Optimum Sequential Bidding in Maturing Industries: Implications for Generating Competitive Advantage

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Sequential bidding by suppliers on complex engineering/manufacturing contracts has become pervasive in many manufacturing industries. In maturing industries, such as autos, relational ties between suppliers and the OEMs they serve have become key ingredients in profit performance, initial and subsequent pricing, and the probabilities of winning sequential contracts. Yet, the literature is relatively barren in studies that explore this phenomenon. In this paper, we attempt to fill this void. We develop alternative models of sequential bidding by a tier one supplier in the automotive industry. We show how optimum bid prices for each bidding cycle over a fixed time period can be derived through the use of backward dynamic programming. This unique approach takes into account the supplier's ability to learn from its experiences with a particular OEM and explores the value of relational ties with that OEM and the use of loss-leader pricing when developing a long-term, sequential bidding strategy.

Keyword: Sequential bidding, optimum bid price, supplier-buyer relationship

1 Introduction

Building and sustaining business relationships between original equipment manufacturers (OEMs) and their suppliers have become increasingly important during the last two decades as the confluence of pervasive globalization and profound developments in information technology have placed increasing burdens on both OEMs and suppliers to be lean manufacturers while simultaneously being increasingly responsive to customer demands worldwide. Nowhere have these burdens been so immense than in the maturing industries, such as autos, where institutional arrangements such as contracting, ownership, and social ties have become reshaped recently, requiring new and energized mindsets that value customer responsiveness, cost efficiency, and profits from a long-term, joint-gain perspective, rather than the short-term, self-gain point of view which had been the norm. Asymmetries among OEMs and their suppliers of yesteryear are now giving way to longer term relationships that possess, even thrive on, the increasing equity invested in partnerships among players in maturing markets. Gone are the purchasing practices of yesteryear where suppliers could be forced into pricing arrangements favorable to the OEM at the expense of the very suppliers with whom the OEM had been doing business for many years. In today's maturing industries, global competitors are finding it increasingly necessary to develop and nurture strategic, long-term relationships based on reciprocal and/or collaborative aims and responsibilities. Recent research has shown, for example, that the building of trust across dyads between partners through sustained relationships lead to increased levels of interorganizational commitment and healthier joint returns in mature, industrial markets (Narayandas and Rangan 2004).

We observe clear examples of these in the world around us. In the auto industry, for example, long the locomotive of industrial growth in many countries, OEMs are now requiring suppliers to assume greater engineering design responsibility while holding the line on manufacturing costs over ever-shorter product development timelines. Suppliers, for their part, are cutting into their eroding margins to win continuous business from OEMs for derivatives of the models they have been serving, especially for components that are unrelated to current contracts but could be relevant for future models. This appears to be true, especially, in Japanese OEMs' relationships with their suppliers, where the building of credibility and trust from initial contracts seem to enhance the possibilities for future contracts, even for components that are currently unrelated to present products (Liker 2004).

In this paper, we focus on bidding, one dimension of the institutional arrangements between OEMs and suppliers, to explore the possible impact that sequential bidding might have on supplier gains. We develop a model for bidding on automotive system design and subsequent manufacture for a tier one auto supplier in North America and show how this model might be applied in practice. We believe that this is a significant contribution to the literature since bidding models in the extant literature tend to focus on single bidding, appropriate when each business opportunity is viewed as unique. Suppliers today, however, work to develop and nurture relationships with OEMs based on their expertise in specific areas that enable them to bid on components and systems that they wish to market for installation on their OEMs' multiple product lines in future periods. In these cases, the business opportunity can extend to vehicle models across multiple years, across a common, or even multiple, platforms and/or to multiple vehicle lines in a particular OEM. Further, the credibility gained by winning business with one OEM might also help in winning business on similar products across multiple OEMs. Thus, from the point of view of the supplier, the impact of winning an initial bid on winning subsequent business from that or other OEMs can be substantial.

On the other side of the equation, the OEM's satisfaction in its relationship with a particular supplier can also be critical (Dyer and Ouchi 1993). That is, the probability of winning a sequential bid from a particular OEM can be enhanced if the OEM is satisfied in its relationship with a given supplier through a previous bid and subsequent contract. This can be especially important in the situation where the supplier and the OEM do not share a previous relationship. A supplier may even follow a loss leader pricing strategy in its initial bid to start a relationship with a particular OEM, especially when entering an area in which it does not have a proven track record, but the area is significant in achieving its corporate goals or strategic intent.
From the supplier's perspective, learning gains from its relationship with a particular OEM can also be important since cost reductions will naturally accrue to the supplier in later bids or bidding cycles as a result of its learning from its relationship with a particular OEM; this will improve the supplier's profit margins and its chances of winning future bids, especially in OEM-supplier dyads where the satisfaction has been relatively high. Cost may decline in the second bidding cycle, since a supplier incurs some of its start-up costs during only its first bid or first bidding cycle. Suppliers that are unable to reduce cost, on the other hand, are likely to lose bargaining power in their relationships and be forced to forgo possible marginal gains or lose their business with that OEM altogether.

In this paper, we develop bidding models that maximize expected profit over a two bidding cycle time horizon while incorporating an OEM's satisfaction in its relationships with a particular supplier, a form of competitive advantage. We also explore the impact of learning benefits that accrue to the supplier from the successful completion of contracts. Our work is significant because we incorporate the possible impacts of these constructs in arriving at an optimum solution in a sequential bidding context. Our two models consider sequential bidding over two cycles of bidding years under different pricing assumptions.

In the first model, we consider the situation where a supplier wins business from a particular OEM, and then increases its price in the second bidding cycle. This situation might be exemplified by a second bidding cycle that involves a component or subsystem that is somewhat more complex than the first so that the OEM cannot insist on a reduced, or constant, price. From the supplier's perspective, fixed start-up costs might be reduced and learning gains could accrue from winning, and then carrying out the first contract. We investigate the conditions under which a supplier might offer an aggressive bid price that generates a loss in the first bidding cycle, but maximizes the two-cycle time horizon. In this model, we also explore the impact of uncertain variable (cost) and the results of bidding on profit using simulation and provide cumulative risk profile.

In the second model, we consider the case where the price in the second bidding cycle is lower than, or equal to, that in the first bidding cycle. This context arises when car models are refreshed every three to five years and OEMs insist that suppliers keep component prices at bay.

2 Literature Review

The literature on bidding models can be traced back to Friedman's pioneering work (1956). Studies since then have involved the development, and sometimes empirical testing of mathematical models, exploration of the theoretical dimensions of competitive bidding, deriving equilibria conditions in auction contexts, and multistage modeling (Skitmore 2002).

In one dimension of this literature, scholars have extended Friedman's work to help contractors determine optimum bids. These have typically involved determining the optimum bid price which maximized expected contribution to profit in a competitive bidding environment. (Gates 1967, Carr 1982, Skitmore 1991).

Other studies have explored the theoretical foundations of competitive bidding in the construction, petroleum and electrical industries (Morin and Clough 1969, Capen et al. 1971, Ward and Chapman 1988, Pin and Scott 1994, Rothkopf and Harstad 1994 Mercer and Teilin 1996). For example, Skitmore and Pemberton (1994) and King and Mercer (1991) have shown empirical evidence of profitable bidding strategies in several industries. Most of these studies, however, have focused on a single, isolated auction of a single asset.

Oren and Rothkopf (1975) pioneered the modeling of sequential auctions as a multi-stage control process. In their work, the bidder's expected profit from each auction depended on the bidding policy of the competitors and the bidder's own bidding approaches. They modeled the impact of the optimal bid on future competitive bids using a reaction function. Here, as it is true in economics, the bidder's objective was to choose that approach that would maximize the expected present value of profits over an infinite time horizon. Dynamic programming was used to derive an equation for the optimal, infinite time horizon bidding strategy.

The research into sequential and simultaneous bidding has been applied to bidding on identical assets, called multi-unit auctions (Pitchik 1998, Benoit and Krishna 1998, Elmaghraby 2003). Some multi-unit sequential auction studies have focused on the ordering process used in auction design (Pitchik 1998 and Elmaghraby 2003)

In the literature, the sequential modeling environment is viewed in a classic game theoretic framework; that is, the primary impact of sequential bidding is that each of the bidders will gain knowledge regarding competitive behavior that affects the probabilistic forecast of the next set of bids, and thus the optimal strategy. In our context, the sequencing of bids has a much different impact that is characteristic of bidding in complex engineering and manufacturing projects. The strategy for the second or sequential bid is affected by the following factors.

- Winning the first bid provides a competitive advantage for the next bidding cycle because of the relationship that has developed.
- Winning the first bid affects the cost structure for the second bid because the fixed costs decline and learning reduces the annual operating costs.

These dynamics affect the optimal bidding strategy. They raise the possibility that an optimal strategy could involve on average losing money on the first bid while making money on the second contract because of lower fixed and operating costs in the second cycle.

3 Model Overview

Bidding on auto system design and manufacturing is a complex and risky decision. Automotive suppliers expect to reduce cost from one year to the next through organizational learning and may be required to share some of the benefits with the OEMs. From the other perspective, automotive OEMs value their relationships with their suppliers and usually consider other tangible and intangible criteria when choosing suppliers. Although the motivation for our work is our automotive experience, the specifics of the model are not uniquely automotive and can be applied equally to any environment in which a supplier has to compete over and over again for a segment of a continually evolving complex product line.

