November 2003

Delegating Procurement to Experts*

Abstract

Buyers frequently delegate purchase decisions to sellers who are better informed about supply options and the cost of service. This paper analyzes how buyers optimally contract with sellers who vary in their expertise at prescribing service. We show that the most expert suppliers offer the greatest variation in advice. Buyers benefit from dealing with experts provided they contract sequentially whereby terms are negotiated gradually as the supplier acquires information.

Chifeng Dai Department of Economcs, University of Florida,

Tracy R. Lewis Fuqua School of Business, Duke University

*We we thank seminar participants at the 2003 Summer Econometics Society Meetings and the University of Florida for their comments on an earlier version of this paper.

1 Introduction

Procurers of goods and services frequently delegate their purchase decisions to suppliers. There are several explanations for this behavior. It may be necessary for buyers to rely on suppliers to recommend credence goods, which consumers are not qualified to evaluate. ((see Biglaiser (1993), Emmons (1997), Taylor (1995) and Wolinski (1993). Still, buyers often delegate to suppliers, the purchases of experience goods, which they can evaluate. This arises because sellers are better informed than buyers about the availability and cost of different supply options. For instance a home owner may consult an insurance agent to proscribe the type and level of coverage to insure against theft, fire, and accidental damage. Or, a procurer of communication services for a large corporation may rely on an information technology expert to estimate costs and recommend services to establish communication within the corporation.

While delegation of purchase decisions is useful, it does pose some problems for the procurer. For instance, the buyer may be unable to observe the supplier's expertise at forecasting cost. Further, the buyer may be unable to assess the accuracy of the supplier's forecast ex post, if he can't observe the supplier's actual costs. Added to this is the possibility that a privately informed supplier may recommend service to maximize his profits rather than the buyer's surplus. One often proscribed remedy is to separate the diagnosis from the supply of service. This rarely occurs in practice, though, as separating tasks dampens incentives for the expert to make accurate prescriptions of service. Another reason is that prescribing and supplying service may be complementary and therefore more costly to perform independently.

This paper is motivated by the following questions. How do procurers contract with suppliers who privately know their abilities to forecast cost and to prescribe service? What devices and sequence of negotiation, are used to induce suppliers to provide accurate estimates of supply costs and to prescribe services most beneficial for the buyer? When suppliers have similar but uncertain costs, what is the buyer's preference for contracting with experts who vary in their ability to forecast future costs of supply?

To address these questions we extend the existing incentive contracting model to settings where the supplier's private information at contracting time is his ability to predict the eventual costs of supply. Starting with the seminal analysis of Baron and Myerson (1982), most studies focus on contracting with sellers who are perfectly and privately informed at the time they contract[1]. In contrast we model a setting where suppliers are privately, but imperfectly informed of their costs at the time of contracting. We assume suppliers differ in their expertise at forecasting costs, and they privately know their forecasting ability at the time of contracting. We model a sequential contracting process, where the supplier chooses terms gradually over time as as he receives more accurate forecasts of cost. Based on these forecasts the supplier prescribes a quantity of service for the buyer to purchase.

Our analysis begins by defining what constitutes expertise in forecasting. Since all suppliers are presumed to draw their costs from the same distribution, they are distinguished only by the forecast of costs that they receive. Intuitively it seems that forecasts that track or systematically vary with actual costs are more accurate. When forecasts are relatively constant and invariant to actual costs, sellers are unable to adjust their supply decisions to take advantage of better cost information. Our findings confirm this intuition in the following sense. We find sellers prefer receiving more varied forecasts that enable them to earn greater surplus for any given supply contract. This ranking provides an ordering of forecast structures satisfying Rothschild's and Stiglitz's (1970) mean preserving spread. That is, for a given distribution of actual costs, suppliers prefer one frequency of forecasts to another if it is a mean preserving spread.

To the extent that buyers delegate purchases to sellers, one might naturally presume buyers benefit from expert advice. After all, experts can prescribe more efficient levels of services to the buyer. But, they command greater information rents from buyers in return. What we find is that the buyer's ability to benefit from expert advice depends on the contracting sequence employed. When all contract terms are negotiated after the expert has observed his forecast, the buyer may benefit little or not at all by this advice. An informed seller may extract too much rent for the buyer to benefit from his superior advice. However when contract terms are determined gradually as the expert acquires information about supply conditions, we find the buyer always benefits from dealing with expert sellers.

