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by

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Abstract

This paper investigates the impact of program budget size on monitoring and competitive bidding in the public sector. A sequential game is developed involving a ministry and bureau strategically interacting in the provision of a public sector good. The ministry copes with imperfect information about the bureau's costs by choosing to monitor or to conduct a first price sealed bid auction between the bureau and a set of firms. In this respect, this study represents an extension of the Niskanen budget maximizing bureau framework. The results predict that the ministry will tend to conduct competitive bidding at low and high levels of budgetary allocation. Otherwise, the bureau is monitored. Second, increases in the budget expand the range of costs over which the bureau can win the competitive bid. Third, increases in management compensation tends to reduce the spread between the bureau's costs and its reported cost for providing the public sector good.

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Contents

List of Figures

Monitoring and Competitive Bidding in the Public Sector

1 Introduction

This paper investigates the impact of program budget on monitoring and competitive bidding in the provision of services in the public sector. In recent years, governments in North America as well as Europe have increasingly looked towards outsourcing and privatization as an alternative to the provision of goods and services in the public sector (De Fraja, 1993; Osborne and Gaelber, 1993; Feenstra and Hanson, 1996; and Donahue, 1989). This trend has been coupled with increased interest in having government departments and private sector firms compete for the rights to provide public sector goods. This competitive bidding process has been suggested by several authors, such as Osborne and Gaebler (1992), as an alternative to the monitoring of government bureaus.

Savas (1977) reports that a combination of public and private sector providers are utilized throughout the USA in the provision of services such as health care, street light maintenance, water supply, snow removal, refuse collection, emergency ambulance transportation and policing. This also applies to the Canadian setting (Laux, 1993). Hart, Shleifer and Vishny (1997) report that private prisons in the USA represented capacity of about 50,000 prisoners in 1994 as compared with only 1,200 in 1985 during a period of rising prison budgets and population. These private facilities are operated at about 15 percent less cost per prisoner than public facilities.

Stevens (1978) found a significant difference between public and private sector monopoly providers of refuse collection services. In cities with populations of over 50,000 residents, a significant difference of some 29 percent in refuse collection costs was found in favor of private over public sector monopoly service providers. In cities of under 50,000, no significant cost differences were found between the two service providers (Stevens, 1978, and Savas, 1977). These results suggest that government activities involving high program budget may realize cost savings from outsourcing, while these savings are unlikely to be realized for activities involving small program budgets.

Savas (1977) pointed to potential public sector "bureaucratic inefficiency" as possibly being the primary factor likely contributing to the apparent higher cost of services provided by the public sector over private sector providers. The present study focuses on how program budget influences the cost of services provided by government bureaus and its implications for the choice by government to monitor in-house service provision or to conduct competitive bidding for these services.

The public sector has often been characterized as being inefficient due to the objectives pursued by decision-makers within the various branches of government (Mueller,1989). In 1975, Niskanen developed a formal model of the public sector which assumed budget maximizing bureaus, information asymmetry between the bureau and the funding source and the granting of monopoly powers to these bureaus by the funding source (Mueller, 1997). Niskanen's model predicted that, under these assumptions, public sector production takes place at levels where the social marginal cost exceeds the marginal benefits. This is consistent with the empirical observations of some political scientist and economists which showed the production cost of government bureaus were as much as twice those of comparable private sector providers (Miller and Moe, 1983, and Mueller, 1989). Niskanen (1975) further suggested that monitoring of these bureaus could limit public sector inefficiency.

Bendor *et al* (1985) pointed out that Niskanen's assumption was too restrictive and implied control of the legislative agenda by the bureau. Specifically, it was assumed that the funding source could only choose between taking or leaving the bureau's budget for producing the public sector good. Bendor *et al*, therefore, extended the Niskanen model to include monitoring and found that monitoring was an effective mechanism in reducing the misreporting of costs by the bureau to the funding source. The model developed by Bendor *et al*, however, did not involve the endogenous determination of the optimal monitoring level of the bureau by the funding source as is done in this paper. Recently, Khalil and Lawarree (1995) showed that a principal could utilize an auditor to monitor an agent in order to cope with asymmetric information about a productivity parameter known only to the agent. Monitoring was shown to reduce shirking, but was potentially vulnerable to the agent bribing the auditor.

Bose (1995) quotes Becker as suggesting that a planner's social welfare function is increasing in the size of the fine levied against an agent for noncompliance and decreasing in the cost of monitoring. Consequently, it has been suggested that the fine should be set at the maximal penalty for noncompliance and the probability of conviction at the minimum level needed to enforce compliance (Andreoni, 1991). Dickens *et al* (1989) points out, however, that US businesses spend approximately $12 billion annually on security products, personnel and services aimed at monitoring and deterring non-compliance such as theft conducted by employee. Additionally, legal precedent obliges the courts to ensure that the "punishment fits the crime", which limit the enforceability of maximal penalties or contractual arrangements. Wintrobe (1997) further points out that bureaucrats' promotional opportunities and other compensation may moderate budget maximizing behavior in the public sector. On the other hand, the cost of control devices may limit the ability of the funding source to prevent the bureau from extracting some rents.

Employee bonds or pay withholding are used in the private sector as penalty instruments to complement expenditures on monitoring (Dickens, 1989). In the public sector, the principle of honorable retirement or discharge is prevalent and entitles employees to a full government sponsored pension and severance package. Dishonorable discharge is accompanied by a number of penalties including a reduced benefits package which may represent a substantial financial loss to the employee.

Niskanen's model has continued to be used as a theoretical framework for examining public sector decision making and government bureau cost reporting (Wintrobe, 1997). More recently, Borge (1996) found that, in a theoretical framework of a multi-bureau regime, these bureaus could coordinate their reporting of financial information in order to further increase their budgetary allocation and, implicitly, inefficiency.

The rising cost of government and increasing tax resistance have resulted in the exploration of strategies aimed at curtailing inefficiency in the public sector. These strategies have included the establishment of budget review committees, information gathering facilities and value-for-money audit procedures aimed at increasing the probability of bureaus being detected misreporting cost information (Mueller, 1989, Graham, 1990, Mathewson, 1996). Many of these strategies involve legislation aimed at setting institutional procedures and regulation for the monitoring of costs reported by government bureaus (Graham, 1990, and Donahue, 1989). The cost of monitoring and providing the public sector services has potentially fueled the drive towards privatization (Thatcher, 1993, Laux, 1993, Feenstra and Hanson, 1996, and Perotti, 1995). Between the extremes of doing nothing and privatization lies the operation of "government like a business" described by Graham (1990) and "competitive government" outlined by Osborne and Gaebler (1993). The choice between monitoring and competitive bidding is investigated in this present paper.

Competition between government bureaus and the private sector in the provision of public sector goods and services through a competitive bidding process provides the government with an alternative to monitoring when there are information asymmetries. Examples of this paradigm include cities such as Phoenix, which permits both the private sector and some government bureaus to bid on public sector contracts (Osborne and Gaebler, 1993). In Canada and the US, the private and public sector compete directly and indirectly for contracts to operate prisons, remove snow, collect garbage and administer long-term care facilities. When these contracts are won by the private sector firm through a competitive bidding process involving the government bureau, it is referred to as competitive outsourcing of public sector services. This is distinct from simple outsourcing which involves the issuance of public sector contracts to the private sector without giving the government agency the right to compete for the contract. In recent years, governments have focused on opportunities to conduct competitive bidding and privatization (Laux, 1993, Feenstra and Hanson, 1996 and Matthewson, 1996, Shleifer and Vishny, 1994). In the present paper, the impact of the scale of a program on the choice made by government between monitoring and competitive bidding is analyzed.

Donahue (1989) points out that the General Accounting Office establishes a monitoring structure or institutional framework for detecting misappropriation and misreporting among US federal government agencies. This framework is established through reporting requirements and standards. In Canada, the Auditor General plays a similar role with reporting requirements and standards being also established through Management/Treasury Board of Cabinet at the provincial and federal levels of government. These reporting requirements and standards as well as accounting systems are generally invariant to individual government agencies since they are often established in relation to the budget size of various agencies.

Monitoring and competitive bidding in the public sector raise several questions about government organizations and their budgeting processes. First, what budgetary allocations result in the funding source (ministry) choosing competitive bidding over monitoring of the bureau's cost? Second, what cost realizations will result in the bureau winning the competitive bidding process when competitive bidding is the choice selected by the funding source? Third, what are the implications of each of these regimes for the scale of expected production of the bureau?

The questions raised in this study are addressed through the development of a sequential game involving a ministry (funding source), modified Niskanen bureau and private sector firms. The ministry is assumed to have a program budget to spend on the provision of a good or service. The bureau possesses private information about its cost of providing the good or service. There also exists a set of firms which can produce the good. However, a competitive process involving a sealed bid (first-price) auction must be held before a contract to produce the good may be awarded. The game proceeds essentially as follows: At stage I, the ministry chooses to monitor the bureau or to conduct competitive bidding. If monitoring is chosen, then the ministry moves again at stage II to set the monitoring level to be conducted by an audit institution using a costly monitoring technology. At stage III, nature draws the unit cost of providing the public sector good which is the bureau's private information. At stage IV, the bureau observes it's cost realization and chooses the cost of providing the service to report to the ministry. At stage V, the ministry observes the reported cost and chooses the level of output of the good or service to fund. At stage VI, nature probabilistically detects the bureau misreporting its cost given the probability distribution induced by the ministry's monitoring intensity.

If competitive bidding is chosen at stage I, then nature draws the unit cost at stage II and the ministry at stage III accepts sealed bids from the bureau and private sector firms capable of providing the good or service. At stage IV, the ministry awards the contract to provide the good or service to the lowest bidder and chooses the level of the good or service to fund. The focus of the study is on the equilibrium outcome of the bidding process. If the bureau loses the bid, its resources may be redeployed to other activities within the government and result in a non-negative redeployment payoff.

The study proceeds as follows: In section two, the basic model is developed with the bureau determining the unit price to report to the ministry for providing the good or service. In section three, monitoring and competitive bidding subgame perfect equilibrium outcomes for the ministry and bureau are characterized. In section four, the ministry's equilibrium strategy concerning the choice of monitoring or competitive bidding is characterized. The impact of the program budget on the ministry's choices in equilibrium is also considered in this section. In section five, the conclusions are outlined.

This paper generalizes the Niskanen model to include monitoring and competitive bidding. The main findings of the study are as follows: First, the study predicts that the ministry will tend to conduct competitive bids at low and high level of budgetary allocation. This result is consistent with the empirical findings reported by Savas (1977) and Stevens (1978). Consequently, the institutional arrangement of government can be anticipated to switch between competition and monitoring and back to competition as the budget of the ministry increases. Second, the results predict that, given a positive redeployment payoff, increases in the program budget tend to increase the range of cost realizations over which the bureau wins the competitive bidding process with positive probability. However, when the redeployment payoff is zero the probability of the bureau winning the competitive bid is invariant to program budget levels. Third, the results predict that the ministry will tend to choose monitoring of the bureau over competitive bidding as other compensation and the re-deployment income increases.