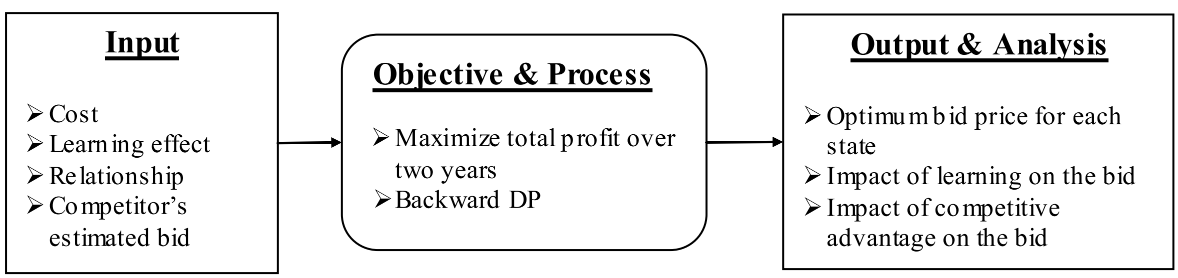


Figure 1: Overview of sequential bidding models

We introduce two bidding models that take into consideration the impact of a supplier's learning on its cost structure and the competitive advantage obtained by winning and successfully executing a first contract (Figure 1). The models aim to maximize total profit over two cycles of bidding years. The first of these assumes that once a supplier wins a project from an OEM, it can increase price in the second bidding cycle but risks losing the business if it increases its price too much. This assumption is valid in instances in which the second contract involves a somewhat more complex product that is closely related but not identical to the first. The second model assumes the OEM will allow no price increase from year-to-year and thus the second bid must be less than or equal to the first bidding cycle's price.

The basic solution approach is analogous to backward dynamic programming. We optimize a cycle's bid conditioned on the different states in the immediately prior stage. The optimum at each state is found by differentiating the profit function. The second model includes the constraint that the second bid cannot be higher than the first. We use these various models to derive conditions and insights as to optimal bids.

3.1 Problem Definition

In this paper, we envision a supplier, SX, who wants to establish a long-term relationship with a particular OEM, but does not currently enjoy such a relationship. We also envision a Competitor CY who is in competition with SX to win the OEM's business. We feel that SX has to overcome two barriers in this case while bidding for the OEM's business. First, since SX lacks a relationship with this particular OEM, it must provide a substantial financial advantage to the OEM to convince it to change its current sourcing strategy to SX. Second, it must overcome the significant start-up costs invested into developing this new relationship. If SX has processes in place that enable it to learn and improve its design and manufacturing processes over time, its fixed and variable costs will decline with each bid it wins from the same OEM. We assume that SX is bidding against CY, a competitor who has a pre-existing relationship with the OEM. We model CY's bid as a random variable which in our models we assume to be uniformly distributed. To capture the significant elements of sequential bidding, we introduce the following parameters:

- δ: The amount a new supplier will have to underbid an existing supplier in order to win a first contract. Defined as the percentage savings to the OEM, we assume that this term will be converted into an advantage in the second bid if supplier SX wins the first bid.
- τ: The percentage reduction in cost associated with a second winning bid due to reduced fixed cost and learning benefits.
- : CY's bid
- ϕ_U = Upper limit of CY's bid
- = Lower limit of CY's bid
- φ = Difference between the upper and the lower limits of CY's bid price

We allow the total cost to decline by τ% in the second bidding cycle due to learning benefits that accrue to the supplier and reduced start-up cost. Because we assume that the supplier is risk neutral and is maximizing expected value, we treat its cost as a non-random variable and its expected net profit as simply a function of the expected value of its costs. Thus, we view cost and profit as follows:

- C: Estimated cost
- μ : Mean total cost
- C^1: Total cost in bidding cycle 1,
- C_1^2 =Total cost in bidding cycle 2 if the supplier wins the first bid
- C_0^2 = Total cost in bidding cycle 2 if the supplier does not win the first bid
- R: Total profit over a given time horizon
- R^1: Profit in bidding cycle 1,
- R_1^2 : Profit in bidding cycle 2 if the supplier wins the first bid,
- R_0^2 : Profit in bidding cycle 2 if the supplier doesn't win the first bid
- γ: Bidding cycle (annual) discount factor
- B: Bid price where B* is the optimum bid price,
- B^1: Bid amount in bidding cycle 1,
- B_1^2 : Bid amount in bidding cycle 2 if the supplier wins the first bid,
- B_0^2 : Bid amount in bidding cycle 2 if the supplier does not win the first bid.

Probabilities

We use the probability density function of the ratio of the competitor's bid to the supplier's first bidding cycle cost estimate to estimate the probability of the competitor's bid price and employ a uniform distribution to predict the competitor's bid price in the first two models. In our modeling effort, the probability of winning a bid is a function of three factors, bid price, the competitor's bid, and the relationship between a supplier and a given OEM (competitive advantage). Thus we have:

- P (W|B): The probability of winning a bid given a bid amount, B
- θ : The ratio of the competitor's bid to the supplier's cost estimate (c)
- θ_U : Upper limit of θ
- θ_L : Lower limit θ

States

- S^1: State in Bidding cycle 1
- S_1^2 : State in Bidding cycle 2 given that the supplier won the first bid
- S_0^2 : State in Bidding cycle 2 given that the supplier did not win the first bid

Competition

- We further assume that the OEM would be willing to pay δ% more to the supplier with which it has a satisfactory relationship when compared to the lowest bid submitted by another supplier that has either an unsatisfactory or no relationship with that OEM. Further, we model a one key competitor situation. Thus, we surmise that:
- CY, the competitor, will use the same bid pricing strategy whether it wins the bid or not
- SX, the supplier, does not yet have an established relationship with this OEM, but that CY does have a satisfactory relationship with it (The last two assumptions can be modified if SX has a successful relationship with the OEM, but CY does not have such a relationship).

3.2 The Probability of Winning

In line with Friedman (1956), we estimate the probability of winning a given bid by using statistics from past competitions. We assume that SX and CY have competed against each other for different contracts before, with different cost and bid structures. The differences in bid prices are due mainly to differences in the costs of the projects. Because of the bid price differences in different projects, we use the ratio of CY's bid price to SX's cost estimate instead of CY's actual bid price in estimating the probability distribution function of CY's bid price. The ratio of CY's bid (ϕ) to SX's cost estimate for the first bidding cycle (c) is plotted to yield the probability distribution of CY's bid in the current competition.

Friedman's model and those that followed it are built on the assumption that a bidder with the lowest bid wins. This, however, would be the case only if both SX and CY don't have a satisfactory relationship with the particular OEM or both have such a relationship. If both SX and CY have the same kind of relationship with the OEM, the probability of winning the bid with a bid price B, $P(W|B)$, is $\int_{B/c}^{\infty} f(r)dr$ (see Figure 2, scenario I), where f(r) represents the probability density function of the ratio of CY's bid to SX's cost estimate in the first bidding cycle.

If SX has a satisfactory relationship with the OEM, it will take advantage of this with that

OEM when it offers a bid price, B (see Figure 2, scenario II). As mentioned earlier, the OEM would be willing to pay δ% more in this case to the supplier that has a satisfactory relationship with the OEM when compared to the lowest bid submitted by the other supplier. Thus, the probability of winning the bid with the bid price B, $\mathrm{P}(\mathrm{W}|B)$, will become $\int_{\mathrm{B}(1-\delta)/c}^{\infty} f(r)dr$ if SX has a satisfactory relationship with that OEM. If, in contrast, CY has a competitive advantage with that OEM, SX's probability of winning the business from the OEM will decrease to $\int_{\mathrm{B}(1+\delta)/c}^{\infty} f(r)dr$.

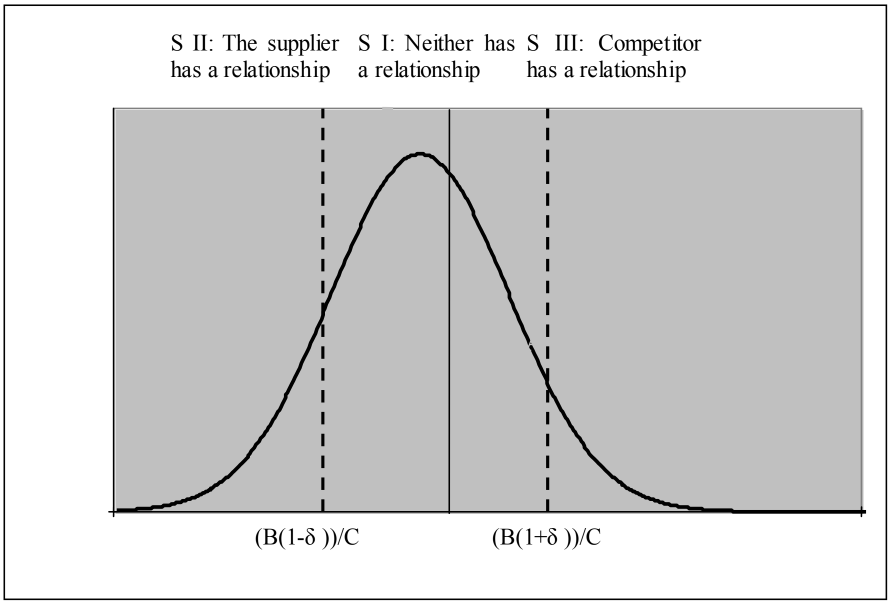


Figure 2: The supplier's probability of winning the bid over its competitor, CY

We use a uniform distribution in our models to estimate the probability of winning the bid with a bid price, B, and a competitive advantage factor, δ. We prefer a uniform distribution since we are interested in finding an analytical solution, not merely a numerical one. We assume that in bidding cycle one, CY has the competitive advantage. If SX wins the bid in the first bidding cycle, SX gains a competitive advantage over its competitor in the second bidding cycle. Otherwise, CY will have the competitive advantage in the second bidding cycle, as well. There are two scenarios regarding competitive advantage in the second bidding cycle; hence, the probability of winning the bid in the second bidding cycle changes when (a) CY has the competitive advantage, and (b) SX has the competitive advantage. We, therefore, adjust the probability of winning the bid in each of these cases as follows:

(a) If CY has a satisfactory relationship with the OEM, the probability of defeating SX's bid is:

$$\mathrm{P}(\mathrm{W}|B) = \int_{\mathrm{B}(1+\delta)/c}^{\infty} f(r)dr = \int_{\mathrm{B}(1+\delta)/c}^{\infty} \frac{1}{\theta_U - \theta_L} dr = \frac{\theta_U - \frac{B(1+\delta)}{c}}{\theta_U - \theta_L} \qquad (1)$$

where θ is the ratio of CY's bid to SX's cost estimate for the first bidding cycle, θ_U shows the upper limit, and θ_L illustrates the lower limit.

$$\theta = \frac{\phi}{c} \qquad (2)$$

To simplify equation (1), we multiply the numerator and the denominator with the total cost estimate, c. In this case, we arrive at:

$$\mathrm{P}(\mathrm{W}|B) = \left(\frac{\phi_U - B(1+\delta)}{\varphi} \right) \qquad (3)$$

where φ is ϕ_U - ϕ_L .