The buyer's ability to benefit from expert advice depends on the supply contract he employs to delegate purchases. We demonstrate below, that the buyer optimally offers different supply contracts to sellers with varying expertise. Interestingly we discover, that the contracts differ by the amount of decision authority the supplier is delegated. Under the expert supply arrangement the seller is free to select the efficient level of service based on his forecast of cost. In contrast, under the non expert supply agreement, the seller's ability to adjust supply to his forecast of costs is constrained by the buyer. Offering different contracts

[1] See Laffont and Tirole (1993) for a comprehensive review of this literature.

with varying degrees of delegation authority, allows the buyer to screen suppliers by their ability to forecast. Naturally the expert prefers the contract with the greatest delegation authority. This screening of suppliers is precluded of course, when sellers already know their forecast before contracting begins.

Before proceeding we indicate how our findings relate to previous work. At a general level this study relates to the large and growing literature on delegation in agency relationships. Early papers in this area by Holmstrom (1984) and Armstrong (1994) analyze how to optimally delegate decisions to an exogenously endowed expert whose preferences are imperfectly aligned with the principal. These studies show in the absence of payments, it is desirable to confine experts' decisions to certain areas. Our analysis extend these studies by considering how payment provisions, along with decision restrictions may improve delegation. Aghion and Tirole (1997) and Szalay (2002) consider settings where an agent's expertise is acquired. They describe how the degree of decision authority afforded the agent determines an expert's acquisition of information. Our analysis shows in a procurement setting, it is the targeting of compensation to supply levels that determines incentives for sellers to acquire expertise.

More closely related to our analysis are several recent papers that investigate information acquisition in procurement environments. Cremer and Khalil (1992) and Cremer et al (1998a) analyze how supply contracts are modified to mitigate the acquisition of non productive information by sellers to increase their bargaining power. Our analysis, in contrast focuses on the acquisition of productive knowledge that is useful for prescribing service to buyers. In this respect our analysis is most closely related to recent studies by Cremer et al (1998b), Lewis and Sappington (1993a,b, 1994, 1997) and Sobel (1993). Together these papers examine how contracts are designed to accommodate differently informed agents as well as to manage the acquisition of information by these agent.[2] Our analysis studies similar issues, but in settings that incorporate more general information structures and allow for sequential contract negotiations. We show that allowing for variations in the timing of contract negotiations and partial information acquisition leads to very different analysis of supply agreements with distinct implications for how buyers value expert advice, as compared to previous studies.[3]

The remainder of the paper is organized as follows: Section 2 lays out our general model

[2] In a related study, Crocker and Snow (1992) investigate the question of how to ration information to agents, to prevent them from wasteful signalling of their abilities in the marketplace.

[3] Coutry and Li (2000) and Riordan and Sappington (1987) similarly investigate sequential contracting, where agents are assigned different contracts depending on their privately known distributions of preferences. The expertise of the agent, however, is not an issue in these analyses.

and demonstrates supplier preferences for variable forecasts. In section 3 we characterize optimal supply contracts. We demonstrate the optimality of limited delegation contracts that limit the decision authority of non expert suppliers. The preferences of procurers for dealing with expert forecasters is studied in Section 4. There we also examine procurer preferences for informing suppliers about their forecasting ability. Section 5 concludes with a summary of results and thoughts for extensions.

2 Model

2.1 Description of Buyer and Expert Suppliers

A risk-neutral buyer, B, contracts with a risk neutral seller, S, to obtain some quantity (or quality) , $q \geq 0$, of a good or service. The buyer's known valuation for the product, $V(q)$, is an increasing and strictly concave function of q. The buyer's net surplus from the purchase is $W = V(q) - T$, where T is $B's$ payment to S.

A seller's actual cost of supplying $q \geq 0$ is $C(x, q) = xC(q)$, where $x \in X = [\underline{x}, \overline{x}]$ is a shift parameter that determines cost. Possible interpretations of x are that it is an index of the materials cost, or a measure of the difficulty of designing the required good which determines production cost. We assume $C(q)$ is smooth with $C'(q) > 0$, $C''(q) \geq 0$, and $C(0) \geq 0$.