The findings of the study have several implications for empirical work on the choices concerning monitoring and competitive bidding in the public sector. Specifically, it would be expected that the probability of private (competitive bidding) as opposed to public (bureau) provision of services will be positively related to the program budget size at low and high budget levels. At intermediate budgetary levels, this probability is predicted to be negatively related to the size of the program budget. The probability of the provision of the public sector good or service through competitive bidding is also predicted to be positively related to the redeployment opportunities of the bureau's resources and to the costs of monitoring the bureau. On the other hand, this probability is predicted to be negatively related to the senior management compensation package and the magnitude of the sanctions facing the bureau for misreporting.

2 The Model

Consider a sequential game involving two strategic players: a bureau denoted by $\mathcal{B}$ that is in a position to provide a good or service in the quantity x and a ministry denoted by $\mathcal{M}$. The ministry oversees the bureau and provides the funds necessary to cover the costs associated with the production of the good or service x. Additionally, there exists a set of n firms denoted by $\mathcal{F}$ which are also capable of providing the good or service x. For instance, x may be the number of livestock inspected by a bureau which reports to Agriculture Canada or to a provincial Ministry of Agriculture or the amount of refuse collection by a bureau reporting to a municipal works department. Other examples may include schools, basic health care and policing services.

The bureau is an extended Niskanen bureau receiving a grant G from the ministry (funding source) for the provision of x units of the public sector good or service. The ministry cares about having as much x as possible with its preferences over x represented by $u_{\mathcal{M}}(x) = x$. On the other hand, the bureau's discretionary budget is given by $E = G - cx$ if it produces x units of the public sector good or service at its realized costs c. Otherwise, the bureau's discretionary budget is zero. In what follows, it is assumed that the bureau quotes to the ministry a unit price w for providing the good or service. If the ministry chooses to fund the provision of services in quantity x, the bureau receives a grant of $G = wx$ and, hence, its discretionary budget is $E = (w - c)x$.

The bureau receives other compensation in addition to the grant G. This compensation is exogenous to the ministry's budget and comes in the form of salary, benefits, retirement and severance packages and discretionary funds from other (not modelled) projects. The magnitude of this other compensation is denoted by μ. The bureau cares about its discretionary budget and other compensation with its payoff function defined by $u_{\mathcal{B}} = E + \mu$.

Formally, the game is structured as follows: The ministry's program budget $R \in R_{++}$ is common knowledge. At stage I, $\mathcal{M}$ chooses $a \in \{C, M\}$ with C denoting competitive bidding and M denoting monitoring.

The Monitoring Subgame. The *M-subgame* is first considered. Given $a = M$, $\mathcal{M}$ moves again at stage II choosing $q \in [0, 1]$ which can be interpreted as an institutional monitoring intensity with the probability q of the bureau being detected reporting $w > c$.

Assumption A1: *The ministry incurs monitoring costs given by the function $m(q)$ with $m(0) = \overline{m} > 0$, $m' > 0$, $m'' > 0$ for $q \in [0, 1)$ and $lim_{q \to 1} m(q) = lim_{q \to 1} m'(q) = \infty$.*[1] *It is further assumed that $R > \overline{m}$.*

At stage III, nature draws a unit cost c from a probability distribution

[1]It is assumed that the probability of detecting the bureau misreporting is a function of the cost of collection of evidence. Expenditures on collection activities is given by m and there exists a fixed cost $\overline{m}$. Let $q = F(-\overline{m} + m)$, where $F(.)$ the distribution function. Therefore, $m(q) = \overline{m} + F^{-1}(q)$ with $\partial F^{-1}(q)/\partial q > 0$ and $\partial^2 F^{-1}(q)/\partial q \partial q > 0$. For example, let $1 - q = exp\{-[-\overline{m} + m]\}$. This implies monitoring costs are given by $m(q) = \overline{m} - ln(1 - q)$. Alternatively, let $1 - q = exp\{ln(\overline{m}) - ln(m)\}$ which results in $m(q) = \overline{m}/[1 - q]$. These functions have all the described properties and may be further generalized. Clearly, other cost functions may also satisfy the assumptions outlined.

$f(c)$ over $[\underline{c}, \overline{c}]$ with $\underline{c} > 0$. This draw is private information to the bureau, but the probability distribution from which it is drawn is common knowledge.

At stage IV, $\mathcal{B}$ observes the ministry's choice of $q \in [0,1]$ and nature's draw $c \in [\underline{c}, \overline{c}]$ and chooses a value $w \in R_{++}$ to report to $\mathcal{M}$ for producing a unit of x. At stage V, the ministry chooses the quantity of x to fund subject to the constraint $wx + m(q) \leq R$. At stage VI, nature observes w and chooses $d \in \{D, N\}$ with the probabilities $\{q, 1-q\}$, where D denotes detecting misreporting (i.e., $w > c$) and N denotes misreporting not being detected.

The bureau's payoff is given by $(w-c)x + \mu$ if it is not detected cheating (i.e., $d = N$). If the bureau is detected cheating (i.e., $d = D$), the bureau loses its discretionary budget $E = (w-c)x$ which is returned to the government's consolidated revenue fund. Additionally, the bureau loses some of its other compensation μ in proportion to the degree of misreporting (i.e., $w - c > 0$). The proportion lost is represented by $\theta \cdot (w-c)$ with $\theta > 0$. Therefore, the bureau's payoff is given as follows: $(w-c)x + \mu$ if $d = N$ and $[1 - \theta \cdot (w-c)]\mu$ if $d = D$.

The Competition Subgame. Given $a = C$, nature at stage II draws c from a pdf $f(c)$ over $[\underline{c}, \overline{c}]$. At stage III, n firms submit sealed bids to the ministry as part of a first price sealed bid auction between the n firms and bureau. The ith firm's bid is a random variable denoted by w_{fi} with $i \in \{1, 2, ..., n\}$ (McAfee and McMillan, 1987; and Paarsch and Donald, 1992). These bids are generated from an equilibrium bidding rule $w_{f_i} = \beta(z_i)$ which is strictly increasing and differentiable in the ith firm's cost realization $z_i \in [\underline{s}, \overline{s}]$. Let w_f denote the lowest bid of the n firms. This lowest bid is a first order statistic of n random variables with a marginal probability distribution function given by $h(w_f)$ over $[\underline{w}_f, \overline{w}_f]$ (Paarsch and Donald, 1992). $H(w_f)$ is the distribution function corresponding to $h(w_f)$.[2] This distribution is common knowledge. Therefore, if the bureau bids w_b, the probability of it winning the competitive bidding process is $1 - H(w_b)$.

[2] Let w_f be the first order statistic of n random variables, specifically, $w_f = min\{w_{f1}, w_{f2}, .., w_{fn}\}$. The joint p.d.f. for the jth order statistic is given by $g_j(w_{fj}) = n!f(w_{f1})f(w_{f2})..f(w_{fn})$, $\underline{w}_f \leq w_f \leq \overline{w}_f$ and zero elsewhere. The marginal pdf for the $j = 1$, with $w_{f1} = w_f$, order statistic is $h(w_{f1}) = \int_{w_{f1}}^{\overline{w}_f} .. \int_{w_{f1}}^{\overline{w}_f} n!f(w_{f1})f(w_{f2})..f(w_{fn})dw_{fn}$ $dw_{fn-1}..dw_{f2} = n[1 - F(w_{f1})]^{n-1}f(w_{f1})$; $\underline{w}_f \leq w_f \leq \overline{w}_f$ and zero elsewhere (Hogg and Craig, 1978). In this framework, the bureau may be considered to be the nth firm when the bureau's redeployment payoff (i.e., payoff if it loses the bid) is zero and, hence, symmetric with the payoff of the (other) firms.

At stage IV, the bureau observes the draw c, knows $H(w_f)$ and R, and chooses its bid $w_b \in R_{++}$ to submit to the ministry. At stage V, $\mathcal{M}$ observes $\{w_f, w_b\}$ and chooses $b \in \{\mathcal{B}, \mathcal{F}\}$ which denotes the winner of the competitive bidding process. It then chooses how much x to have the winner produce at the winning bid. Thus, the ministry's payoff is given by $x_b = R/w_b$ if $b = \mathcal{B}$ and by $x_f = R/w_f$ if $b = \mathcal{F}$. The bureau's payoff is given by $(w_b - c)x + \mu$ if $b = \mathcal{B}$ and by μ if $b = \mathcal{F}$.

The bureau and ministry's expected payoffs are represented as follows:

$$u_{\mathcal{B}} = \begin{cases} (1-q)[(w-c)x+\mu] + q\mu[1-\theta\cdot(w-c)] & \text{if } a = M \\ [1-H(w_b)][(w_b-c)x+\mu] + H(w_b)\mu & \text{if } a = C \end{cases} \tag{1}$$

and

$$u_{\mathcal{M}} = \begin{cases} \frac{R-m(q)}{w} & \text{if } a = M \\ \frac{R}{w_f} & \text{if } a = C \text{ and } b = \mathcal{F} \\ \frac{R}{w_b} & \text{if } a = C \text{ and } b = \mathcal{B} \end{cases} \tag{2}$$

3 Monitoring and Competitive Bidding

The conduct of the bureau and the ministry is determined by examining their subgame perfect equilibrium strategies. These strategies are determined through backward induction starting at the terminal node for each subgame. From these results, the expected payoff of the ministry from choosing monitoring or competitive bidding is identified. This allows for the determination of the values of R under which the ministry will choose competitive bidding over monitoring given the program budget $R > \overline{m}$. I will first derive the subgame perfect equilibrium strategies that follow from the ministry's choice of monitoring.

3.1 Monitoring

Monitoring is the result of the ministry's choice of $a = M$ at stage I. The equilibrium behavior of $\mathcal{M}$ and $\mathcal{B}$ is now derived for the M-subgame. At stage V, the ministry chooses the quantity of x to fund given the program budget $R > \overline{m}$, the monitoring level $q \in [0,1]$ and the reported price $w \in R_{++}$. Therefore, $x(R, q, w : M) = [R - m(q)]/w$.

Bureau. The bureau anticipates nature's choice $d \in \{D, N\}$ with probability $\{q, 1-q\}$ at stage VI, and the ministry's choice $x(R, q, w : M)$ at stage V. At stage IV, the bureau chooses the reported price $w(q, R, c)$ to satisfy

$$w(q, R, c) = \arg\max_{w} \{(1-q)[(w-c)x(R, q, w : M) + \mu] + q\mu[1 - \theta \cdot (w-c)]\} \tag{3}$$

The bureau's subgame perfect equilibrium strategy $w(q, R, c)$ is as follows:

$$w(q, R, c) = \left\{ \left(\frac{1-q}{q} \right) \left[\frac{c[R - m(q)]}{\theta\mu} \right] \right\}^{\frac{1}{2}} \tag{4}$$

The reported price in equation 4 is a global maximum since the second order derivative of the bureau's payoff function with respect to w is strictly negative. The reported price $w(q, R, c)$ is strictly increasing in c and decreasing in q. Nature chooses c at stage III.

