Int. J. Production Economics 145 (2013) 199–207

Contents lists available at SciVerse ScienceDirect

Int. J. Production Economics

journal homepage: www.elsevier.com/locate/ijpe

Using Nash bargaining to design project management contracts under cost uncertainty

Steven A. Lippman, Kevin F. McCardle, Christopher S. Tang *

UCLA Anderson School of Management, 110 Westwood Plaza, Los Angeles, CA 90095-1481, USA

ARTICLE INFO

Article history:
Received 27 September 2012
Accepted 19 April 2013
Available online 29 April 2013

Keywords:
Project management
Nash bargaining
Fixed-price contracts
Cost-plus contracts

ABSTRACT

In the design of procurement contracts, cost sharing, wherein the contractor receives a fixed fee plus a fraction of his cost, is common when the cost for completing the project is uncertain. We determine the best cost-sharing contract between a risk-neutral project manager and a risk-averse contractor when negotiation proceeds in accord with Nash bargaining. We examine the characteristics of the contract when the contractor can invest to reduce the mean and/or the uncertainty of the project cost. We show that cost-plus contracts dominate fixed-price contracts as well as all other cost-sharing contracts. In order to extend our analysis to the case when the value of the project itself is uncertain, we employ the recent method of embedded Nash bargaining. Finally, we generalize our main result by allowing an asymmetric Nash bargaining solution.

1. Introduction

The inherent uncertainty in the cost of completing a project in industries such as construction, defense, management consultancy, and hardware and software development compels the project manager to design a contract that provides incentives to the contractor to work efficiently so as to minimize the cost of completing the project, with some regard for risk. In fact, survey studies found in Simister (1994) and in Akintoye and MacLeod (1997) indicate that contract design is the second most important mechanism for managing projects with uncertain cost.[1] Some papers in the project management literature, notably Turner and Simister (2001), suggest the use of specific contract terms, but there is a notable lack of quantitative analysis to justify these suggestions.[2]

The goal of this paper is to investigate cost-sharing contracts between a risk-neutral manager and a risk-averse contractor when the outcome of their negotiation is in accord with Nash bargaining.[3]

Economists have studied contract design for at least 40 years (see McCall, 1970). In considering a multitude of issues, they have produced an enormous literature with some emphasis on moral hazard, adverse selection, signaling, asymmetric information, contracting in a dynamic setting, and contracting in competitive markets. (See the near encyclopedic book by Bolton and Dewatripont, 2005 for background and more than 500 references.)

Of particular relevance to our work, Bajari and Tadelis (2001) argue that it is not practical to use a menu (i.e., a list) of contracts to entice the contractor to reveal his hidden information by selecting a contract from the menu (e.g., Laffont and Tirole, 1993). Instead, they argue that it is more practical to use either a *fixed-price* or a *cost-plus* contract, especially when managing projects in the construction industry where use of such contracts is a commonplace (see Bajari and Tadelis, 2001; Bajari et al., 2009; Bartholowmew, 1998; Ibbs et al., 1986). Under a fixed-price contract, the manager makes a fixed payment (an amount agreed upon before the project commences) to the contractor upon project completion; under a cost-plus contract, the manager pays a fixed fee plus all relevant costs incurred by the contractor. Clearly, use of a cost-plus contract finds both parties carefully monitoring and auditing the costs.

* Corresponding author. Fax: +1 310 206 3337.
E-mail addresses: slippman@anderson.ucla.edu (S.A. Lippman), kmccardl@anderson.ucla.edu (K.F. McCardle), chris.tang@anderson.ucla.edu, ctang@anderson.ucla.edu (C.S. Tang).

[1] The survey studies found in these two papers reveal that, after insurance, project contract design is the most common mechanism for managing projects with uncertain cost. Insurance is essentially a post-event compensatory mechanism. In contrast, contract design is a proactive approach to managing uncertain projects.

[2] As discussed in Turner and Simister (2001), it is not clear which types of project contracts are effective in the face of uncertainty. By applying some basic concepts of organizational theory such as conflict, cooperation, and transaction cost analysis, they come to suggest two types of cost-based contracts for managing risky projects. The first is the *cost-plus contract*: the project manager pays the contractor the actual cost incurred plus a margin (either a fixed amount or a percentage of the actual cost). The second is the *alliance contract*: the project manager works closely with the contractor to improve productivity and reduce cost.

[3] Because Nash bargaining is crucial for this paper and many readers may not be familiar with it, we provide a brief introduction in Appendix A.

0925-5273/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ijpe.2013.04.036

In this paper, we analyze the full class of *cost-sharing* contracts under which the payment made to the contractor equals the sum of a fixed fee α plus a fraction β of the contractor's total cost. In addition to fixed-price (when $\beta=0$) and cost-plus contracts (when $\beta=1$), this class of contracts includes contracts under which both parties share the uncertain cost (i.e., when $\beta\in(0,1)$).[4] While cost-sharing contracts have been examined in the economics literature, our exploration of the optimal contract design has three fundamental differences.