(b) If, on the other hand, SX has the satisfactory relationship with the OEM, not CY, than the probability of beating CY's bid will be:

$$\mathrm{P}(\mathrm{W}|B) = \int_{\mathrm{B}(1-\delta)/c}^{\infty} f(r)dr = \int_{\mathrm{B}(1-\delta)/c}^{\infty} \frac{1}{\theta_U - \theta_L} dr = \frac{\theta_U - \frac{B(1-\delta)}{c}}{\theta_U - \theta_L} \qquad (4)$$

We simplify Equation (4) by multiplying the numerator and the denominator with the total cost estimate, c, and arrive at:

$$\mathrm{P}(\mathrm{W}|B) = \left(\frac{\phi_U - B(1-\delta)}{\varphi} \right) . \qquad (5)$$

3.3 The Objective Function

We assume that the supplier's objective is to maximize expected total profit over two bidding cycles (E(R)), as illustrated in Equation (6). We assume that if SX doesn't win the bid, it does not incur any cost or profit. The first term in Equation (6) summarizes expected profit in the first bidding cycle as the product of profit, given that SX wins the bid with its bid price, B^1, and the probability of winning the bid. The second bidding cycle's bid profit depends upon whether SX won the bid in the first bidding cycle. The expected profit in the second bidding cycle is the sum of the profit in the second period if SX wins the bid in the first bidding cycle and the profit expected in the second bidding cycle if SX does not win the bid during the first cycle. We also multiply the second bidding cycle's profit with a time discount factor of γ. Our objective function, therefore, becomes:

$$\text{Max } E(R) = E(R^1|W_1 \cap B^1)P(W_1|B^1) + \gamma * E(R_1^2|W_2 \cap W_1 \cap B^1 \cap B_1^2)\ P(W_1 \cap W_2|B^1 \cap B_1^2) + \gamma * E\ (R_0^2| W_2 \cap {\sim}W_1 \cap B^1 \cap B_0^2)\ P\ ({\sim}W_1 \cap W_2|B^1 \cap B_0^2) \qquad (6)$$

The profit that can be realized with a given bid for each bidding cycle in this case becomes the difference between the bid amount and the estimated cost. The cost in the first year and the cost in the second period given that SX did not win the first bid are the same as depicted in our Equation (7).

$$C^1 = C_0^2 = \mu_1 \qquad (7)$$

As discussed earlier, we further stipulate that once SX starts a relationship with a particular OEM, its total cost will decrease by τ% in the second year. Equation (8) represents the cost for the second period given that SX wins the first bid.

$$C_1^2 = (1-\tau)\mu_1 \qquad (8)$$

When we add the appropriate expected profit (B-C) and the probability functions to equation (6) we arrive at equation (9).

$$\text{Max} \qquad \text{E(R)}=(\text{B}^1 - \text{C}^1)\left(\frac{\phi_U - B^1(1+\delta)}{\varphi}\right)+\gamma(\text{B}_1^2 - \text{C}_1^2)\left(\frac{\phi_U - B_1^2(1-\delta)}{\varphi}\right)\left(\frac{\phi_U - B^1(1+\delta)}{\varphi}\right)$$

$$+\gamma(\text{B}_0^2 - \text{C}^1)\left(\frac{\phi_2 - B_0^2(1+\delta)}{\varphi}\right)\left(\frac{B^1(1+\delta)-\phi_L}{\varphi}\right) \qquad (9)$$

We then expand Equation (9) and derive equation (10) to arrive at the objective function as a second order non-linear problem with three decision variables. As we analyze the bidding model over a longer time period, the problem becomes more complex as it involves more decision variables, and becomes a higher order nonlinear problem.

$$\text{Max} \qquad \text{E(R)} \qquad = \qquad \left(\frac{1}{\varphi}\right)\left(\phi_U \text{B}^1 - (\text{B}^1)^2(1+\delta) - C^1\phi_U + C^1(1+\delta)\text{B}^1\right) \qquad + \qquad \left(\frac{\gamma}{\varphi^2}\right)$$

$$\left\{(\phi_U)^2\text{B}_1^2 - \phi_U(\text{B}_1^2)^2(1-\delta) - C_1^2(\phi_U)^2 + C_1^2\phi_U\text{B}_1^2(1-\delta)\right.$$

$$\left.-\text{B}_1^2\text{B}^1(1+\delta)\phi_U + \text{B}^1(\text{B}_1^2)^2(1+\delta)(1-\delta) + \text{B}^1(1+\delta)C_1^2\phi_U - C_1^2\text{B}^1\text{B}_1^2(1+\delta)(1-\delta)\right\}+$$

$$\left(\frac{\gamma}{\varphi^2}\right)\left\{\text{B}_0^2\text{B}^1(1+\delta)\phi_U - \text{B}^1(\text{B}_0^2)^2(1+\delta)^2 - \text{B}^1(1+\delta)C^1\phi_U + C^1\text{B}^1\text{B}_0^2(1+\delta)^2\right.$$

$$\left.-\text{B}_0^2\phi_U\phi_L + (\text{B}_0^2)^2(1+\delta)\phi_L + \phi_L C^1\phi_U - \phi_L C^1\text{B}_0^2(1+\delta)\right\} \qquad (10)$$

4 Model I

In our first model, we assume that SX may increase its bidding price in the second bidding cycle if it wins the first bid. The model does not have a constraint; hence, the sequential bidding problem is an unconstrained nonlinear problem.

4.1 Deriving the Optimum Solution for the Unconstrained Problem

In bidding cycle one, there is only one state (State S^1, where SX does not have a relationship with the OEM), while in bidding cycle two, there are two possible states as depicted in Figure 3: (1) SX has won the bid in the first bidding cycle (State S_1^2), and (2) SX did not win the bid in the first bidding cycle (State S_0^2). SX's goal in either state in the second bidding cycle is to maximize profit in only the second bidding cycle. At the time of the second bid, SX knows whether or not it has won the first bid. Thus the expected profit in each of these states (State S_1^2 and State S_0^2) is the product of profit given that SX has or has not won the bid and its associated probability of winning in year two. In State S_1^2, SX's goal is to maximize profit at this state as shown in equation (11).

$$E\,(R_1^2|W_1) = (B_1^2 - C_1^2)\left(\frac{\phi_U - B_1^2(1-\delta)}{\varphi}\right) \quad (11)$$

Similarly in State S_0^2, SX's goal is to maximize profit at this state as shown in equation (12).

$$E\,(R_0^2|{\sim}W_1) = (B_0^2 - C^1)\left(\frac{\phi_2 - B_0^2(1+\delta)}{\varphi}\right) \quad (12)$$

We use backward dynamic programming to find the optimum solution and optimum bid prices, B_1^2 and B_0^2, as follows.

Step 1: Calculate optimum bid prices in bidding cycle 2

- Calculate B_1^{2*} (the optimum bid price in bidding cycle two given that SX has won the bid in bidding cycle one) that maximizes expected profit in State S_1^2 (equation (11)). Take the first derivative of E (R_1^2|W$_1$) with respect to B_1^2 and find the optimum value.
- Calculate B_0^{2*} (the optimum bid price in bidding cycle two given that SX did not win the bid in bidding cycle one) that maximizes expected profit in State S_0^2 (equation (12)). Take the first derivative of E (R_0^2|~W$_1$) with respect to B_0^2 and find the optimum value.