Sellers draw their cost parameter, x, from the same increasing, absolutely continuous distribution $G(x)$. Since all sellers draw their actual costs from the same distribution, they all have the same ex ante expected cost of supply for any output level where $\hat{x} = E_X x$ is the ex ante expected unit cost. However, sellers differ exogenously in their ability to predict supply costs. We assume each seller observes a signal denoted by $\tilde{x} \subset X = [\underline{x}, \overline{x}]$. The signal observed is the conditional expected value of costs so that $\tilde{x} = E(x \mid \tilde{x})$.[4] A seller's information structure is given by $F^i(\tilde{x} \mid x)$ which is his signal distribution conditional on actual cost, x. The seller's marginal distribution of signals $F^i(\tilde{x}) = E_X F^i(\tilde{x} \mid x)$ is computed using $G(x)$ the prior distribution of costs. The signal distribution may be discrete, continuous, or mixed, so we denote $dF^i(\tilde{x})$ as the density or probability mass at $\tilde{x}$.

A seller's ability to forecast is characterized by the distribution of signals, $F^i(\tilde{x})$,he receives. At the time of contracting S privately knows what distribution, $F^i(\tilde{x})$, he has

[4] This is without loss of generality, provided it is possible to compute the expected value of x conditional on observing any informative signal z.

inherited, where F^i is drawn with probability $\mu_i \geq 0$ from the set of possible distributions $\{F^i()\}_{i=1,...,N}$. For the most part we assume $N = 2$, implying a seller may either be an "expert" or "non expert" denoted by S^e or S^n, respectively. Below we specify the relationship between $F^e(\tilde{x})$ and $F^n(\tilde{x})$ that defines the seller's degree of expertise.

To complete our model, we specify the timing and contractual relation between B and S as follows: (1) S privately learns his distribution $F^i(\tilde{x})$. (2) B offers S a set of contract menus $M^i = \{T^i(\tilde{x}), q^i(\tilde{x})\}$ for $i = e, n$ conditioned on the seller's type i and his eventual forecast, $\tilde{x}$. (3) Each seller S^i selects his preferred menu M^i given his private knowledge of F^i. (4) S^i observes his forecast, $\tilde{x}$, and selects a desired option $(T^i(\tilde{x}), q^i(\tilde{x}))$ from M^i. (5) Exchange occurs according to the contract terms.

Before proceeding we comment on some noteworthy features of our model. First, notice we specify contracting as a sequential process. Sellers initially select a preferred supply schedule based on private knowledge of their forecast ability. Later after observing their forecast they choose an option from their supply schedule. This contrasts with most earlier analyses that presume the supplier does not agree to the contract terms until after he has privately observed all the information he can acquire.[5] But, delaying agreement is clearly detrimental to the buyer. His ability to bargain is diminished as the seller acquires more information about cost. Consequently it seems most reasonable to presume buyers will negotiate sequentially with sellers whenever possible. In some settings however, sequential contracts may be precluded when the parties are unable to commit to long term agreements.[6] The analysis to follow demonstrates the central importance of sequential contracting in determining the willingness of buyers to delegate supply decision to experts.

Second, our current model assumes sellers' forecast ability is exogenously. The possibility that suppliers must invest to acquire expertise is examined in Sections 3 and 4. There we demonstrate how inducing suppliers to acquire expertise may be easier when the corporate buyer contracts out instead of obtaining services from divisions within the firm.

Third, we abstract from career concerns of forecasters in the current model. Later we consider how suppliers may wish to manipulate their forecasts to give the appearance of being an expert for future clients.

[5] Exceptions are Courty and Li (2000) and Riordan and Sappington (1987) who also study sequential contracting in procurement.

[6] Chung (92) and Stole (92) discuss how the ability of parties to commit to long term agreements is limited by constraints on financial liability and legal provisions for contract breach.

2.2 Supplier Preferences for Information Structures

A contract, $M = \{T(\tilde{x}), q(\tilde{x})\}$, consists of a payment-quantity pair for all $\tilde{x} \in X$. Notice the contract is extended to cover all possible forecasts $\tilde{x} \in X$ that the population of sellers may observe, even though a particular supplier may observe only a subset of these forecasted values. This permits us to readily compare different forecast structures without a loss of generality.

Each supplier S^i is characterized by the information structure he inherits, $F^i(\tilde{x})$. $S^i s$ expected surplus, $U^i(M)$, is

$$U^i(M) = E^i_{\tilde{x}} U^i(\tilde{x} \mid M) \tag{1}$$

where $E^i_{\tilde{x}}$ is the expectation over $\tilde{x}$ taken with respect to F^i and,

$$U^i(\tilde{x} \mid M) = \max_{\tilde{x}' \in X} T^i(\tilde{x}') - \tilde{x}C(q^i(\tilde{x}')) \tag{2}$$

is $S^{i\prime}s$ net surplus under contract M given realization $\tilde{x}$. We say a supplier prefers one distribution F^e to another F^n for the set of feasible contracts M, if $U^e(M) \geq U^n(M)$ so that the expected surplus is greater under F^e than F^n. The set of feasible contracts M imposes some structure on the supplier's surplus function allowing us to represent preferences for forecast distributions in terms of well known stochastic dominance relations, as we demonstrate below.