First, instead of using the traditional Stackelberg game in which the manager acts as the leader and specifies the contract (that is, he alone selects the pair (α,β)), and the contractor acts as the follower by responding to the contract offered by the manager (e.g., Kwon et al., 2010a), we model the process of contract selection as the outcome of Nash bargaining. What is particularly appealing is that the details of the negotiation process in our model – a game in which the players act together when each player's purpose is to maximize his own utility or gain – do not need to be specified. The possibilities in bargaining are complex beyond description. By comparison, in a non-cooperative game, the rules of the negotiating process are specified in unctuous detail.[5] We view the Nash bargaining method of contract design as more realistic than the "take-it-or-leave-it" contract that results from a Stackelberg game; this realism especially holds in the construction industry. For instance, the empirical study conducted by Bajari et al. (2009) found that nearly half of the private sector building contracts awarded in Northern California during the years 1995–2000 were negotiated.[6]

Second, instead of the manager using cost sharing to entice the contractor to exert more effort to reduce the project cost,[7] in our model the manager and the contractor jointly determine how much to invest and how to share the cost of an investment that reduces the mean and/or the variance of the project cost. Such investments include, for example, process re-engineering, enhanced structural design, and the use of better construction equipment for a construction project.

Third, in addition to project-cost uncertainty, we extend our analysis to the case when both the value of project and the cost of the project are uncertain.

Given a value v for the project and a contract specified by a pair (α,β), the project manager and the contractor each receive an expected utility if the contract is accepted. They each receive a different, and by assumption smaller, utility if the contract is not accepted: this is known as the disagreement payoff. The outcome of Nash bargaining maximizes what we call the *Nash product*: the product of the two net gains from accepting the contract, each measured in the party's utility. The contract (α^*,β^*) that maximizes the Nash product produces the Nash bargaining solution to this problem of contract design. Nagarajan and Sosic (2008) provide a recent review of the operations literature that employs Nash bargaining and other cooperative solutions for contracting and profit sharing in a supply chain. Their review uncovers no publication in which a cooperative approach to project management is employed; in fact, a Stackleberg approach predominates this literature (see Kwon et al., 2010a, 2010b, for an example).[8] Rather than using a Stackleberg model, our paper introduces the less-familiar Nash bargaining framework to project management.

Employing the Nash bargaining solution, we determine the fixed fee α and investment level k for any cost-sharing contract with a given β, and we provide appropriate comparative statics. Then we specifically consider both fixed-price and cost-plus contracts. Not only does the cost-plus contract selected via Nash bargaining dominate all fixed-price contracts but also it dominates all cost-sharing contracts. In fact, the cost-plus contract is robust in the sense that it maximizes the total channel profit.

Our focus in the first part of the paper is on the symmetric Nash bargaining solution, i.e., each of the parties is assumed to have equal bargaining power. We do, however, assume that the manager is risk neutral and the contractor is risk averse. As noted in Nagarajan and Sosic (2008), differing risk attitudes yields a form of differential bargaining power: the more risk-averse decision maker has less bargaining power. Methods for assessing an individual's risk aversion are well established (see for instance, Delquie, 2008); such is not the case for bargaining power. With that said, in the penultimate section we extend our main result to allow for differential power: the relevant concept is the asymmetric or generalized Nash bargaining solution (Harsanyi and Selten, 1972).

We also extend our analysis to examine the case when the value of the project is also uncertain. Applying the embedded Nash bargaining approach developed in Lippman and McCardle (2004, 2012), we determine the unique cost-plus contract that results from embedded Nash bargaining. We show that both parties are made better off by reaching agreement before the value of the project is realized: the project manager pays a lower (expected) amount, and the contractor receives a greater expected utility from avoiding the risk.

This paper is organized as follows. Section 2 presents our model along with the problem formulation. In Section 3, we analyze the cost-sharing contract negotiated via Nash bargaining for any given β in the interval $[0,1]$. We establish a key result in Section 4: the cost-plus contract produced by Nash bargaining dominates all other cost-sharing contracts. In Section 5 we employ embedded Nash bargaining to extend our model to the case when the value of the project is uncertain. Section 6 contains the extension to asymmetric Nash bargaining. This paper concludes in Section 7.

2. The model

Consider a project manager (manufacturer) for whom the value of a specific project when complete is V. We begin by assuming that the value of the project is fixed, $V=v$, though in Section 5 we allow for V to be random. The project will be carried out by a contractor (supplier). The cost X of completing the project is uncertain. We assume $X\sim Normal(\mu,\sigma^2)$, the distribution of X is common knowledge, and its realized value is verifiable by both parties. In our static analysis with perfect information, we assume that monitoring is sufficient to eliminate moral hazard. Furthermore, we assume that μ is sufficiently large relative to σ so that

[4] This class of contracts is known as "incentive" contracts in the contract theory literature (e.g., Hiller and Tollison, 1978; McCall, 1970); in the project management literature, this class is known as the "cost-plus incentive fee" contract (e.g., Al-Subhi Al-Harbi, 1998). When $\beta<1$, the contractor has an incentive to control costs. Hiller and Tollison (1978) investigated the benefit of such cost sharing in defense contracts while Al-Subhi Al-Harbi (1998) effected a numerical examination of the impact of β on expected utility of the firm and the contractor.

[5] For example, one possible set of rules is that the players make alternating take-it-or-leave-it offers, a game made exceedingly popular in Rubinstein (1982).

[6] Besides negotiated contracts, Bajari et al. (2009) reported that 18% of the jobs were let on an open bidding process while the rest were awarded on invited bids from pre-selected contractors.

[7] In Kwon et al. (2010a), additional effort decreases the time until project completion.

[8] The reader is referred to Cachon (2003) and Tang (2006) for two comprehensive reviews of the supply contract literature. In a different context, Gurnani and Shi (2006) employ Nash bargaining to examine supply contracts with uncertain delivery dates.