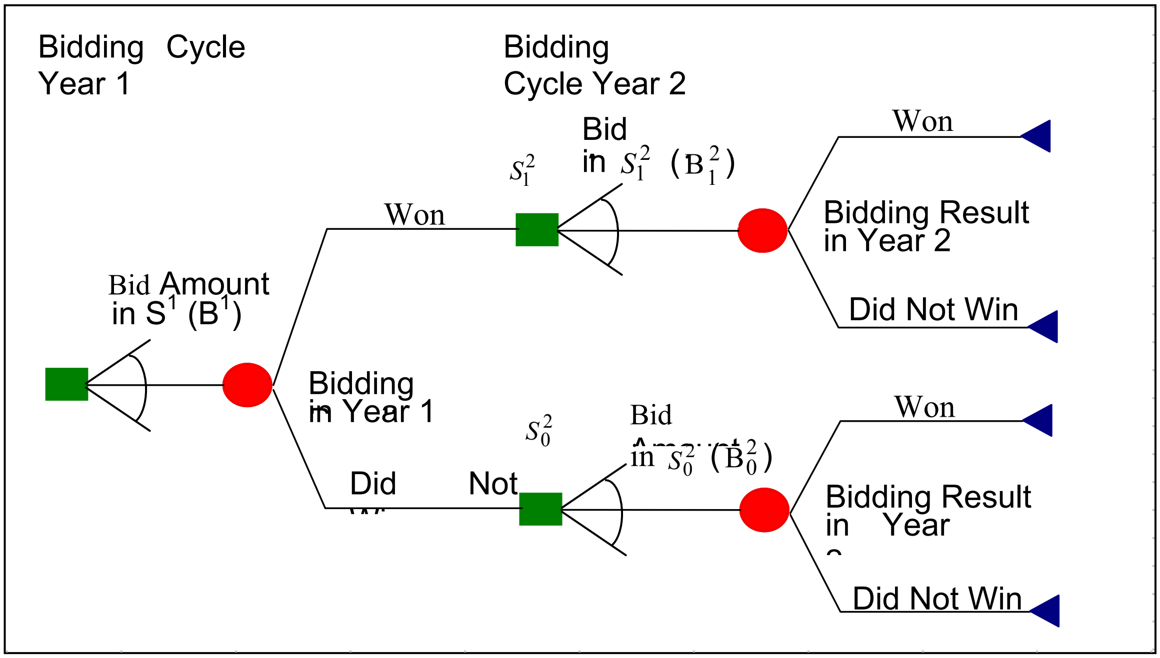


Figure 3: Bidding decisions and their possible results

Step 2: Calculate B^{1*} (the optimum bid price in bidding cycle 1) that maximizes total expected profit over the two bidding cycle time horizon (equation (9)). Note that we have already derived the optimum bid amounts for bidding cycle 2 (B_1^{2*}, and B_0^{2*}) in step 1. Since we know these optimum values in step 2, the problem is a second order nonlinear problem with only one variable. More specifically, we derive optimum bidding prices for all states by expanding on the steps presented above. We start from the second bidding period.

Step 1 –a: We calculate B_1^{2*} by taking the first derivative of E(R_1^2|W_1) with respect to B_1^2. The stationary point, $B_1^{2*} = \frac{[\phi_U + (1-\tau)\mu_1(1-\delta)]}{2(1-\delta)}$ is optimum because $\frac{d^2E(R_1^2|W_1)}{(dB_1^2)^2} = \left(\frac{\gamma}{\varphi}\right)[-2(1-\delta)] < 0.$

Observation 1a: The optimum bid price in the second bidding cycle given that **<u>SX has won the bid</u>** in the first period depends on the upper limit of CY's bid, SX's cost and its cost reduction percentage, and its relationship or competitive advantage. As the competitive advantage parameter increases, the optimum bid B_1^{2*} also increases. Because SX has a satisfactory relationship with the OEM, SX can offer a higher bid price as δ increases. However as the impact of cost reduction (τ) increases, B_1^{2*} will decline such that the probability of winning the bid will increase.

Step 1 –b: We find the optimum bid amount in bidding cycle two if SX did not win the first bid in similar fashion (State S_0^2). The stationary point for the bid price in bidding cycle two given that SX lost the first bid, $B_0^{2*} = \frac{[\phi_U + \mu_1(1+\delta)]}{2(1+\delta)}$, is optimum since $\frac{d^2E(R_0^2|\sim W_1)}{(dB_0^2)^2} = \left(\frac{\gamma}{\varphi}\right)[-2(1+\delta)]<0.$

Observation 1b: The bid price in the second bidding cycle in State S_0^2 depends on the upper limit of CY's bid, its competitive advantage and SX's cost in the first bidding cycle. Note that the percentage reduction in SX's cost (τ) does not influence B_0^{2*}. However, as CY's competitive advantage increases, B_0^{2*} declines. Because CY has a satisfactory relationship with the OEM, SX must offer lower bid prices to win the bid as δ increases.

Step 2: To find the optimum bid price in bidding cycle one, we take the first derivative of E(R) (equation (9)) with respect to B^1 and find the stationary point (Equation (13)). B^{1*} is optimum since $\frac{d^2E(R)}{(dB^1)^2} = \frac{d^2E(R)}{dB_1^2} = \left(\frac{\gamma}{\varphi}\right)\left(-2(1+\delta)\right) < 0.$

$$B^{1*} = \left(\frac{\gamma}{2\varphi}\right)\Big\{-B_1^{2*}\phi_U + (B_1^{2*})^2(1-\delta) + (1-\tau)\mu_1[\phi_U - B_1^{2*}(1-\delta)]$$

$$+ B_0^{2*}\phi_U - (B_0^{2*})^2(1+\delta) - \mu_1\phi_U + \mu_1 B_0^{2*}(1+\delta)\Big\} + \frac{\phi_U + \mu_1(1+\delta)}{2(1+\delta)} \tag{13}$$

The bid price in the first bidding cycle depends on SX's cost, cost reduction percentage, competitive advantage, optimum bid prices in the second period (and therefore profits), and upper limit of CY's bid. Note that while the original problem is a second order nonlinear problem with three decision variables, with backward dynamic programming, we now have a second order nonlinear problem with only one decision variable.

Observation 2: Here, we investigate the circumstances under which SX should assume an aggressive bidding strategy that will lead to losses on average in the first year in order to start a relationship with the OEM. Equation (13) implies that as competitive advantage (δ), or cost reduction (τ) increases, the optimum bidding price in the first cycle will decline. As δ increases, SX can take more advantage of its relationship with the OEM in the second bidding cycle if it wins the first bid. SX, therefore, will offer a lower price in the first bidding year so as to increase its chance to win as δ increases. Similarly, as the percentage cost reduction increases, the cost declines more in the second year if SX wins in the first year. Consequently, SX will offer a lower first bid price as its cost reduction increases and will make greater profit in the second period.

4.2 Numerical Example

In our example, SX and CY are competitors trying to win a multi-million dollar project contract from an OEM. SX estimates that the mean of the project's cost in the first year will be \$25 million. It further predicts that CY will offer a bid price between \$22 million and \$28 million. It knows that the OEM is willing to pay up to 5% more to the supplier with which it has a satisfactory relationship when compared to the lowest bid submitted by another supplier with whom it has no such relationship. SX also estimates that its costs will decline by 15% in the second period due to a reduction in its fixed costs and learning benefits it will gain if SX were to win the first bid. It estimates the annual discount factor as 95%.

The bid prices we derive for this example using a sequential bidding approach (our model) and a single cycle competitive bidding strategy are summarized in Table 1. Both strategies lead to the same bidding prices for the second bidding cycle since sequential bidding does not consider anything beyond the second bidding cycle. In bidding cycle one, the optimum bidding amount is \$24.62 million for the sequential bidding approach. The probability of winning the bid is 0.36. SX loses \$0.38 million in bidding cycle one to increase its chances of starting a relationship with this OEM. The total expected profit for the two cycles of bidding years is \$0.85 million.

Let us now compare this to the typical approach used in the literature in which only the current cycle is considered when making a bid. The optimum bid amount for that approach (single cycle competitive bidding) is \$25.83 million, \$1.2 million more than the optimum bid of the sequential strategy we used in the first cycle. The probability of winning the first bid is only 0.15 (42% of the probability found in the sequential bidding strategy). SX's gain in the first year is \$0.83 million if it wins the first bid. SX's expected total profit over the two cycles of bidding years is \$0.57 million, 32% less than the expected profit found in our sequential bidding approach.

To further examine the impact of cost reductions and competitive advantage benefits on the bidding decision and profit, we also conducted a detailed analysis of one parameter at a time through three scenarios. In Scenario I, we assume that the cost does not decline from year to year and the relationship between SX and the OEM has no impact on the probability of winning the bid (τ=0, δ=0). In Scenario II, we assume that costs will decline from year to year, but the relationship between SX and the OEM will not impact the probability of winning the bid (δ=0). Here, we specifically examine the impact of a cost reduction when δ=0.05. In Scenario III, we assume that the relationship between SX and the OEM does impact the probability of winning the bid, but costs do not decline (τ=0). We also explore the impact that competitive advantage might have on profits when τ is 0.15.

Table 1: Comparison of the possible gains through a sequential bidding strategy with those in a single cycle competitive bidding strategy

Bidding Strategy	Sequential Bidding Strategy	Single Cycle Competitive Bidding Strategy
B^{1*} (Millions Dollars)	24.62	25.83
B_1^{2*} (Millions Dollars)	25.36	25.36
B_0^{2*} (Millions Dollars)	25.83	25.83
R^1 (Millions Dollars)	-0.38	0.83
R_1^2 (Millions Dollars)	4.11	4.11
R_0^2 (Millions Dollars)	0.83	0.83
P^1	0.36	0.15
P_1^2	0.65	0.65
P_0^2	0.15	0.15
E(R^1) (Millions Dollars)	-0.14	0.12
E(R_1^2)(Millions Dollars)	0.91	0.35
E(R_0^2)(Millions Dollars)	0.07	0.10
E(R) (Millions Dollars)	0.85	0.57

4.2.1 Scenario I: Competitive Bidding with No Learning or Competitive Advantages

In this scenario, we assume that SX is unable to reduce cost from year to year and the relationship between SX and the buyer does not impact the probability of winning the bid. This scenario happens if SX produces a standard product for a long time and there are many suppliers producing and many customers in the market for the same standard product. In this case, the percentage reduction in costs will be zero and the impact of the relationship between the buyer and SX on the probability of winning the bid will also be zero.