Ministry. At stage II, the ministry chooses the monitoring level $q(R) \in [0, 1]$ to maximize its expected payoff function anticipating the bureau's strategy $w(q, R, c)$. The ministry's choice $q(R)$ is given by

$$q(R) = \arg\max_{q} \int_{\underline{c}}^{\overline{c}} \frac{R - m(q)}{w(q, R, c)} f(c) dc \tag{5}$$

Substituting equation 4, $q(R)$ is expressed as follows:

$$q(R) = \arg\max_{q} \int_{\underline{c}}^{\overline{c}} \left\{ [R - m(q)] \left(\frac{\theta\mu}{c} \right) \left(\frac{q}{1-q} \right) \right\}^{\frac{1}{2}} f(c) dc \tag{6}$$

The first order condition for the ministry's problem is given by

$$\left(\frac{1}{2}\right) \left\{ -m'(q) \left(\frac{q}{1-q} \right) + [R - m(q)] \left(\frac{1}{[1-q]^2} \right) \right\} * \tag{7}$$
$$\left\{ [R - m(q)] \left(\frac{q}{1-q} \right) \right\}^{\frac{-1}{2}} \gamma_c = 0$$

where: $\gamma_c = \int_{\underline{c}}^{\overline{c}} \left(\frac{\theta\mu}{c}\right)^{\frac{1}{2}} f(c) dc$.

The equilibrium strategy $q(R)$ satisfies[3]

$$R = m(q(R)) + m'(q(R))q(R)[1 - q(R)] \tag{8}$$

Given the first order condition, the second derivative of the ministry's payoff function with respect to q is given by

$$\left(\frac{1}{2}\right)\left\{-m''(q)\left(\frac{q}{1-q}\right)+\left(\frac{2}{[1-q]^3}\right)\{R-m(q)-m'(q)[1-q]\}\right\}* \\ \left\{[R-m(q)]\left(\frac{q}{1-q}\right)\right\}^{\frac{-1}{2}}\gamma_c < 0 \tag{9}$$

Proposition 1 *If A1 holds, then* $q(R) \in [0, 1)$.

Proposition (1) can be verified by considering that $lim_{q\to 1}m(q) = lim_{q\to 1}m'(q) = \infty$ from **A1**. Therefore, if $R - m(q(R)) > 0$, then $0 \leq q(R) < 1$ since $R = m(q(R)) + m'(q(R))q(R)[1 - q(R)]$.

Equilibrium behavior. The equilibrium strategies for the M-subgame are as follows:

1. For the monitoring intensity, $q(R)$ must satisfy:

$$R = m(q(R)) + m'(q(R))q(R)[1 - q(R)] \tag{10}$$

2. For the reported price, $w(q, R, c)$:

$$w(q, R, c) = \left\{\left(\frac{1-q}{q}\right)\left[\frac{c[R-m(q)]}{\theta\mu}\right]\right\}^{\frac{1}{2}} \tag{11}$$

3. For the public sector good or service, $x(R, q, w)$:

$$x(R, q, w) = \frac{R - m(q)}{w} \tag{12}$$

[3]The assumption that the other compensation function is given by $\mu[1 - \theta \cdot (w - c)]$, if $d = D$, is important to the determination of the equilibrium strategy $q(R)$. If the other compensation function is non-linear in w and c, then the equilibrium monitoring strategy can be easily expressed in closed form and is a function of the expected cost realization as well as the program budget R. This latter consideration will be further explored later in the paper.

Proposition 2 *If c and $q(R)$ are such that $m'(q) > \frac{\mu\theta c}{[1-q]^2}$, then the bureau's subgame perfect equilibrium strategy satisfies $w(q, R, c) > c$.*

Proof:
The bureau's payoff function is given by

$$u_B(q, R, c, w : M) = (1-q)\left[(w-c)\left(\frac{R-m(q)}{w}\right)+\mu\right] + q\mu[1-\theta\cdot(w-c)] \tag{13}$$

$$\frac{\partial u_B(q, R, c, w : M)}{\partial w} = c\left[\frac{R-m(q)}{w^2}\right](1-q) - q\mu\theta \tag{14}$$

At $w = c$ and $R = m(q(R)) + m'(q(R))q(R)(1-q(R))$, it can be shown that

$$\frac{\partial u_B(q, R, c, w : M)}{\partial w} = \frac{m'(q(R))q(R)(1-q(R))^2}{c} - q\mu\theta \tag{15}$$

For all $q \in [0, 1)$, $\frac{\partial u_B(q,R,c,w:M)}{\partial w}|_{w=c} > 0$ if

$$m'(q(R)) > \frac{\mu\theta c}{[1-q(R)]^2} \tag{16}$$

□

Specifically, proposition 2 tends to hold for values of c on $[\underline{c}, \bar{c}]$ near to $\underline{c}$ given any $q \in [0, 1)$, μ and θ.The bureau's payoff from misreporting is given by $u_B(q, R, c, w : M) = (1-q)\{(w-c)[R-m(q)/w]+\mu\}+q\mu\{1-\theta\cdot(w-c)\}$ and by μ if it reports $w = c$. Misreporting by setting $w > c$ reduces the demand for the good or service $x = [R-m(q)]/w$ and yields a smaller payoff for the bureau when c is close to $\bar{c}$ as compared with c close to $\underline{c}$.

Equation 16 further suggests that the choice of other compensation μ and the parameter θ are important in the determination of whether or not the bureau will misreport given any program budget R. If μ is sufficiently large, then the inequality in equation 16 does not hold and the bureau reports $w = c$. Additionally, this result suggests that the bureau will not misreport for some set of cost realizations $c \in [\underline{c}, \bar{c}]$. Let $c(q)$ be defined by

$$c(q) \;=\; \inf\left\{c \in [c, c] : \frac{m'(q)q(1-q)^2}{c} - q\mu\theta > 0\right\} \tag{17}$$

$$= \frac{m'(q)[1-q]^2}{\mu\theta}$$

Corollary 3 *The bureau truthfully reports its costs with $w = c$ when $c > c(q)$.*

The corollary suggests that the ministry's choice of q is important in determining the cost realizations over which the bureau will truthfully report.[4]

Assumption A2: *It is assumed that $m'(q) > \frac{\mu\theta\bar{c}}{[1-q]^2}$ for all q.*

Assumption **A2** suggests that the marginal cost of monitoring the bureau is such that the probability of the bureau being detected misreporting is too small to fully deter cheating. This assumption also implies that $c(q) > \bar{c}$. In what follows, **A2** is assumed to hold.

Equilibrium outcome. The equilibrium outcome for the M-subgame conditional on the values of R, c is as follows:

For the monitoring intensity, $q(R)$ satisfies:

$$R = m(q(R)) + m'(q(R)q(R)[1-q(R)] \tag{18}$$

For the reported price, $w(R, c)$:

$$\begin{aligned} w(R,c) &= \left\{ \left(\frac{1-q(R)}{q(R)} \right) \left[\frac{c[R-m(q(R))]}{\theta\mu} \right] \right\}^{\frac{1}{2}} \\ &= (1-q(R)) \left[\frac{cm'(q(R))}{\theta\mu} \right]^{\frac{1}{2}} \end{aligned} \tag{19}$$

For the public sector good or service, $x(R, c)$:

$$\begin{aligned} x(R,c) &= \frac{R-m(q(R))}{w(R,c)} \\ &= m'(q(R))q(R)[1-q(R)] \left\{ \left(\frac{q(R)}{1-q(R)} \right) \left[\frac{\theta\mu}{c[R-m(q(R))]} \right] \right\}^{\frac{1}{2}} \end{aligned} \tag{20}$$

[4] If $c(q) < \bar{c}$, then the ministry's problem would be generalized to the follows: $q(R) = argmax_q \left\{ \int_{c(q)}^{\bar{c}} [(R-m(q))/c] f(c)dc + \int_{\underline{c}}^{c(q)} [(R-m(q))/w] f(c)dc \right\}$.

The resulting subgame perfect equilibrium strategy $q(R)$ is dependent on the distribution of c as well as $m(q)$.

$$
\begin{aligned}
&= m'(q(R))q(R)[1-q(R)]\left\{\left(\frac{q(R)}{1-q(R)}\right)\left[\frac{\theta\mu}{c\{m'(q(R))q(R)[1-q(R)]\}}\right]\right\}^{\frac{1}{2}} \\
&= \left\{m'(q(R))q(R)[1-q(R)]\left(\frac{\theta\mu}{c}\right)\right\}^{\frac{1}{2}}\left\{\frac{q(R)}{1-q(R)}\right\}^{\frac{1}{2}} \\
&= q(R)\left[m'(q(R))\left(\frac{\theta\mu}{c}\right)\right]^{\frac{1}{2}}
\end{aligned}
$$

3.1.1 Ministry's Expected Payoff from Monitoring

At stage I, the ministry's subgame perfect equilibrium payoff is expressed as $E[u_{\mathcal{M}}(R,c):a]$ for $a \in \{C, M\}$. If the ministry chooses $a = M$, its expected payoff from the M-subgame is as follows:

$$
\begin{aligned}
E[u_{\mathcal{M}}(R,c) \; &: \; M] = \int_{\underline{c}}^{\overline{c}} \left\{\frac{R-m(q(R))}{w(R,c)}\right\} f(c)dc \\
&= q(R)[m'(q(R))]^{\frac{1}{2}}\gamma_c
\end{aligned}
\tag{21}
$$

The response of the ministry's M-subgame expected payoff to changes in R is given as follows:

$$
\begin{aligned}
&\frac{\partial E[u_{\mathcal{M}}(R,c):M]}{\partial R} \\
&= \left\{\left(\frac{dq(R)}{dR}\right)[m'(q(R))]^{\frac{1}{2}} + q(R)m''(q(R))[m'(q(R))]^{\frac{-1}{2}}\left(\frac{dq(R)}{dR}\right)\right\}\gamma_c \\
&= \left\{1 + q(R)\left(\frac{1}{2}\right)m''(q(R))[m'(q(R))]^{-1}\right\}\left\{[m'(q(R))]^{\frac{1}{2}}\left(\frac{dq(R)}{dR}\right)\right\}\gamma_c \\
&= \left(\frac{1}{2}\right)[m'(q(R))]^{-1}\{2m'(q(R)) + q(R)m''(q(R))\} \times \\
&\quad \left\{[m'(q(R))]^{\frac{1}{2}}\left(\frac{dq(R)}{dR}\right)\right\}\gamma_c \\
&= \left(\frac{1}{2}\right)[m'(q(R))]^{-\frac{1}{2}}\{2m'(q(R)) + q(R)m''(q(R))\}\left(\frac{dq(R)}{dR}\right)\gamma_c
\end{aligned}
\tag{22}
$$

The response of the ministry's expected payoff from monitoring to the program budget is thus dependent on $dq(R)/dR$. This total derivative can be determined from the equilibrium outcome in equation 18 as follows:

$$
\begin{aligned}
dR &= m'(q(R))dq(R) + m''(q(R))dq(R)\{q(R)[1-q(R)]\} \\
&\quad + m'(q(R))\{1-2q(R)\}dq(R) \quad (23)\\
&= \{2m'(q(R))\{1-q(R)\} + m''(q(R))\{q(R)[1-q(R)]\}\}\, dq(R) \quad (24)
\end{aligned}
$$

$$
\begin{aligned}
\frac{dq(R)}{dR} &= \frac{1}{2m'(q(R))\{1-q(R)\} + m''(q(R))\{q(R)[1-q(R)]\}} \quad (25)\\
&= \frac{1}{\{2m'(q(R)) + m''(q(R))q(R)\}\,[1-q(R)]} > 0
\end{aligned}
$$