A contract is feasible (or implementible) provided it is *incentive compatible* and *individually rational*. Incentive compatibility requires the supplier to truthfully report his forecast so that $\tilde{x}' = \tilde{x}$. Individual rationality requires $U^i(M) \geq 0$ implying the seller agrees to supply service under the contract terms.[7] A well known characterization of feasible contracts is the following:

Lemma 1: *A contract M is feasible if and only if,*

(a) $U^i_{\tilde{x}}(\tilde{x} \mid M) = -C(q^i(\tilde{x})) \leq 0$

(b) $q^i(\tilde{x})$ *is non increasing*

(c) $U^i(M) \geq 0$

[7] Here we assume the supplier commits to ex ante terms of supply given in the menu M. In contrast, in some settings an expost participation constraint may require $U^i(\tilde{x} \mid M^i) \geq 0$ for all $\tilde{x}$ to insure the supplier's participation. In these instances, the procurer may collect an initail payment at the time of contracting to compensate the buyer for the additional surplus it cedes to the supplier to satisfy ex post participation. constraints.

Proof: The proof, which follows standard arguments (see Fudenberg and Tirole(1991)), is omitted.

According to Lemma 1 feasible contracting requires the supplier's surplus, $U^i(\tilde{x} \mid M)$, to be decreasing in $\tilde{x}$. A further property of the surplus function imposed by feasible contracting is recorded in :

Lemma 2 *$U^i(\tilde{x} \mid M)$ is convex in $\tilde{x}$ for all feasible contracts M.*

Proof: For all $\tilde{x}', \tilde{x}'' \in X$ and $\lambda \in [0,1]$ we have,

$$\begin{aligned} U^i(\lambda\tilde{x}' + (1-\lambda)\tilde{x}'' \quad &\mid \quad M) \qquad (3) \\ &= T(\lambda\tilde{x}' + (1-\lambda)\tilde{x}'') - (\lambda\tilde{x}' + (1-\lambda)\tilde{x}'')C\left(q\left(\lambda\tilde{x}' + (1-\lambda)\tilde{x}''\right)\right) \\ &= \lambda\left[T(\lambda\tilde{x}' + (1-\lambda)\tilde{x}'') - \tilde{x}'\left(C\left(q\left(\lambda\tilde{x}' + (1-\lambda)\tilde{x}''\right)\right)\right)\right] \\ &\quad + (1-\lambda)\left[T(\lambda\tilde{x}' + (1-\lambda)\tilde{x}'') - \tilde{x}''\left(C\left(q\left(\lambda\tilde{x}' + (1-\lambda)\tilde{x}''\right)\right)\right)\right] \\ &\leq \lambda\left[T(\tilde{x}') - \tilde{x}'\left(C(q\left(\tilde{x}'\right)\right)\right] + (1-\lambda)\left[T(\tilde{x}'') - \tilde{x}''\left(C(q\left(\tilde{x}''\right)\right)\right] \\ &= \lambda U^i(\tilde{x}' \mid M) + (1-\lambda)U^i(\tilde{x}'' \mid M) \end{aligned}$$

The inequality in the fourth line follows from noting the supplier selects contract terms that maximize surplus for each $\tilde{x}$. QED

The intuition for this finding is as $\tilde{x}$ increases, there is less than a proportionate increase in the supplier's cost. The seller responds to an expected cost increase by decreasing the quantity supplied. Consequently, supplier surplus is decreasing in $\tilde{x}$ at a decreasing rate, meaning seller surplus is decreasing and convex in $\tilde{x}$.[8]

Given these properties of the surplus function one can rank distributions from the well known mean preserving spread, stochastic dominance result of Rothschild and Stiglitz (1970). Recall, F^e is a mean preserving spread *(MPS)* of F^n if they have the same mean and $\int_{\underline{x}}^{x}\left(F^e(\tilde{x}) - F^n(\tilde{x})\right)d\tilde{x} \geq 0$ for all $\tilde{x} \in \dot{X}$ with strict inequality holding for some $x \in X$ with positive measure. It follows from Rothschild and Stiglitz (1970) that:

Lemma 3 *Suppliers prefer F^e to F^n for all feasible contracts if and only if F^e is a mean preserving spread of F^n*

[8] Scotchmer (1999) similarly has recognized and exploited the convexity property of agent's surplus functions in her discussion of optimal renewal of patents.