Observation 3: When costs do not decline and the relationship between the supplier and the OEM does not influence the probability of winning the bid (τ=0, δ=0), the sequential and single cycle competitive bidding strategies will yield the same bidding prices as depicted in Equation (14). In this scenario, SX will offer the same bidding price regardless of the relationship between SX and the buyer.

$$B^{1*} = B_1^{2*} = B_0^{2*} = \frac{[\phi_U + \mu_1]}{2} \quad (14)$$

The optimum bidding policy for each state is \$26.50 million and SX's profit is \$1.50 million if it wins the bid. The probability of winning the bid under this scenario is 0.25. In year one, expected profit is \$0.38 million (=1.50*0.25). If SX won the first bid, SX's expected profit in year two will be \$0.09 million (=1.50*0.25*0.25*0.95). The total expected profit over the two bidding cycles will then be \$0.73 million.

Competitive Advantage and Cost Reductions

As mentioned earlier, a supplier can reduce its costs in the second bidding cycle if it wins the first bid. In some cases, the supplier may incur higher start-up costs in the first year of a relationship with an OEM. But fixed costs decline in the second period since start-up costs no longer occur once the relationship between the OEM and the supplier is established. In addition, the supplier may reduce its variable costs as a result of its learning from this established relationship. In this paper, we combine variable cost reductions through learning with the reduction in fixed costs in the second bidding cycle and treat these reductions as the percentage reduction in total costs.

While SX will always benefit from a reduction in its total costs, the impact of the competitive advantage parameter on SX depends on the relationship between SX and the OEM. We assume that CY has established a relationship with the OEM and therefore as δ increases, SX must offer a lower bid price to win. For example if δ is 0.05, SX must offer at least a 5% lower bid price than that offered by CY in the first year. On the other hand, if it wins the first bid, it will accrue competitive advantage benefits. Hence, SX may offer a much lower bid price, and even be willing to lose the first bid in order to gain benefits from the second bid. If SX won the first bid, in year two, SX will win the bid even it offers up to 5% more on its bid price compared to the bid price offered by CY. If SX does not win the first bid, it will suffer from higher competitive advantage in the second year. SX's goal in this case will be to maximize its profit in the second cycle. We assumed earlier that CY will offer a bid price that is between \$22 million and \$28 million. If δ is 0.12, CY wins the bid if CY offers lower or even up to 12% higher bid price. The lowest price that may be offered by SX in this state is \$25 million by making \$0 profit. When SX offers \$25 million, SX can win the bid if CY offers more than \$28 million (=25*1.12). In other words, SX must offer a bid price that is lower than \$25 million to create a chance to win the bid if δ is 0.12. However, SX will not offer a bid price in this state if δ is 0.12 or more since it will lose money.

4.2.2 Scenario II: Impact of a Cost Reduction

In Scenario II, we assume that cost declines from year to year and view the relationship between SX and the OEM under two different δ parameters (δ=0 and δ=0.05). We first investigate the impact of a cost reduction on the bidding prices, the probability of winning the bid, and expected profit in each state and expected total profit over two cycles by changing the percent reduction in total cost from 0 to 0.30 when δ is zero (see left column of Figure 4). If SX is not able to reduce its cost (τ=0), its optimum bidding price will be \$26.5 million in each state. In this case, SX's profit will be \$1.5 million in each state if SX wins the bid and there is a 25% chance that SX will win the bid. Thus, SX's expected profit over two years will reach \$0.73 million.

This cost reduction will not influence the optimum bid price in the second period given that SX did not win the first bid. As the percent reduction in total cost increases, SX will offer more aggressive bid prices in the first bidding cycle to increase its chances of winning the first bid. If total cost declines by 5%, SX's optimum bid price in the first cycle, B^{1*}, will reduce to \$26.32 million (1% reduction) but its probability of winning the first bid will increase to 28% from 25%.

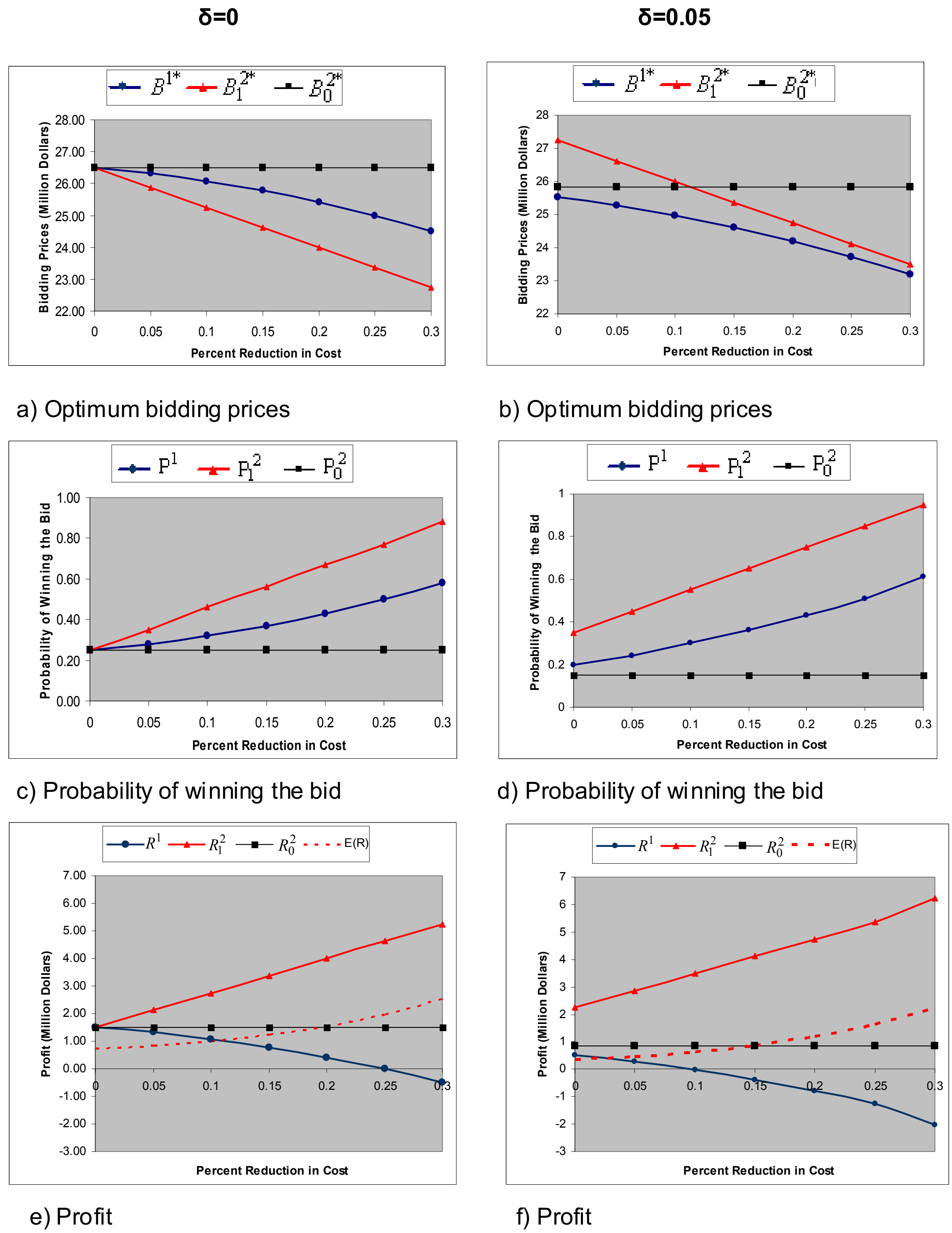


Figure 4: The impact of cost reductions (in percentages)

SX's profit in the first cycle will reduce from \$1.5 million to \$1.32 million. The 5% reduction in cost will result in a 2.5% reduction in B_1^{2*} (B_1^{2*}=\$25.88 million). If SX follows the optimum strategy in this case, the probability of winning the second bid will increase to 35%. Though SX will offer a lower bid price, its profit will increase to $2.13 million due to the cost reduction in this case. SX's expected total profit will increase from $0.73 million to $0.83 million (a 14% increase).

If costs were to decline by 15% (our base case assumption), the optimum bid price in the first cycle will reduce to $25.78 million and the probability of winning the bid will increase to 37%. SX's profit will decline by almost 50% ($0.78 million). But once SX has won the first bid, it will benefit from a 15% reduction in costs in the second year. To take this advantage, SX will reduce B_1^{2*} to $24.63 million by estimating a profit of $3.38 million if it wins the second bid. The probability of winning the second bid in this state will increase to 0.56 (more than a 50% increase). SX's expected total profit will increase to $1.18 million (a 62% increase).

If SX were able to reduce its total costs by 25% or more in the second bidding cycle, it would be willing to lose money to increase its chances of winning the OEM's business. If SX were to reduce its total costs by 30%, it would offer an optimum bidding price of $24.50 million in the first bidding cycle and, on average, will lose $0.50 million in the first cycle if it wins the business from the OEM. But when SX offers its optimum bid price, it will increase its probability of winning the bid in the first cycle to 58%. Once SX has won the first bid, it will offer an optimum bid price of $22.75 million and will make a profit of $5.25 million in the second bidding cycle if it wins. In this case, there will be an 88% chance that SX will win the second bid under the optimum bidding price, and SX's expected total profit over the two bidding years will increase to $2.40 million.

Figure 4- illustrates the impact of a cost reduction on the optimum bidding prices (B^{1*}, B_1^{2*} and B_0^{2*}) in each state. The optimum bid price in the second bidding cycle (B_0^{2*}) given that SX did not win in the first bidding cycle is not affected by a cost reduction. As we consider only a two-period time horizon in this model, winning the second bid will have no impact on winning subsequent business from the OEM, and therefore, cost reduction will not influence B_0^{2*}. On the other hand, as cost reduction increases, SX lowers optimum bid prices of B^{1*}, and B_1^{2*}.