Equation 22 can therefore be expressed as follows:

$$
\begin{aligned}
&\frac{\partial E[u_{\mathcal{M}}(R,c):M]}{\partial R} \\
&= \left(\frac{1}{2}\right)[m'(q(R))]^{-\frac{1}{2}}\{2m'(q(R)) + q(R)m''(q(R))\} * \\
&\quad \left(\frac{1}{\{2m'(q(R)) + m''(q(R))q(R)\}\,[1-q(R)]}\right)\gamma_c \\
&= \left(\frac{1}{2}\right)[m'(q(R))]^{-\frac{1}{2}}\left(\frac{1}{1-q(R)}\right)\gamma_c > 0
\end{aligned}
$$

Additionally, the second derivative of $E[u_{\mathcal{M}}(R,c):M]$ with respect to R is given as follows:

$$
\frac{\partial^2 E[u_{\mathcal{M}}(R,c):M]}{\partial R \partial R} \quad (26)
$$

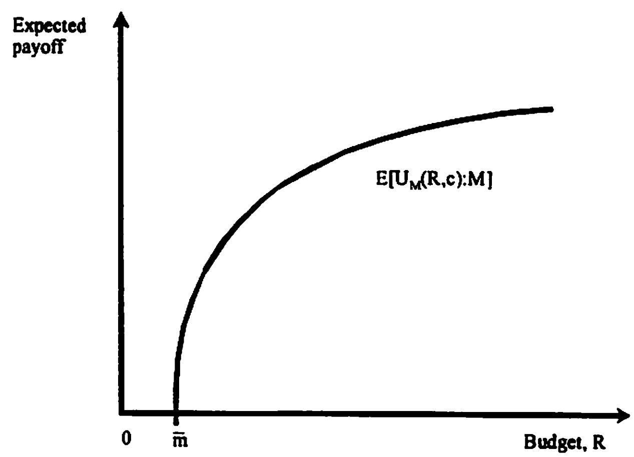
$$
\begin{aligned}
&= \left\{\frac{[1-q(R)](-1/2)m''(q(R))[dq(R)/dR][m'(q(R))]^{\frac{-3}{2}} + [dq(R)/dR][m'(q(R))]^{\frac{-1}{2}}}{2[1-q(R)]^2}\right\}\gamma_c \\
&= \left(\frac{-1}{4}\right)\left\{\frac{[1-q(R)]m''(q(R))[m'(q(R))]^{\frac{-3}{2}} - 2[m'(q(R))]^{\frac{-1}{2}}}{[1-q(R)]^2}\right\}\left(\frac{dq(R)}{dR}\right)\gamma_c
\end{aligned}
$$

This derivative is negative if $m'(q)$ for all q satisfies:

$$1 - q > \frac{2m'(q)}{m''(q)} \tag{27}$$

The value of the ministry's expected payoff with respect to R is depicted in Figure 1.

Figure 1: Ministry's Expected Payoff Function under Monitoring



Assumption **A3**: *It is assumed that* $1 - q > 2m'(q)/m''(q)$ *for all* $q \in [0, 1)$.

Lemma 4 *Given **A1**, **A2**, and **A3**. The ministry expected payoff is strictly concave in* R *for all* $R > \overline{m}$.

The lemma suggests that the ministry's expected payoff from monitoring will be increasing at a decreasing rate.[5] Specifically, the marginal cost of monitoring the bureau is increasing with these expenditures being extremely large if any misreporting by the bureau is to be detected with near certainty. The bureau is therefore able to report $w(R, c) > c$ when assumption **A2** holds which is more readily satisfied at high values of the program budget R. Additionally, $w(R, c)$ is increasing in R when **A3** holds (see Appendix 2). Consequently, the ministry's expected payoff is increasing in R. The rising

[5]The function $m(q) = \overline{m}/(1 - q)$ satisfies equation 27 with equality. This function therefore represents a boundary condition on the set of functions satisfying **A3**.

cost of monitoring however results in this expected payoff increasing at a decreasing rate. In what follows, **A3** is assumed to hold.

3.2 Competitive Bidding

Competitive bidding is the result of the ministry's choice of $a = C$ at stage I. The equilibrium behavior of $\mathcal{M}$ and $\mathcal{B}$ is now derived for the C-subgame through backward induction. At stage V, $\mathcal{M}$ chooses $b \in \{B, F\}$ with the resulting payoff R/w_b if $b = \mathcal{B}$ and R/w_f if $b = \mathcal{F}$. The firms' lowest bid w_f is drawn from a distribution $H(w_f)$ with pdf $h(w_f)$ on $[\underline{w}_f, \overline{w}_f]$.[6] $\mathcal{M}$ chooses $b = \mathcal{B}$ if and only if $w_f < w_b$ which occurs with probability $1 - H(w_b)$.

Assumption A4: *It is assumed that* $\underline{c} < \underline{w}_f < \overline{c} < \overline{w}_f$.

Assumption **A4** holds if the bureau has a cost advantage over the firms participating in the competitive bidding process for the provision of x. This advantage may be the result of the bureau acquiring some cost saving knowledge about the production of x through learning-by-doing. Furthermore, McAfee and McMillan (1987) report that firms tend to bid with a quote w_f which is strictly greater than their own cost realization. If the firms lose the bid to the bureau, the firms are assumed to earn zero profits in an alternative activity.

The probability of the firm winning the bid is expressed by $Pr\{w_f \leq w_b\} = H(w_b)$, if $\overline{w}_f > w_b \geq \underline{w}_f$, and zero if $w_b \leq \underline{w}_f$ and one if $w_b > \overline{w}_f$.

At stage IV, the bureau chooses its bid and wins the competitive bidding process with probability $1 - H(w_b)$. If the bureau wins, its payoff is given by $E + \mu = (w_b - c)[R/w_b] + \mu$. On the other hand, if the bureau loses, its resources are re-allocated to other activities which earn u_{bl} and, as before, μ. Hence, the bureau's payoff is given by $u_{bl} + \mu$ with $u_{bl} \geq 0$ if it loses.

The bureau's subgame perfect equilibrium bid, $w_b(R, c, u_{bl})$, is therefore chosen to maximize its expected payoff given by

[6] Kim (1997) provides a characterization of the lowest bid in a sealed-bid auction with the private cost realizations having a uniformed distribution. Paasch and Donald (1992) also determine the distribution function for the first order statistic in a first price sealed bid auction.

$$E[u_B(c,w_b,R,\mu,u_{bl}:C)] = \begin{cases} (w_b-c)[R/w_b]+\mu & w_b \le \underline{w}_f \\ [1-H(w_b)]\{(w_b-c)[R/w_b]+\mu\}+ \\ \quad H(w_b)[u_{bl}+\mu] & \overline{w}_f > w_b \ge \underline{w}_f \\ u_{bl}+\mu & w_b \ge \overline{w}_f \end{cases} \tag{28}$$

If the bureau were to bid any $w_b \le \underline{w}_f$, it would necessarily choose $w_b(R,c,u_{bl}) = \underline{w}_f$ since $\partial E[u_B(c,w_b,R,\mu,u_{bl}:C)]/\partial w_b = cR/w_b^2 > 0$, for any $c \in [\underline{c},\overline{c}]$ and $w_b \in [\underline{c},\underline{w}_f)$.

For bids $\underline{w}_f \le w_b < \overline{w}_f$, the bureau chooses $w_b(R,c,u_{bl})$ to satisfy

$$w_b(R,c,u_{bl}) = \arg\max_{w_b} \{[1-H(w_b)]\{(w_b-c)[R/w_b]+\mu\}+H(w_b)[u_{bl}+\mu]\} \tag{29}$$

The choice $w_b(R,c,u_{bl})$ over $[\underline{w}_f,\overline{w}_f)$ is derived from the following first order condition:

$$-h(w_b)\left[(w_b-c)\left(\frac{R}{w_b}\right)+\mu\right]+[1-H(w_b)]\left(\frac{cR}{w_b^2}\right)+h(w_b)[u_{bl}+\mu] = 0$$
$$\Rightarrow h(w_b)\left\{\frac{u_{bl}}{R}+\frac{c}{w_b}-1\right\}+[1-H(w_b)]\left(\frac{c}{w_b^2}\right)=0 \tag{30}$$

The second order condition is given by

$$\frac{\partial^2 E[u_B(c,w_b,R,\mu,u_{bl}:C)]}{\partial w_b \partial w_b} = \tag{31}$$
$$h'(w_b)\left\{\frac{u_{bl}}{R}+\frac{c}{w_b}-1\right\}-2h(w_b)\left(\frac{c}{w_b^2}\right)+[1-H(w_b)]\left(\frac{-2c}{w_b^3}\right)<0$$

Equation 30 can be expressed in terms of the inverse hazard function for the bureau with bid w_b as follows:[7]

[7] The hazard function is defined by $h(w_b)/[1-H(w_b)]$ and inverse hazard function has the following derivative with respect to w_b: $\partial\{[1-H(w_b)]/h(w_b)\}/\partial w_b = \{-h'(w_b)h(w_b) - h'(w_b)[1-H(w_b)]\}/[h(w_b)]^2$.

$$
\begin{aligned}
w_b\left\{w_b\left[1-\frac{u_{bl}}{R}\right]-c\right\} &= \left[\frac{1-H(w_b)}{h(w_b)}\right]c \\
\frac{u_{bl}}{R}+\frac{c}{w_b}-1 &= -\left[\frac{1-H(w_b)}{h(w_b)}\right]\frac{c}{w_b^2} \qquad (32)
\end{aligned}
$$

Equation 32 can be substituted into the second order condition with the following result:

$$
\begin{aligned}
h'(w_b)\left[\frac{1-H(w_b)}{h(w_b)}\right]\left(\frac{-c}{w_b^2}\right)-2h(w_b)\left(\frac{c}{w_b^2}\right)+[1-H(w_b)]\left(\frac{-2c}{w_b^3}\right) &< 0 \\
\left\{\frac{h'(w_b)\left[1-H(w_b)\right]+[h(w_b)]^2}{h(w_b)}\right\}\left(\frac{-c}{w_b^2}\right)+\{h(w_b)+[1-H(w_b)]\}\left(\frac{-2c}{w_b^3}\right) &< 0 \\
\left\{\frac{h'(w_b)\left[1-H(w_b)\right]+[h(w_b)]^2}{h(w_b)}\right\}\left(\frac{-c}{w_b^2}\right) < \{h(w_b)+[1-H(w_b)]\}\left(\frac{2c}{w_b^3}\right) \\
\left\{\frac{h'(w_b)\left[1-H(w_b)\right]+[h(w_b)]^2}{[h(w_b)]^2}\right\} > -\left(\frac{2}{w_b}\right)\left[\frac{h(w_b)+[1-H(w_b)]}{h(w_b)}\right] \\
-\frac{\partial}{\partial w_b}\left\{\frac{[1-H(w_b)]}{h(w_b)}\right\} > -\left(\frac{2}{w_b}\right)\left[\frac{h(w_b)+[1-H(w_b)]}{h(w_b)}\right]
\end{aligned}
$$

The second order condition holds if $\frac{\partial}{\partial w_b}\left\{\frac{[1-H(w_b)]}{h(w_b)}\right\} \leq 0$ and, correspondingly, $w_b(R, c, u_{bl})$ is a global maximum for the bureau's problem.

Assumption A5: *It is assumed that* $\frac{\partial}{\partial w_b}\{[1-H(w_b)]/h(w_b)\} \leq 0$ *for all* $w_b \in [\underline{w}_f, \overline{w}_f)$.

