = \begin{cases} \hat{c}^{*}_{gir} \text{ if } \hat{c}^{*}_{gir} \leq (1+\Delta)\hat{c}_{pir} \\ \hat{c}_{pir} \text{ else.} \end{cases}$$

The equation for scenarios (F) and (G) are identical to (A); the scenarios differ from (A) only in the observables (l_{bi} and z_i) substituted into the formulae. In (A) the observables come from the original data set. In (F), the secret bidding dummy is set equal to one for all observations; but in other respects the data from the original set are maintained. In (G), the observables come from the data set where functions are bundled.

The simulations require an estimate, $\hat{\Sigma}$, of the error covariance matrix. In view of Equation (8), this involves six parameter estimates, $\hat{\sigma}^2_g$, $\hat{\sigma}^2_p$, $\hat{\sigma}^2_l$, $\hat{\sigma}_{gp}$, $\hat{\sigma}_{gl}$ and $\hat{\sigma}_{pl}$. We obtain $\hat{\sigma}^2_g$, $\hat{\sigma}^2_p$, and $\hat{\sigma}_{gp}$ from the joint estimation of Equations (4) and (5). Parameter $\hat{\sigma}^2_l$ is obtained from the generalized Tobit estimation of Equation (6). The remaining two parameters are calculated from the covariance between estimated residuals ($\hat{\sigma}_{gl}$ from the covariance between $\hat{\epsilon}_{gi}$ and $\hat{\epsilon}_{li}$; $\hat{\sigma}_{pl}$ from the covariance between $\hat{\epsilon}_{pi}$ and $\hat{\epsilon}_{li}$). One difficulty in this exercise is that, due to censoring, $\hat{\epsilon}_{li}$ is not always observable, but taking only those observations for which $\hat{\epsilon}_{li}$ is observable leads to a biased sample of the $\hat{\epsilon}_{li}$. We solve this problem by only using those observations for which $L(l_{bi}, z_i, \hat{\beta}_l)$ is sufficiently low relative l_{bi} to ensure that the probability of censoring of $\hat{l}_{gi}$ at l_{bi}, and hence any bias in $\hat{\epsilon}_{li}$, is miniscule. In any event, we repeated the simulations in Table 4 with alternative values of $\hat{\sigma}_{gl}$ and $\hat{\sigma}_{pl}$ in reasonable ranges and found the quantitative results were not sensitive.

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CHRISTOPHER M. SNYDER is an Associate Professor, Department of Economics, George Washington University, Washington DC.

ROBERT P. TROST is a Professor, Department of Economics, George Washington University.

R. DEREK TRUNKEY is a Senior Analyst, The CNA Corporation.

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