Figure 4-c depicts the impact of a cost reduction on the probability of winning. The cost reduction does not affect the probability of winning the bid in the second cycle given that SX did not win the first bid. As the cost reduction percentage increases, the probability of winning the first bid and winning the second bid given that SX has already won the first bid, will increase.

We also examine the impact of a cost reduction on SX's profits in each state (R^1, R_1^2 and R_0^2) and its expected total profit (E(R)) as depicted in Figure 4-e. The optimum bid price in the second period when SX did not win the first bid is not influenced by the cost reduction, and therefore, the profit in this period is not affected by the cost reduction. The relationships between the impact of a cost reduction and profits in other states are non-linear. As the cost reduction increases, SX makes less profit, or even loses money in the first bidding cycle, but makes more profit in the second period if it wins the first bid. For example, SX would be willing to lose money in the first period if the cost reduction is 25% or more when δ is zero.

Observation 4: As the percentage reduction in cost increases, SX will offer more aggressive (lower) bidding prices in the first bidding cycle to increase its chances of winning the bid.

Observation 5: As the reduction in cost increases, SX will make less profit or even lose in the first bidding cycle, but will increase its probability of winning the first bid.

Observation 6: As the percent reduction in cost increases, SX will offer more aggressive (lower) bidding prices in the second bidding year if SX won the first bid. SX's profit and probability of winning in the second bidding cycle will also increase in this state.

Observation 7: As the percentage reduction in cost increases, SX's expected total profit will also increase when the optimum bidding price is followed.

Competitive Advantage is 0.05

Next, we investigate how optimum bidding decisions are affected by cost reductions when the competitive advantage is 0.05. In this case, even if costs do not decline (τ=0), SX will offer a different price for each state. SX will suffer from a high competitive advantage parameter in its first cycle since its competitor CY has an established relationship with the OEM, but will benefit in the second bidding cycle if it wins the first bid.

If costs do not decline, SX will offer an optimum bid price of $25.51 million in the first cycle and will make a profit of $0.51 million if it wins the bid. Here, there is a 20% chance that SX will win the first bid. If SX wins the first bid, it will offer a higher bid price in the second cycle ($27.24 million). SX's average profit in the second period will be $2.24 million if it wins in the second cycle. The probability of winning the bid will be 0.35. Under these assumptions, SX's expected total profit over two years will be $0.35 million.

As costs decline, SX will offer more aggressive bidding prices in the first year and will increase its chances of winning the bid. If costs decline by 30%, SX will offer an optimum bid price of $23.20 million and will lose $1.80 million if it wins the bid. But it will increase its chances of winning the bid from 20% to 61%. Once SX wins the first bid, its optimum bid price in the second bidding cycle will be $23.49 million. There will be a 95% chance that SX will win the second bid if it won the first bid. Its expected total profit in this case will increase from $0.35 million to $2.22 million.

Figure 4-b shows how optimum bidding decisions are affected by cost reductions when the competitive advantage is 0.05. Since CY obtains a competitive advantage, SX will reduce its bidding price in the first and the second bidding cycles given that SX did not win the first bid. Once SX wins the bid, it will increase its bidding price in the second period since SX will now gain a competitive advantage.

Figure 5 depicts the impact of cost reduction on optimum bidding prices if δ is 0.03. If τ is less than 15%, the optimum bid price in the first cycle (B^{1*}) is lower than that in the second year (B_1^{2*}). Otherwise B_1^{2*} is lower than B^{1*}.

When competitive advantage is 0.05, the probability of winning the first bid and the second bid given that SX has won the first bid will increase as cost declines (Figure 4-d).

We also examined the impact of cost reduction on the profits in each state (R^1, R_1^2 and R_0^2) and the expected total profit (E(R)) as depicted in Figure 4-f. The optimum bid price in the second period when SX did not win the first bid is not influenced by the cost reduction; thus, profit is not affected by cost reductions in this period. The relationship between the impact of cost reductions and profits in other states are non-linear. As the cost reduction increases, SX stands to make less profit or even lose money in the first bidding cycle. SX will make more profit in the second period if it wins the first bid, however.

Observation 8: When competitive advantage is not zero, SX will offer more aggressive (lower) bidding prices in the first period to gain a competitive advantage. For example, SX will be willing to lose money in the first period if its cost reduces by 25% or more when δ is zero. If δ is 0.05, SX will be willing to lose money in the first bidding cycle if cost reduces by 10% or more.

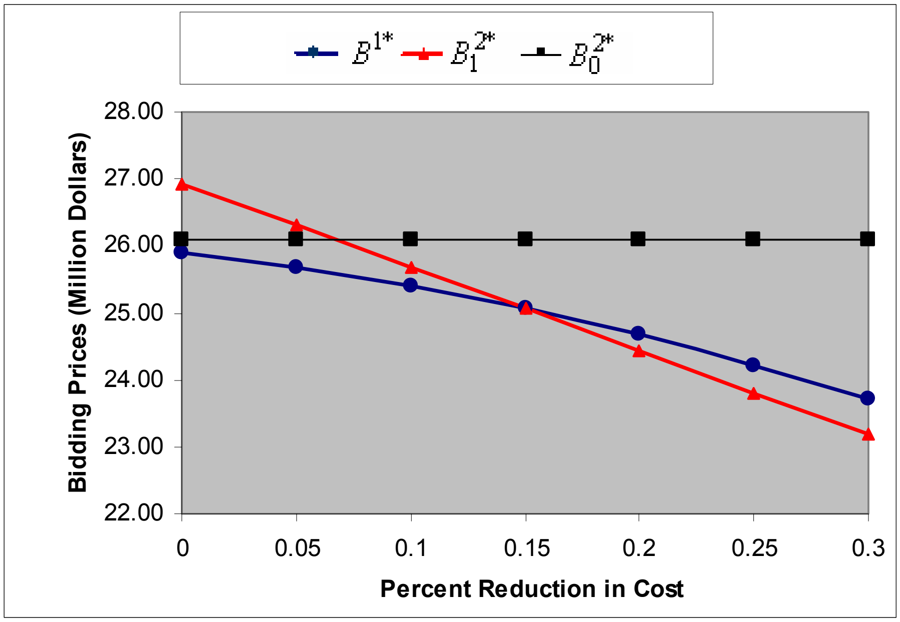


Figure 5: The impact of cost reductions on optimum bidding prices when δ=0.03

4.2.3 Scenario III: Impact of Competitive Advantage

In the third scenario, we studied the impact of the relationship between SX and the OEM on the bidding decisions and their consequences under two different cost reduction parameters: where τ is zero and where τ is 0.15.

No Cost Reduction

We explored the impact of competitive advantage on optimum bidding price, probability of winning the bid, and expected profit as depicted in Figure 6. As we increased competitive advantage, B1* declined significantly, as we had expected. That is, when CY had the competitive advantage over SX, winning the first bid was more difficult for SX, again, as we had expected.

Figure 6-a illustrates the impact of competitive advantage (δ) on the optimum bidding price in each state. As δ increases, B^{1*} and B_0^{2*} will decline and B_1^{2*} will increase. SX will offer more aggressive bidding prices in bidding cycle one to gain a competitive advantage over its competitor in the second period as the impact of competitive advantage on profitability increases.

Observation 9: If δ is more than zero, SX will offer a higher bid price in the second cycle than its first bid price given that it won the first bid.

If competitive advantage is more than 12%, SX can not make money in the second bidding cycle if it did not win the first bid. SX, therefore, would not be willing to offer such a price that is less than the total cost of $25 million in bidding cycle two given that it did not win the first bid.

Figure 6-c illustrates the impact of competitive advantage on the probability of winning the bid. As competitive advantage increases, the probability of winning the second bid if SX has won the first bid will increase. On the other hand, competitive advantage has adverse impact on the