Assumption **A5** implies that the hazard function is non-decreasing in the bureau's bid (i.e., w_b) (Fundenberg and Tirole, 1991). Branco (1995) indicates that this assumption is required to yield optimality in standard auction models. For instance, McAfee and McMillan (1987) makes a similar assumptions to **A5** about the hazard function associated with the distribution function of the bidder's evaluation or cost realization. Here, **A5** concerns the distribution function of the first order statistic of bids from the set of firms capable of providing the public sector good or service (i.e., $h(w_f)$ evaluated at bureau's bid w_b).

The distribution function for the lowest bid of the firms (i.e., $h(w_f)$) has been characterized by Donald and Paarsch (1992) for an exponential distribution function and by Kim (1997) for a uniform distribution of the firms' cost realizations (i.e., the random cost realization z_i with an equilibrium bidding rule $w_f = \beta(z_i)$). Donald and Paarsch (1992) show that an exponential distribution of cost realizations (i.e., $f(z_i)$) results in a linear equilibrium bidding rule (i.e., $w_f = z_i + constant$).[8]

The distribution of the first order statistic can be shown to be exponential when the probability distribution function for the underlying cost realizations is itself an exponential. Correspondingly, Fundenberg and Tirole (1991) indicate that the property assumed in **A5** holds for exponential distributions. In particular, it can be shown that the hazard function associated with exponential distributions is a constant (Freund, 1971). Consequently, **A5** holds with $\frac{\partial}{\partial w_b}\{[1 - H(w_b)]/h(w_b)\} = 0$ for an exponential distribution of the underlying costs faced by the bureau.

Assumption **A5** is sufficient for the second order condition for the bureau's problem in equation 29 to hold, but it is not necessary. In what follows, it is assumed that **A5** holds.

Proposition 5 *If* $1 - H(w_b) > 0$, *then the bureau's bid* $w_b(R, c, u_{bl})$ *will result in the payoff from winning necessarily exceeding the payoff from losing the bid.*

Proof:

For any $w_b \in [\underline{w}_f, \overline{w}_f)$, the probability of the bureau winning the bid is denoted by $1 - H(w_b) > 0$.

From equation 30, $w_b(R, c, u_{bl})$ satisfies

$$w_b^2\left[1 - \frac{u_{bl}}{R}\right] - cw_b = \left[\frac{1 - H(w_b)}{h(w_b)}\right]c$$

Thus,

$$w_b^2\left[1 - \frac{u_{bl}}{R}\right] - cw_b > 0, \text{ if } 1 - H(w_b) > 0.$$

This implies

[8] Paarsch and Donald (1992) indicate that the probability distribution function for the first order statistic for n firms submitting a sealed bid in a first price auction with an equilibrium bidding rule $\beta(c) = w$ is as follows: $h(w) = \{n[1 - F(\beta^{-1}(c))]^{n-1} f(\beta^{-1}(c)\}/\beta'(\beta^{-1}(c)))$, where: $f(c)$ is the pdf and $F(c)$ is the cdf for cost realization c. Donald and Paarsch (1992) assumed that $f(c) = \theta\exp\{-\theta c\}$ and results in $\beta(c) = c + 1/\theta(n-1)$ when the n firms are risk neutral. It can be shown that $h(w) = n[\exp\{\theta[w - (1/\theta)(n-1)]\}]^{n-1}[\theta\exp\{\theta[w - (1/\theta)(n-1)]\}]$.

$$\frac{R}{w_b}(w_b - c) > u_{bl} \tag{33}$$

□

The result in equation 33 suggests that for $w_b(R, c, u_{bl})$ to be SPE the bureau's payoff from winning the bid denoted by $\frac{R}{w_b}(w_b - c)$ must be greater than the payoff given by u_{bl} from losing. Conversely, the proposition implies that the bureau will not submit a bid $w_b \in [\underline{w}_f, \overline{w}_f)$ if the payoff from losing the bid is sufficiently large or the program budget is sufficiently small.

The relationship between the bureau's SPE bid $w_b(R, c, u_{bl})$ and the parameters in the model are as follows[9]:

$$\frac{dw_b(.)}{dc} = \frac{\{h(w_b)w_b + [1 - H(w_b)]\}R}{h'(w_b)[w_b^2(R - u_{bl}) - cw_bR] + h(w_b)[2w_b(R - u_{bl})]} > 0 \tag{34}$$

$$\frac{dw_b(.)}{du_{bl}} = \frac{h(w_b)w_b}{h'(w_b)[w_b^2(R - u_{bl}) - cw_bR] + h(w_b)[2w_b(R - u_{bl})]} > 0 \tag{35}$$

$$\frac{dw_b(.)}{dR} = \frac{-h(w_b)w_b(w_b - c) + [1 - H(w_b)]c}{h'(w_b)[w_b^2(R - u_{bl}) - cw_bR] + h(w_b)[2w_b(R - u_{bl})]} < 0 \tag{36}$$

Equation 34 indicates that the bureau's SPE bid $w_b(R, c, u_{bl})$ is increasing in its cost realization c on $[\underline{c}, \overline{c}]$ if $R > u_{bl}$. Additionally, this increase is related to the probability of the bureau winning the bid, $1 - H(w_b)$, and the program budget R. The probability of the bureau winning the bid is also important in the determination of the spread between the bid $w_b(R, c, u_{bl})$ and the realized cost c as shown in equation 32.

Equation 35 indicates that the bureau's SPE bid $w_b(R, c, u_{bl})$ is increasing in the payoff the bureau receives from alternative activities if it loses the bid. Consequently, the returns from competing alternatives given by u_{bl} establishes a lower bound on the returns the bureau will accept to produce the good or service x.

Equation 36 indicates that the bureau's bid $w_b(R, c, u_{bl})$ is decreasing in the ministry's program budget R. Substituting the first order condition,

[9] The detailed derivations of these results are shown in Appendix 3.

equation 36 can be simplified to

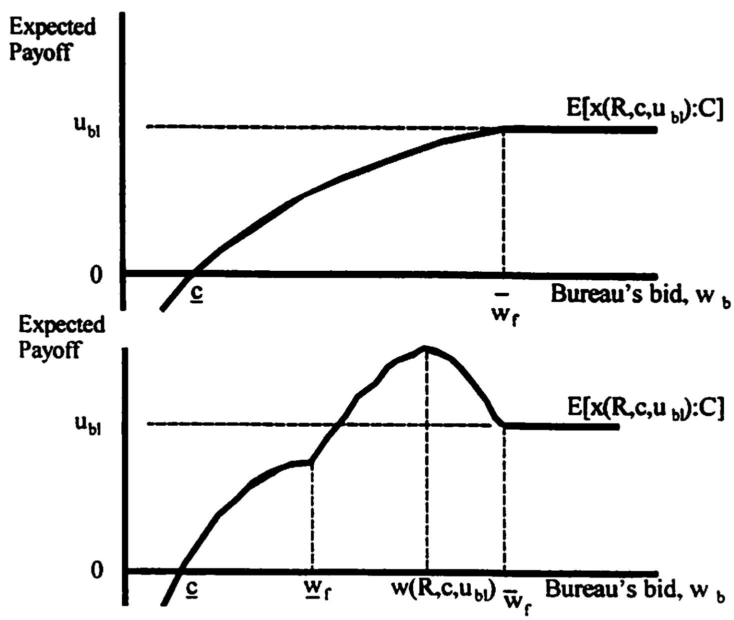
$$\frac{dw_b(.)}{dR} = \frac{-[u_{bl}/R]\{w_b^2 h(w_b)\}}{h'(w_b)[w_b^2(R-u_{bl}) - cw_bR] + h(w_b)[2w_b(R-u_{bl})]} \tag{37}$$

Proposition 6 *If $u_{bl} = 0$, then the bureau's SPE bid $w_b(R, c, u_{bl})$ is independent of the ministry's program budget R.*

This proposition also then implies that the pdf $h(w_f)$ is independent of R when $u_{bl} = 0$ since the payoff from losing the bid for the bureau and firms is now zero. Thus, the discretionary budget maximizing bureau and the profit maximizing firms' bids are symmetric and independent of R when $u_{bl} = 0$. This result correspond to and justify the simplifying assumption that the probability distribution function for w_f is simply $h(w_f)$ and independent of R.

For $w_b \geq \overline{w}_f$, the bureau loses with certainty and receives the payoff u_{bl}. The expected payoff schedule of the bureau with respect to its bids $w_b(R, c, u_{bl}) > \underline{c}$ is shown in Figure 2.

Figure 2: Bureau's payoff schedule under competitive bidding



In the top panel of Figure 2, the bureau's SPE bid is shown to be $w_b(R, c, u_{bl}) \geq \overline{w}_f$ when $u_{bl} = u'_{bl}$ is sufficiently large. At smaller values of u_{bl} say $u_{bl} = u''_{bl} < u'_{bl}$, the bureau's SPE bid is given by $w_b(R, c, u_{bl}) \in [\underline{w}_f, \overline{w}_f]$ determined at the peak of the bureau's expected payoff.

What realization of c results in $\underline{w}_f \leq w_b < \overline{w}_f$? Let $c_1(R)$ be the value of c defined by $w_b(R, c, u_{bl}) = \underline{w}_f$ and $c_2(R)$ defined by $w_b(R, c, u_{bl}) = \overline{w}_f$. These derivations are as follow:

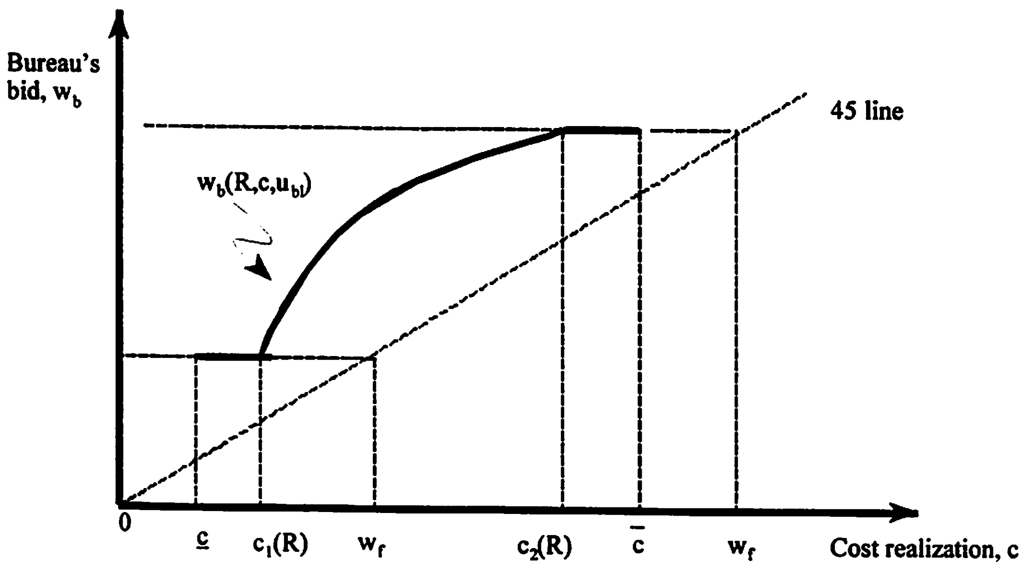
$$c_1(R) = \left\{\underline{w}_f^2 \left(1 - \frac{u_{bl}}{R}\right)\right\} \left[\underline{w}_f + \frac{1}{h(\underline{w}_f)}\right]^{-1} \tag{38}$$

$$c_2(R) = \overline{w}_f \left[1 - \frac{u_{bl}}{R}\right] \tag{39}$$

The cost levels $c_1(R)$ and $c_2(R)$ are both increasing in R with $c_1(R) < \underline{w}_f$ and $c_2(R) < \overline{w}_f$. $c_1(R)$ tends towards some $w_f < \underline{w}_f$ and $c_2(R)$ tends to $\overline{w}_f$ as R increases. The interval $[\underline{c}, c_1(R)]$ corresponds to the set of cost realizations over which the bureau makes a bid $w_b \leq \underline{w}_f$ and surely win. This interval expands as R increases with the diminished importance of u_{bl} in the determination of $w_b(R, c, u_{bl})$. On the other hand, the interval $[c_2(R), \overline{c}]$ over which the bureau bids $\overline{w}_f$ and surely loses.

Figure 3 shows the relationship between the bureau's bid and its cost realization.

Figure 3: Bureau's bid and cost realization



Clearly, $c_1(R)$ and $c_2(R)$ may or may not be less than $\underline{c}$ and $\bar{c}$, respectively, given values of u_{bl} and R.

Remark 1 *As R increases, it follows that (1) there is a reduction in the range of cost realizations c for which the bureau submits a surely-losing bid $\overline{w}_f$, and (2) there is an expansion in the range of cost realizations c for which the bureau submits a surely-winning bid $\underline{w}_f$.*

Lemma 7 *Given A4 and A5, the following are implied:*

1. For any cost realization $c \in [\underline{c}, c_1(R)]$, the bureau submits the bid $w_b(R, c, u_{bl}) = \underline{w}_f$ and earns a payoff $(\underline{w}_f - c)(R/w_f) + \mu \geq 0$;

2. For any cost realization $c \in [c_1(R), c_2(R)]$, the bureau submits the bid $w_b(R, c, u_{bl}) > c$ and wins with the probability:

$$\Pr\{w_f \geq w_b\} = \int_{w_b(R,c,u_{bl})}^{\overline{w}_f} H(w_f)dw_f$$

$$= 1 - H(w_b(R, c, u_{bl}))$$

and

3. For any cost realization $c \in [c_2(R), \bar{c}]$, *the bureau submits the bid* $w_b(R, c, u_{bl}) = \overline{w}_f$ *and earns the payoff* $u_{bl} + \mu \geq 0$.

3.2.1 Ministry's Expected Payoff from Competition

At stage I, the ministry chooses $a \in \{C, M\}$ with the expected payoff from the C-subgame given as follows:

$$\begin{aligned} E[u_{\mathcal{M}}(x(R, c, u_{bl}) \ : \ C)] = & \iint_{\Omega_0} \frac{R}{w_b(R, c, u_{bl})} h(w_f) f(c) dw_f dc + \\ & \iint_{\Omega_1} \frac{R}{w_f} h(w_f) f(c) dw_f dc + \\ & \iint_{\Omega_2} \frac{R}{w_b(R, c, u_{bl})} h(w_f) f(c) dw_f dc + \\ & \iint_{\Omega_3} \frac{R}{w_f} h(w_f) f(c) dw_f dc \end{aligned} \tag{40}$$

The regions Ω_0 to Ω_3 are derived from the combination of (c, w_f) for which the firm or the bureau wins the bid given the budgetary allocation $R > u_{bl}$. The region Ω_0 involves bids submitted by the bureau which win always, Ω_1 involves bids submitted by the bureau which result in the firm winning, Ω_2 the bureau wins and Ω_3 the bureau loses always. These regions are defined as follows:

$$\Omega_0 = \{(c, w_f) : c_1(R) \geq c \geq \underline{c} \text{ and } \underline{w}_f \geq w_f \geq \overline{w}_f\}$$

$$\Omega_1 = \{(c, w_f) : c_2(R) \geq c \geq c_1(R) \text{ and } \underline{w}_f < w_f \leq w_b(R, c, u_{bl})\}$$

$$\Omega_2 = \{(c, w_f) : c_2(R) \geq c \geq c_1(R) \text{ and } \underline{w}_f \geq w_f > w_b(R, c, u_{bl})\}$$

$$\Omega_3 = \{(c, w_f) : \bar{c} \geq c \geq c_2(R) \text{ and } \underline{w}_f \geq w_f \geq \overline{w}_f\}$$

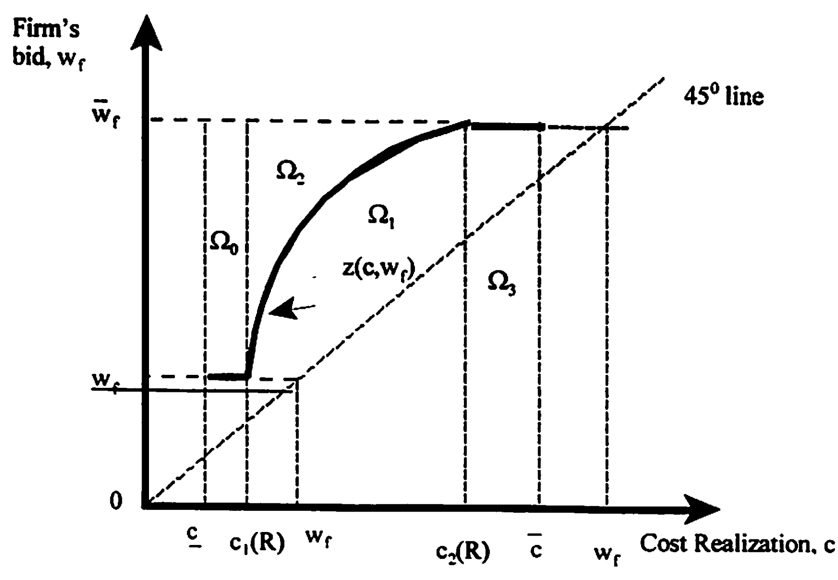
The probability of the firm winning is decreasing in R since the bureau's bid $w_b(R, c, u_{bl})$ is decreasing in R. This implies that the bureau becomes more competitive relative to the firm as the outside option u_{bl} becomes less important with increasing values of R. In the limit, u_{bl} is unimportant to the determination of $w_b(R, c, u_{bl})$ with the firms and bureau's payoffs becoming symmetric.

The boundary separating the regions over which the bureau and firm winning the competitive bid for combinations of (c, w_f) is as follows:

$$Z = \begin{cases} \underline{w}_f & c \in [\underline{c}, c_1(R)\ ] \\ w_b(R, c, u_{bl}) & c \in [c_1(R)\ , c_2(R)] \\ \overline{w}_f & c \in [c_1(R)\ , \overline{c}] \end{cases}$$

Figure 4 shows the locus of points in the set Z with Ω_0 to Ω_3 defined for various combinations of (c, w_f).

Figure 4: Frontier for firm and bureau winning over (c, w_f)



The expected payoff function of the ministry from the C-subgame is defined by

$$E[u_{\mathcal{M}}(x(R,c,u_{bl}) \; : \; C)] = \int_{\underline{c}}^{c_1(R)} \int_{\underline{w}_f}^{\overline{w}_f} \frac{R}{\underline{w}f} h(w_f) f(c) dw_f dc + \tag{41}$$

$$\int_{c_1(R)}^{c_2(R)} \int_{\underline{w}f}^{w_b(R,c,u_{bl})} \frac{R}{w_f} h(w_f) f(c) dw_f dc +$$

$$\int_{c_1(R)}^{c_2(R)} \int_{w_b(R,c,u_{bl})}^{\overline{w}_f} \frac{R}{w_b(R,c,u_{bl})} h(w_f) f(c) dw_f dc +$$

$$\int_{c_2(R)}^{\overline{c}} \int_{\underline{w}_f}^{\overline{w}_f} \frac{R}{w_f} h(w_f) f(c) dw_f dc$$

The bureau's bid $w_b(R, c, u_{bl})$ is increasing in u_{bl}/R as shown by equation 37. Hence, the ministry's expected payoff is decreasing in u_{bl}/R. On the other hand, the ministry's expected payoff at $u_{bl} = 0$ is as follows:

$$E[u_{\mathcal{M}}(x(R,c,u_{bl}) \; : \; C)] = \int_{\underline{c}}^{c_1(R)} \int_{\underline{w}_f}^{\overline{w}_f} \frac{R}{\underline{w}f} h(w_f) f(c) dw_f dc + \tag{42}$$

$$\int_{c_1(R)}^{c_2(R)} \int_{\underline{w}f}^{w_b(R,c,0)} \frac{R}{w_f} h(w_f) f(c) dw_f dc +$$

$$\int_{c_1(R)}^{c_2(R)} \int_{w_b(R,c,0)}^{\overline{w}_f} \frac{R}{w_b(R,c,0)} h(w_f) f(c) dw_f dc +$$

$$\int_{c_2(R)}^{\overline{c}} \int_{\underline{w}_f}^{\overline{w}_f} \frac{R}{w_f} h(w_f) f(c) dw_f dc$$

$$= R \left\{ \int_{\underline{c}}^{c_1(R)} \int_{\underline{w}_f}^{\overline{w}_f} \frac{1}{\underline{w}f} h(w_f) f(c) dw_f dc + \right.$$

$$\int_{c_1(R)}^{c_2(R)} \int_{\underline{w}f}^{w_b(R,c,0)} \frac{1}{w_f} h(w_f) f(c) dw_f dc +$$

$$\int_{c_1(R)}^{c_2(R)} \int_{w_b(R,c,0)}^{\overline{w}_f} \frac{1}{w_b(R,c,0)} h(w_f) f(c) dw_f dc +$$

$$\left. \int_{c_2(R)}^{\overline{c}} \int_{\underline{w}_f}^{\overline{w}_f} \frac{1}{w_f} h(w_f) f(c) dw_f dc \right\}$$

$$= R\delta(\underline{c}, \overline{c}, \underline{w}_f, \overline{w}_f, R, H(w_f))$$

where: $c_2(R) = w_f$ when $u_{bl} = 0$, $\underline{c} < \underline{w}_f < \overline{c} < \overline{w}_f$ and,hence, the integrand involving $c_2(R)$ must be replaced with $\overline{c}$ when $u_{bl} = 0$.