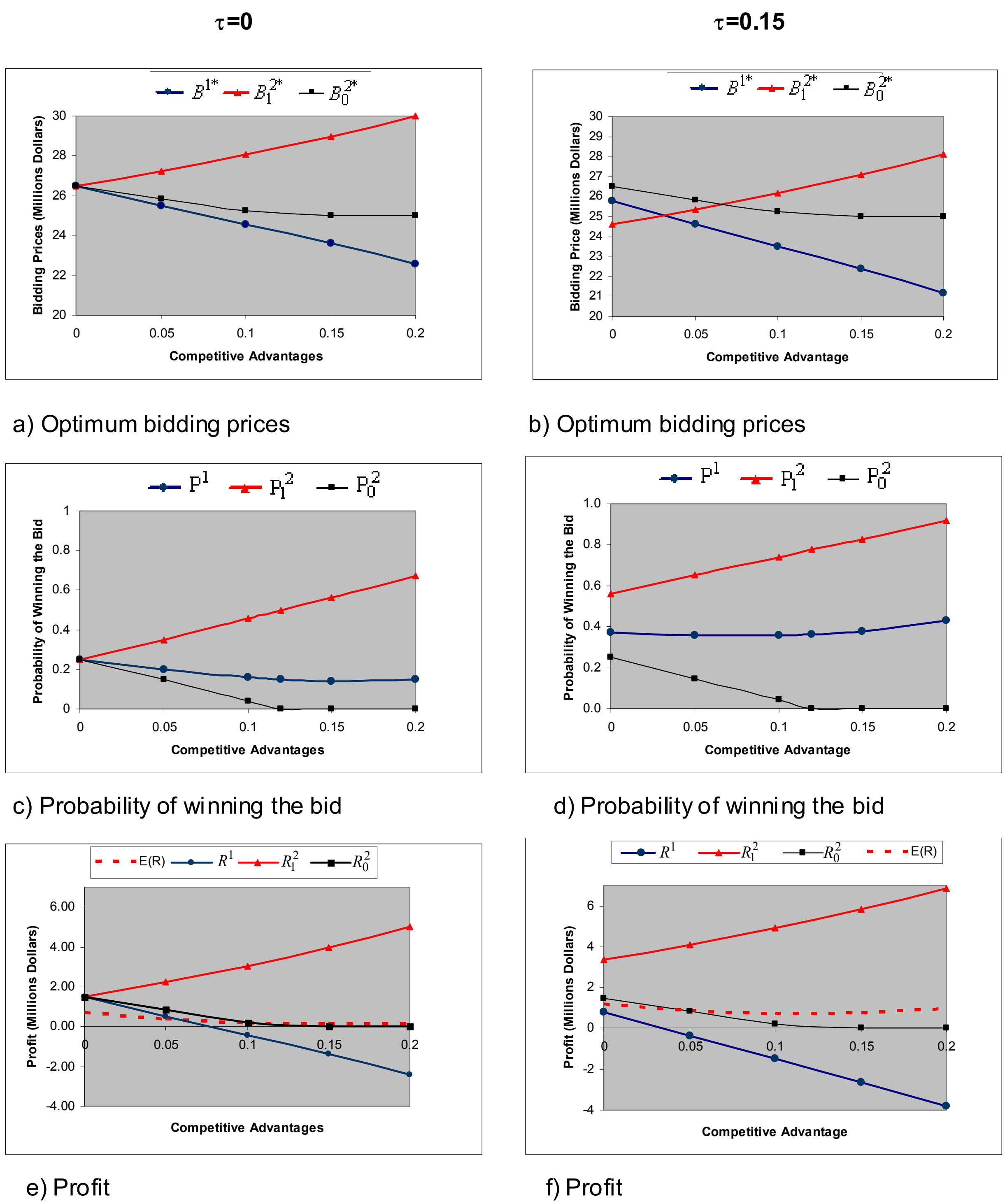


Figure 6: The impact of competitive advantage

probability of winning the second bid if SX has not won the first bid. If competitive advantage is 12% or more, the bid price must be lower than total cost as explained before and therefore SX doesn't offer a bid.

Observation 10: Higher levels of competitive advantage will have an adverse impact on the probability of winning the second bid if SX has not won the first one while it will increase the probability of winning the second bid given that the supplier won the first bid.
Figure 6-e presents the relationship between competitive advantage and profit.

Observation 11: As competitive advantage increases, the profit margin on the first bid decreases while SX makes more profit in the second period once it won the first bid. If competitive advantage is 8% or more, SX will lose money in the first bidding cycle if it wins.

15% Cost Reduction

The impact of cost reduction on the bidding decision, on the probability of winning the bid, profit, and expected total profit is depicted in the right column of Figure 6. If cost is reduced by 15%, SX will reduce its optimum bid prices in states S^1, and S_1^2 but will increase its chances of winning in these states and its expected total profit. As cost is reduced by 15%, SX will make more profit in state S_1^2 and will increase the probability of winning the bid, and therefore, enhancing its expected profit.
Figure 6-b depicts the impact of competitive advantage on optimum bidding prices. If δ is less than 0.03 B_1^{2*} will be lower than B^{1*}.

Observation 12: As δ increases, B_1^{2*} will increase but B^{1*} will decline.

Figure 6-d illustrates the impact of competitive advantage on the probability of winning the bid.

Observation 13: As the competitive advantage parameter increases, the probability of winning the second bid will increase as well if SX wins the first bid.
Figure 6-f presents the relationship between competitive advantage and profit. If competitive advantage is more than 0.03, SX will be willing to lose money in order to increase its chances of getting business and making money in the second bidding cycle.

Observation 14: As competitive advantage increases, the profit margin of the first bid will decrease while SX will make more profit in the second period once it has won the first bid.

4.3 Risk of not Making a Profit

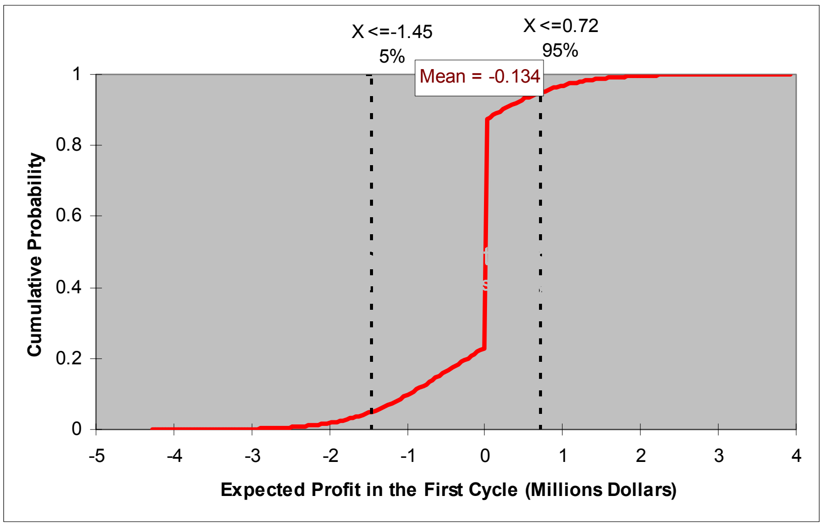
In this paper we used a normal distribution to describe the uncertainty surrounding the forecasted total cost. Since the optimization model maximizes the expected profit, the optimum bidding prices incorporate only the mean of cost (μ_1). Therefore, the impact of uncertainty in cost does not affect the optimum bidding decisions. It is easy to imagine a decision maker who would be uncomfortable with a winning bid that has a significant probability that the company will lose money on the contract even though the expected value is positive.

In this section we use simulation to generate cumulative probability distribution to explore the impact of uncertainty on profits. We start with a base scenario (τ=0.15, δ=0.05). The impact of uncertainty on profit in the first bidding cycle is illustrated in Figure 7-a. SX's expected loss in the first cycle is \$0.134 million. There is 5% chance that supplier may lose \$1.45 million or more and there is 5% chance that SX will make a profit of \$0.72 million or more. The probability that SX loses money in the first bidding cycle is 0.23 when it follows the optimum bidding policy while there is 13% chance that SX makes profit from the first bid.

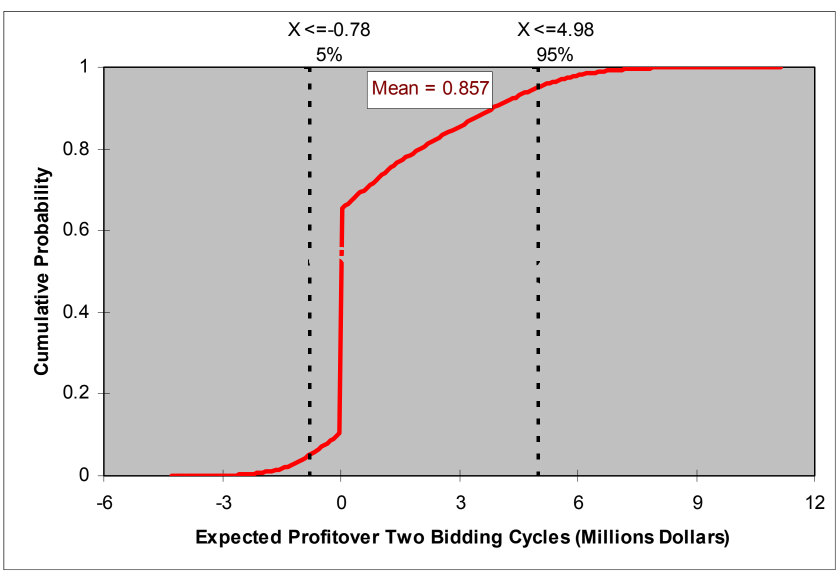
Figure 7-b depicts the cumulative probability distribution of total profit over two years when SX follows the optimum bidding policies. SX's expected total profit is \$0.857 million.

There is 5% chance that SX loses $0.78 million or more and there is 5% chance that SX will make a profit of $4.98 million or more. There is 10% chance that SX loses money over two bidding cycles. The probability making profit over two periods is 34%.

The presentation here is simply a descriptive characterization of the potential losses. A decision maker would use this information to perhaps adjust his bid upwards so as to reduce the risk of losing money. A proposed future research agenda would formalize other types of constraint on the bidding price. We envision adding to the model the right of the decision maker to impose a constraint on a) the maximum potential loss and/or b) the probability of losing money over the two bidding cycles.



a) for profit in the first bidding cycle



b) for total profit

Figure 7: Cumulative probability distribution for profits

5 Model II

In the second model, we assume that the OEM does not allow suppliers to increase the price in a subsequent bidding cycle. Therefore, the bid price in the second bidding cycle must be less than or equal to the bid price in bidding cycle one if SX is able to win the OEM's business in the first bidding cycle. The only constraint that is related to bid price in bidding cycle two in this case is given in equation (15). The objective function is the same as given in equation (10).