As u_{bl}/R approaches zero, the expected payoff of the ministry in equation 41 converges as follows:

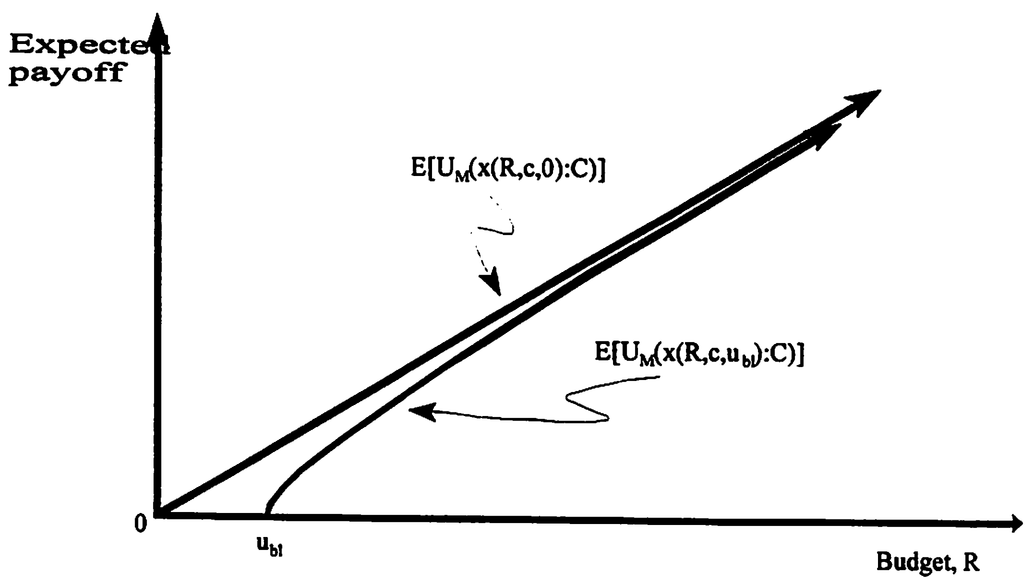
$$\begin{aligned}\lim_{u_{bl}/R \to 0} E[u_{\mathcal{M}}(x(R, c, u_{bl}) \quad &: \quad C)] = E[u_{\mathcal{M}}(x(R, c, 0 : C))] \\ &= \quad R\delta(\underline{c}, \overline{c}, \underline{w}_f, \overline{w}_f, H(w_f))\end{aligned}$$

The ministry's expected payoff for any $u_{bl} > 0$ approaches its payoff for $u_{bl} = 0$ from below as R increases. Additionally, the ministry's payoff is linear in R when $u_{bl} = 0$.[10]

[10] The firms' bids are also independent of the program budget R when $u_{bl} = 0$.

These results are depicted in Figure 5 which shows the expected payoff to the ministry from competitive bidding given by $E[u_{\mathcal{M}}(x(R,c,u_{bl}):C)]$ is bounded from above by $E[u_{\mathcal{M}}(x(R,c,0):C)]$.[11]

Figure 5: Ministry's expected payoff under competitive bidding



4 Characterization of the Ministry Equilibrium Choice

At stage I, the ministry's subgame perfect equilibrium payoff is denoted by $E[u_{\mathcal{M}}(x(R,c,u_{bl}):a)]$ with $a \in \{C, M\}$ and μ, θ, $\overline{m}$ and u_{bl}.

Consider the ministry's equilibrium choice at stage I when $u_{bl} = 0$.[12] Hence, the expected payoff of the ministry under competitive bidding is linear in R.

[11] It is assumed that the expected payoff of the ministry becomes concave in R for values of $u_{bl} > 0$ as it is asymptotic from below to the linear expected payoff for $u_{bl} = 0$.

[12] It is sufficient to determine the ministry's equilibrium choice for $u_{bl} = 0$ without loss of generality since the ministry's expected payoff $E[u_{\mathcal{M}}(x(R,c,u_{bl}):C)]$ approaches $E[u_{\mathcal{M}}(x(R,c,0):C)]$ from below as u_{bl}/R decreases.

Proposition 8 *If A1-A5 holds, $R > 0$ and $u_{bl} = 0$, then a sufficient condition for the ministry to choose competitive bidding over monitoring of the bureau (i.e., $a^* = C$) is given by*

$$\frac{\delta(\underline{c}, \overline{c}, \underline{w}_f, \overline{w}_f, H(w_f))}{\gamma_c} \geq \frac{q(R)[m'(q(R))]^{\frac{1}{2}}}{R} = \lambda(R)$$

Proof:

$a^* = C$ implies $E(u_{\mathcal{M}}(x(R, c, w_f) : C) \geq E(u_{\mathcal{M}}(x(R, c, w_f) : M)$. Based on equations 42 and 21, it follows that this inequality is equivalent to:

$$\begin{aligned} R\delta(\underline{c}, \overline{c}, \underline{w}_f, \overline{w}_f, \mu, H(w_f)) &\geq q(R)[m'(q(R))]^{\frac{1}{2}}\gamma_c \\ \frac{\delta(\underline{c}, \overline{c}, \underline{w}_f, \overline{w}_f, \mu, H(w_f))}{\gamma_c} &\geq \frac{q(R)[m'(q(R))]^{\frac{1}{2}}}{R} = \lambda(R) \end{aligned}$$

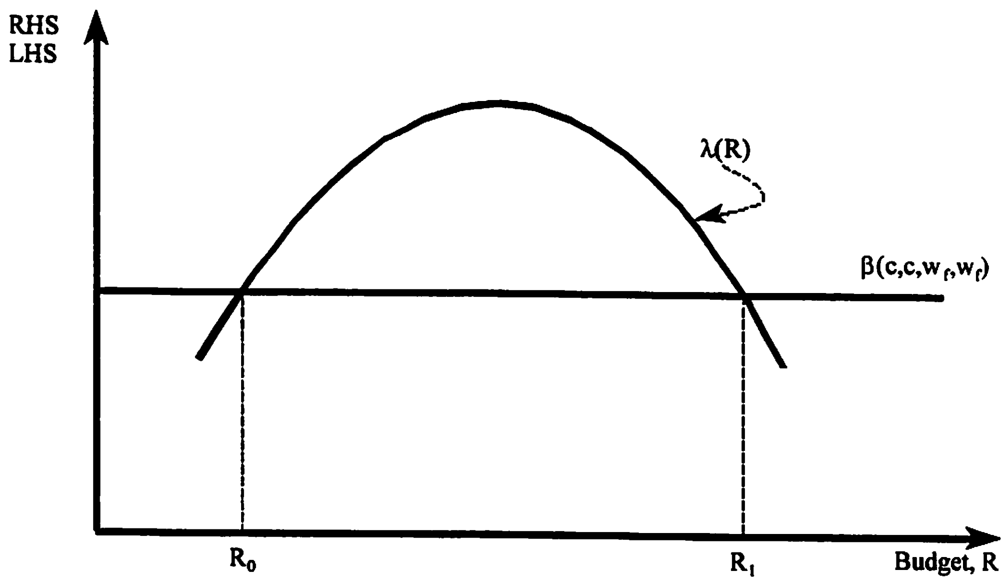
Based on equation 25, the function $\lambda(R)$ has the following properties:

$$\begin{aligned} \frac{\partial\lambda(R)}{\partial R} &= \frac{R\left[\left(\frac{1}{2}\right)[m'(q(R))]^{\frac{-1}{2}}\left(\frac{1}{1-q(R)}\right)\right] - q(R)[m'(q(R))]^{\frac{1}{2}}}{R^2} \\ &= \frac{[m'(q(R))]^{\frac{1}{2}}\left(\frac{1}{2}\right)\left\{\frac{R}{1-q(R)} - 2q(R)[m'(q(R))]\right\}}{R^2} \\ &= \frac{[m'(q(R))]^{\frac{1}{2}}\left(\frac{1}{2}\right)[1-q(R)]\left\{R - 2q(R)[1-q(R)][m'(q(R))]\right\}}{R^2} \\ &= \frac{[m'(q(R))]^{\frac{1}{2}}\left(\frac{1}{2}\right)[1-q(R)]}{R^2}[R - 2\{R - m(q(R))\}] \\ &= \frac{[m'(q(R))]^{\frac{1}{2}}\left(\frac{1}{2}\right)[1-q(R)]}{R^2}[2m(q(R)) - R] \end{aligned} \tag{43}$$

Equation 43 suggests that $\lambda(R)$ achieves a maximum at $R = 2m(q(R))$ which implies half of the program budget being spent on monitoring. Monitoring is an equilibrium outcome of the model and increases at a decreasing rate in the program budget R. Therefore, $\lambda(R)$ is increasing at low values of R and decreasing at high values of R.

Figure 6 shows the range of R for which the ministry chooses competitive bidding over monitoring.

Figure 6: Ministry's equilibrium choice over budgetary allocations

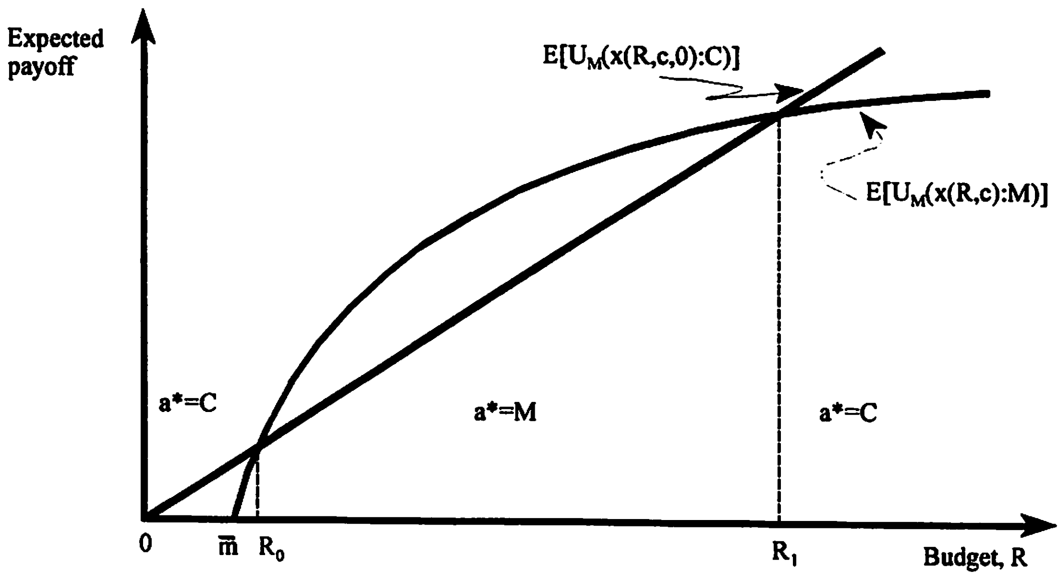


where: $\beta(\underline{c}, \overline{c}, \underline{w}_f, \overline{w}_f) = \delta(\underline{c}, \overline{c}, \underline{w}_f, \overline{w}_f, \mu, H(w_f))/\gamma_c$.

The line $\beta(\underline{c}, \overline{c}, \underline{w}_f, \overline{w}_f)$ shifts downwards as θ or μ increases. Consequently, increases in these parameters result in monitoring over a wider range of program budget R than would otherwise occur. This implies that the reported price under monitoring approaches the actual realization of c as the expected losses from misreporting is increasing in θ and μ. Hence, monitoring becomes preferred by the ministry over a wider range of program budget levels R as θ or μ increases.

The ministry's expected payoff schedules is depicted below in Figure 7 for competitive bidding and to monitoring of the bureau as a function of R and when $u_{bl} = 0$.

Figure 7: Competition and Monitoring over Budgetary Allocations



Let R_0 and R_1 be the values of R for which $\lambda(R) - \beta(\underline{c}, \overline{c}, \underline{w}_f, \overline{w}_f) = 0$ with R_0 being the smaller of the two values.

Proposition 9 *If* ***A1-A5*** *holds, then the ministry equilibrium choice is* C *for* $R \notin [R_0, R_1]$ *and* M *for* $R \in [R_0, R_1]$.

Remark 2 *The program budget level* R_0 *is decreasing and* R_1 *is increasing in the parameters* μ *and* θ.