B_1^2 <= B1 or - B1 + B_1^2 <=0 (15)

Kuhn-Tucker (K-T) conditions are necessary and sufficient for (B^1, B_1^2 and B_0^2) to lead us to an optimal solution to the constrained bidding problem. Kuhn-Tucker conditions for this problem become

$$1)\ \left\{\phi_U - 2B^1(1+\delta) + (1+\delta)C^1\right\} + \left(\frac{\gamma}{\varphi^2}\right)$$

$$\left\{-B_1^2(1+\delta)\phi_U + (1+\delta)(B_1^2)^2(1-\delta) + (1+\delta)C_1^2\phi_U - C_1^2(1+\delta)B_1^2(1-\delta) + B_0^2(1+\delta)\phi_U\right.$$

$$\left. -(B_0^2)^2(1+\delta)^2 - C^1(1+\delta)\phi_U + C^1B_0^2(1+\delta)^2\right\} + \gamma_1 = 0 \quad (16)$$

$$2)\left(\frac{\gamma}{\varphi^2}\right)\left\{(\phi_U)^2 - \phi_U 2(B_1^2)(1-\delta) + C_1^2(1-\delta)\phi_U\right.$$

$$\left. -B^1(1+\delta)\phi_U + B^1(1+\delta)2B_1^2(1-\delta) - C_1^2B^1(1+\delta)(1-\delta)\right\} - \gamma_1 = 0 \quad (17)$$

$$3)\ B^1(1+\delta)\phi_U - 2B_0^2B^1(1+\delta)^2 - C^1B^1(1+\delta)^2 - \phi_U\phi_L + 2B_0^2(1+\delta)\phi_L - \phi_L C^1(1+\delta) = 0 \quad (18)$$

$$4)\ \gamma_1(-\mathrm{B}_1^2 + \mathrm{B}^1) = 0 \quad (19)$$

Either γ_1 or (-B_1^2+B1) must be zero. We first find optimum bid prices (B^{1*}, B_1^{2*}, and B_0^{2*}) for the unconstrained problem. If B_1^{2*} - B^{1*}<=0 (which satisfies the constraint of the bidding problem we now have) then γ_1 must be zero. Otherwise (-B_1^2+B1) must be zero (B_1^2=B1). Note that Equation (18) is always zero for B_0^{2*}. Therefore, the optimum bid amount for the second bidding cycle given that SX did not win the first bidding cycle's bid (B_0^{2*}) is also optimum for the constrained problem.

Because of the relationship between the constrained and the unconstrained problem, we can find the solution for the constrained problem using the solution of the unconstrained problem. The optimum solution for the unconstrained problem is:

a) If B_1^{2*} - B^{1*}<=0 the solution of the unconstrained problem is also valid for the constrained problem.

b) If B_1^{2*} - B^{1*}>0 then the solution of the constrained problem is

$$B_0^{2*} = \frac{[\phi_U + \mu_1(1+\delta)]}{2(1+\delta)} \tag{20}$$

$$B_1^2 = B^1$$

We solve the problem by replacing B_1^2 in the objective function by B^1 to find the optimum bid amounts B^{1*} and B_1^{2*}. In this case, the objective function becomes

Max

$$\begin{aligned}
E(R) = & \left(\frac{1}{\varphi}\right)\left(\phi_U B^1 - (B^1)^2(1+\delta) - C^1\phi_U + C^1(1+\delta)B^1\right) + \left(\frac{\gamma}{\varphi^2}\right) \\
& \Big\{(\phi_U)^2 B^1 - \phi_U (B^1)^2(1-\delta) - C_1^2(\phi_U)^2 + C_1^2\phi_U B^1(1-\delta) - (B^1)^2(1+\delta)\phi_U \\
& + (B^1)^3(1+\delta)(1-\delta) + B^1(1+\delta)C_1^2\phi_U - C_1^2(B^1)^2(1+\delta)(1-\delta) + B_0^2 B^1(1+\delta)\phi_U \\
& - B^1(B_0^2)^2(1+\delta)^2 - B^1(1+\delta)C^1\phi_U + C^1 B^1 B_0^2(1+\delta)^2 \\
& - B_0^2\phi_U\phi_L + (B_0^2)^2(1+\delta)\phi_L + \phi_L C^1\phi_U - \phi_L C^1 B_0^2(1+\delta)\Big\}
\end{aligned} \tag{21}$$

The partial derivative of the objective function with respect to B^1 is

$$\begin{aligned}
f_1 = \frac{dE(R)}{dB^1} = & \left(\frac{1}{\varphi}\right)\Big\{\phi_U - 2B^1(1+\delta) + (1+\delta)C^1\Big\} + \left(\frac{\gamma}{\varphi^2}\right)\Big\{(\phi_U)^2 - \phi_U 2(B^1)(1-\delta) \\
& + C_1^2(1-\delta)\phi_U - 2B^1(1+\delta)\phi_U + 3(B^1)^2(1+\delta)(1-\delta) - C_1^2(1+\delta)\phi_U - 2C_1^2(1+\delta)B^1(1-\delta) + \\
& B_0^2(1+\delta)\phi_U - (B_0^2)^2(1+\delta)^2 - C^1(1+\delta)\phi_U + C^1 B_0^2(1+\delta)^2\Big\} = 0
\end{aligned} \tag{22}$$

When we organize Equation (22) in a standard second order nonlinear equation format, we get

$$\begin{aligned}
& \left(\frac{\gamma 3(1+\delta)(1-\delta)}{\varphi^2}\right)(B^1)^2 + \left\{\left(\frac{-2(1+\delta)}{\varphi}\right) + \left(\frac{\gamma}{\varphi^2}\right)[-\phi_U 2(1-\delta) - 2\phi_U(1+\delta) - \right. \\
& \left. 2C_1^2(1+\delta)(1-\delta)]\right\}B^1 + \left(\frac{\phi_U + C^1(1+\delta)}{\varphi}\right) + \left(\frac{\gamma}{\varphi^2}\right)\Big\{(\phi_U)^2 + C_1^2\phi_U(1-\delta) + \\
& (1+\delta)C_1^2\phi_U + B_0^2(1+\delta)\phi_U - (B_0^2)^2(1+\delta)^2 - (1+\delta)C^1\phi_U + C^1 B_0^2(1+\delta)^2\Big\} = 0
\end{aligned} \tag{23}$$

One of the B^1 values that make the second order derivative with respect to B^1 (Equation

(24)) negative is the optimum bid price for B^1. We check the optimality condition numerically using this equation.

$$f_{11} = \frac{d^2E(R)}{(dB^1)^2} = \left(\frac{\gamma 3(1+\delta)(1-\delta)}{\varphi^2} \right) B^1 + \left(\frac{-2(1+\delta)}{\varphi} \right) + \left(\frac{\gamma}{\varphi^2} \right)$$
$$\left[-2\phi_U (1-\delta) - 2(1+\delta)\phi_U - 2C_1^2(1+\delta)(1-\delta) \right] = 0 \qquad (24)$$

In summary, we use a two-phased approach to find the optimum solution for the constrained nonlinear problem. In phase one, we find a solution for the unconstrained problem that is presented in Section 4. If B_1^{2*} is less than or equal to B^{1*} the solution satisfies the constraint and therefore the solution of the unconstrained problem is valid for the constrained problem. If B_1^{2*} is larger than B^{1*} we use the Kuhn-Tucker conditions to find the optimum solution. These conditions require that B_1^2 be equal to B^1 when it is applied to our problem. In this case, the optimum value of B_0^2 is also optimum for the constrained problem.

We demonstrate the solution for the constrained problem using the example presented in Section 4. Here, we add only the constraint given in equation (15). The optimum bid price for the second bidding cycle ($25.36 million) is larger than the bid price in the first bidding cycle ($24.62 million). We, therefore, solve the problem using the Kuhn-Tucker conditions in the second step. There are two stationary points for B^1: $31.23 million and $24.80 million.
We checked the optimality condition using second order derivation and found that optimum values of B^{1*} and B_1^2* are $24.80 million. In the first bidding cycle, the probability of winning the bid declines from 36% to 33% compared to the unconstrained problem. Note that B_0^2* is $25.83 million. Total expected profit over two cycles of bidding years declines from $0.85 million (unconstrained problem) to $0.83 million.

Observation 15: If the OEM doesn't allow a supplier to increase bid price in subsequent years, the supplier's expected total profit will be lower or equal to the expected total profit of unconstrained problem.

6 Conclusions and Future Research

Sequential bidding is rapidly becoming the norm in competitive bidding situations in many manufacturing industries, such as the auto industry, where suppliers and OEMs alike are under continuous pressure to lower costs while improving customer responsiveness. Yet most studies in the bidding literature offer solutions to bidding problems in unique, single cycle competition contexts. In this paper, we develop two models for bidding in a sequential context. Our approach is straightforward. We derive analytical solutions for sequential bidding over two cycles of bidding years. The first model assumes that SX may increase its bid price in the future once it has won the bid in the first bidding cycle. This assumption is becoming invalid in some contracts since OEMs are increasingly disallowing suppliers to increase their prices in subsequent contracts. Our second model introduces this situation deals by incorporating the assumption that the bid price in bidding cycle two must be less than or equal to the bid price in the first bidding cycle.

Our results suggest that a supplier must consider subsequent bids when it bids on an initial contract, if there is a linkage between the contracts. As SX considers the bidding problem over a longer time period, it can make more efficient decisions by increasing the probability of winning the bid and increasing its annual average expected profit. When SX is able to learn from its past experiences and its startup costs are significant, it may be willing to forego profit or lose money in the first bidding cycle of a relationship to begin and nurture a longer term relationship with a chosen OEM. The supplier can then bid with greater confidence as its learning-based competitive advantage increases over its most relevant competitors.

Like all research, our model is imperfect. It assumes that there is only one relevant competitor, for example, when in fact, there are typically multiple competitors in many bidding situations; hence, it should be extended to include multiple competitors and multiple response scenarios to competitive bidding. We also assume that CY's bidding strategy will not change if it wins or loses in the bidding, when in fact, many behavioral ramifications will result when it does win or lose in the bidding game; it may reduce its bid price in the future, for example. These limitations, however, should not detract from the potential contribution of our work, but should be viewed as ideas for future research on this exciting dimension of industrial organization and engineering.

7 References

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