Remark 3 *Increases in* u_{bl} *result in the ministry choosing monitoring over competitive bidding at lower levels of* R *and maintaining monitoring at higher levels of* R *than would otherwise occur.*

The proposition suggests that the ministry will choose competitive bidding for the provision of the public sector good or services at high program budget levels. This result is consistent with the empirical findings of Savas (1977) and Stevens (1978). Correspondingly, at intermediate program budget levels, the ministry chooses monitoring and the provision of the public sector good or service by the government bureau. At low program budget levels, the ministry again chooses competitive bidding over monitoring. If the bureau's re-deployment payoff (u_{bl}) increases, it results in a reduce probability of the bureau winning the competitive bid. The remarks therefore further predict that high re-deployment payoffs for the bureau relative to the program budget may result in the private firm winning the competitive bid and the provision of the good or services being outsourced without the bureau choosing to submit a competitive bid. Additionally, competitive bidding is preferred to monitoring when the cost of monitoring are relatively high and rapidly increasing in the probability of detecting the bureau misreporting. The model therefore predicts that the ministry (or funding source) will switch between competitive bidding and monitoring in response to changes in the program budget.

5 Conclusions

The paper developed a sequential game involving a ministry and bureau's strategic interaction in the production of a public sector good. The ministry copes with imperfect information about the bureau's costs by monitoring the bureau or by accepting sealed bids from the bureau and outside firms. In this respect, the study extends the Niskanen model of government bureaucracy to include strategies other than the take-it-or-leave-it choices available to the ministry (or funding source). The study also incorporated the effects of promotion or compensation income into the Niskanen budget maximizing bureau framework.

The main findings of the study are as follows: First, the study predicts that the ministry will tend to conduct competitive bids at low and high level of budgetary allocation. This result is consistent with the empirical findings reported by Savas (1977) and Stevens (1978). These authors found that competitive bidding resulted in significant costs savings over in-house (i.e., by the bureau under monitoring) refuse collection when service levels and, hence, budgets were large. No significant cost savings were found at low service levels. On the other hand, at intermediate budget levels, the ministry is predicted to choose incomplete monitoring of the bureau. Consequently, the institutional arrangement of government can be anticipated to switch between competition and monitoring and back to competition as the budget of the ministry increases beyond the fixed cost of monitoring and redeployment income. Second, the results predict that, given a positive redeployment payoff, increases in the program budget tend to increase the range of the bureau's cost realizations over which it can win the competitive bidding process with positive probability. However, when the re-deployment payoff is zero the probability of the bureau winning the competitive bid is invariant to changes in the level of the program budget. Third, increases in the level of other compensation of the bureau (i.e., bureaucrats) tend to reduce the spread between the reported price and the realized cost of providing the public sector good or service. This result is consistent with the supposition forwarded by Wintrobe (1997). This author suggested that the compensation level of bureaucrats' may moderate budget maximizing behavior in the public sector.

There are several opportunities for further studies into the conduct of government bureaucracies. First, empirical work could be conducted to test the validity of the relationship predicted between the likelihood of private provision of public sector goods and the parameters in the model. Second, the study suggested that monitoring was important to the conduct of the bureau and its reported price to the ministry. How this behavior is affected by potential side-payments to the auditor could also be investigated. Third, the study suggests that outside options and other asymmetries between the bureau and the firms capable of providing the public sector good will affect the bids and probability of the bureau winning the auction. Fourth, the study suggests that the testing of the budget maximization hypotheses must also take into account other management compensation, monitoring and outside options available to bureaucrats in the public sector. These considerations warrant further investigation. Fifth, the study assumed that the ministry or funding source was only concerned with and overseeing the provision of a single public sector good or service. Governments in actuality are multi-layered with the Cabinet concerned with the provision of goods and services and the allocation of limited funds amongst competing ministries. How these considerations affect budgetary decisions and the provision of goods and services in the public sector warrant further investigation. Finally, the study addresses positive questions regarding choices between monitoring and competitive bidding in the public sector provision of goods and services. Further research into normative questions regarding the design of mechanisms for monitoring in the public sector would be useful in the effort to identify the gap between what is and what ought to be in the public sector.

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6 Appendix

6.1 Appendix I: Joint Probability Distribution for Firms' Lowest Bid

Let w_f be the first order statistic of n random variables, specifically, $w_f = min\{w_{f1}, w_{f2}, .., w_{fn}\}$. The joint p.d.f. for the jth order statistic is given by $gj(w_{fj}) = n!f(w_{f1})f(w_{f2})..f(w_{fn})$, $\underline{w}_f \leq wf \leq \overline{w}_f$ and zero elsewhere. The marginal pdf for the $j = 1$, with $w_{f1} = w_f$, order statistic is $h(w_{f1}) = \int_{w_{f1}}^{\overline{w}_f} .. \int_{w_{f1}}^{\overline{w}_f} n!f(w_{f1})f(w_{f2})..f(w_{fn})dw_{fn}$

$dw_{fn-1}..dw_{f2} = n[1 - F(w_{f1})]^{n-1}f(w_{f1})$; $\underline{w}_f \leq wf \leq \overline{w}_f$ and zero elsewhere (Hogg and Craig, 1978).

$$\begin{aligned}
h(w_{f1}) &= \int_{w_{f1}}^{\overline{w}_f} .. \int_{w_{f1}}^{\overline{w}_f} n!f(w_{f1})f(w_{f2})..f(w_{fn})dw_{fn-1}..dw_{fn}dw_{f2} \\
&= \int_{w_{f1}}^{\overline{w}_f} .. \int_{w_{f1}}^{\overline{w}_f} n!f(w_{f1})f(w_{f2})..f(w_{fn})[1 - F(w_{fn-1})]dw_{fn-1}..dw_{fn}dw_{f2} \\
&= \frac{n[1 - F(w_{f1})]^{n-1}f(w_{f1})}{(n-1)!} \\
&= n[1 - F(w_{f1})]^{n-1}f(w_{f1});\ \underline{w}_f \leq wf \leq \overline{w}_f \\
&= 0 \text{ elsewhere}
\end{aligned}$$

where: $\int_{w_{f1}}^{\overline{w}_f}[1 - F(w_{fn-1})]dw_{fn-1} = \frac{[1-F(w_{fn-1})]^2}{2}$ since $F(\overline{w}_f) = 1$ and integrating $n - 1$ times resulting in $(n - 1)!$ in denominator.

6.2 Appendix 2: Response of the w(R,c) to R.

From equation 19, the response $w(R,c)$ to R is given as follows:

$$\begin{aligned}
\frac{\partial w(R,c)}{\partial R} &= -q(R)\left\{\frac{cm'(q(R))}{\theta\mu}\right\}^{\frac{1}{2}}\frac{dq(R)}{dR} + \\
&\quad [1-q(R)]\left(\frac{1}{2}\right)[m'(q(R))]^{\frac{-1}{2}}\left\{\frac{c}{\theta\mu}\right\}^{\frac{1}{2}} m''(q(R))\frac{dq(R)}{dR} \\
&= \left\{\frac{c}{\theta\mu}\right\}^{\frac{1}{2}}\left(\frac{1}{2}\right)[m'(q(R))]^{\frac{-1}{2}}\frac{dq(R)}{dR} \times \\
&\quad \{-q(R)m'(q(R)) + [1-q(R)]m''(q(R))]\}
\end{aligned}$$

6.3 Appendix 3: Response of the $w_b(R, c, u_{bl})$ to c, u_{bl} and R.

From equation 30, the response of $w_b(R, c, u_{bl})$ to c, u_{bl} and R is given as follows:

For dw_b/dc:

$$\begin{aligned}-h'(w_b)dw_b[w_b^2(R-u_{bl}) - cw_bR] - h(w_b)[2w_b(R-u_{bl}) - cR]dw_b \\ -h(w_b)[cR]dw_b + h(w_b)[w_bR]dc + [1-H(w_b)]Rdc = 0\end{aligned}$$

$$\begin{aligned}&\left\{h'(w_b)[w_b^2(R-u_{bl}) - cw_bR] + h(w_b)[2w_b(R-u_{bl})]\right\} dw_b \\ = \ &\left\{h(w_b)[w_bR] + [1-H(w_b)]R\right\} dc\end{aligned}$$

$$\frac{dw_b}{dc} = \frac{\{h(w_b)[w_bR] + [1-H(w_b)]R\}}{\{h'(w_b)[w_b^2(R-u_{bl}) - cw_bR] + h(w_b)[2w_b(R-u_{bl})]\}}$$

For dw_b/du_{bl}:

$$\begin{aligned}-h'(w_b)dw_b[w_b^2(R-u_{bl}) - cw_bR] - h(w_b)[2w_b(R-u_{bl}) - cR]dw_b \\ -h(w_b)[cR]dw_b + h(w_b)w_b^2du_{bl} = 0\end{aligned}$$

$$\begin{aligned}&\left\{h'(w_b)[w_b^2(R-u_{bl}) - cw_bR] + h(w_b)[2w_b(R-u_{bl})]\right\} dw_b \\ = \ &h(w_b)w_b^2du_{bl}\end{aligned}$$

$$\frac{dw_b}{du_{bl}} = \frac{h(w_b)w_b^2}{\{h'(w_b)[w_b^2(R-u_{bl}) - cw_bR] + h(w_b)[2w_b(R-u_{bl})]\}}$$

For dw_b/dR:

$$\begin{aligned}-h'(w_b)dw_b[w_b^2(R-u_{bl}) - cw_bR] - h(w_b)[2w_b(R-u_{bl}) - cR]dw_b \\ -h(w_b)[cR]dw_b + \{-h(w_b)[w_b(w_b-c)] + [1-H(w_b)]c\} dR = 0\end{aligned}$$

$$\begin{aligned} &\left\{h'(w_b)[w_b^2(R-u_{bl})-cw_bR]+h(w_b)[2w_b(R-u_{bl})]\right\}dw_b \\ = &\left\{-h(w_b)[w_b(w_b-c)]+[1-H(w_b)]c\right\}dR \end{aligned}$$

$$\begin{aligned} \frac{dw_b}{dR} &= \frac{-h(w_b)[w_b(w_b-c)]+[1-H(w_b)]c}{\{h'(w_b)[w_b^2(R-u_{bl})-cw_bR]+h(w_b)[2w_b(R-u_{bl})]\}} \\ \frac{dw_b}{dR} &= \frac{-h(w_b)[w_b(w_b-c)]+[1-H(w_b)]c}{\{h'(w_b)[w_b^2(R-u_{bl})-cw_bR]+h(w_b)[2w_b(R-u_{bl})]\}} \end{aligned}$$

From the first order condition, it is know that

$$\begin{aligned} w_b^2\left[1-\frac{u_{bl}}{R}\right]-cw_b &= \left[\frac{1-H(w_b)}{h(w_b)}\right]c \\ w_b^2\left[R-u_{bl}\right]-cw_bR &= \left[\frac{1-H(w_b)}{h(w_b)}\right]cR \\ w_b[(w_b-c)R-u_{bl}w_b]h(w_b) &= [1-H(w_b)](cR) \\ -\frac{u_{bl}}{R}w_b^2h(w_b) &= -h(w_b)[w_b[(w_b-c)]+[1-H(w_b)]c \end{aligned}$$

Therefore,

$$\frac{dw_b}{dR}=\frac{-[u_{bl}/R]\{w_b^2h(w_b)\}}{\{h'(w_b)[w_b^2(R-u_{bl})-cw_bR]+h(w_b)[2w_b(R-u_{bl})]\}}$$