The intuition underlying Lemma 3 comes from regarding the supply arrangement as a real option. Recall, the seller's surplus is a convex function of his forecasted cost. If one evaluates sellers in terms of their information, those with the greatest variation in forecasts have the highest option value. The expert forecaster is more likely to observe a signal that causes him to revise initial expectation about cost. The expert optimally reduces production when forecasts are high, and increases supply when forecasts are low.[9] Consequently he generates greater expected surplus than the non expert.

As an aside, it's interesting to observe the ranking of information structures by *MPS* of forecast distributions for our problem is formally similar to the ranking of information structures in agency problems with moral hazard. Kim (95) demonstrates that an *MPS* relation between the likelihood ratio distributions coming from the original information system is sufficient for ordering of different information structures in that setting.

More generally, Lemma 3 may be applied to settings other than forecasting, where suppliers draw their costs from different distributions. Suppose for instance, that supplier's actual costs (rather than forecast cost) are $\tilde{x}$. Suppliers have the same ex ante expected cost, but their actual costs are obtained from distributions $F^i(\tilde{x})$. Then lemma 3 implies sellers drawing their cost from more diffuse distributions will earn greater expected surplus for any feasible contract.[10]

3 Optimal Contracts

In this section we characterize optimal procurement contracts. Unlike previous studies (e.g. Baron and Myerson (82)), though, we augment the analysis with the possibility that suppliers vary by their ability to forecast costs. Our analysis demonstrates the interesting differences in contract provisions that arise when suppliers are privately informed of their forecasting skills.

[9] We note that our ordering of forecasts structures can be shown to be a special case of Athey and Levin (2000) who have derived a more general characterization for ranking information structures for the class of monotone decision problems of which the supplier's problem we consider is a special case.

[10] This is consistent with Courty and Li (2000) who find that buyers who have greater variation in demand for services are willing to pay more for a purchasing contract than buyers with more predictable demand.

3.1 Framework

At the time of contracting, S privately knows his type, S^e or S^n which reflects his forecasting ability. The ex ante probability S is of type e is $\mu \in (0,1)$. S receives his forecast of cost after the terms of the contract are set, and just prior to production. Under these conditions, the buyer designs a set of menus $M^i = \{T^i(x), q^i(x)\}$ for $i = e, n$ in order to

$$\max_{M^i_{i=e,n}} \mu \int_x (V(q^e(\tilde{x})) - T^e(\tilde{x}))dF^e(\tilde{x}) + (1-\mu) \int_x^x (V(q^n(\tilde{x})) - T^n(\tilde{x}))dF^n(\tilde{x})) \quad (4)$$

subject to the contracting constraints for $i = e, n$:

(a) $U^i_{\tilde{x}}(\tilde{x} \mid M^i) = -C(q^i(\tilde{x}))$

(b) $q^i(\tilde{x})$ *is non increasing*

(c) $U^i(M^i) \geq 0$

(d).$U^i(M^i) \geq U^i(M^j)$ for all $i \neq j$

Constraints (a)-(c) are required for contract feasibility. Constraint (d) insures sellers truthfully report their types.

Before proceeding to the solution of (4) it is useful to characterize, as a benchmark, the first-best full information supply contract that maximizes the sum of buyer and seller surplus, assuming the procurer can observe the forecaster's type. Assuming a unique interior solution, this contract, denoted by $M^{i*} = \left\{T^{i*}(x), q^{i*}(x)\right\}$, satisfies

$$V'\left(q^{i*}(\tilde{x})\right) = \tilde{x}C'\left(q^{i*}(\tilde{x})\right) \quad (5)$$

$$\int_X \left[T^{i*}(\tilde{x}) - \tilde{x}C\left(q^{i*}(\tilde{x})\right)\right] dF^i(\tilde{x}) = 0 \quad (6)$$

The optimal contract specifies the quantity, $q^{i*}(\tilde{x})$,that equates the marginal value of service to the marginal cost for each realization, $\tilde{x}$. The supplier receives expected payments equal to expected cost for all realizations of $\tilde{x}$ he forecasts to ensure he breaks even on average.

One may implement this contract in two ways. One is to offer the supplier a payment schedule equal to the marginal benefit of service. This schedule will induce optimal supply for each realization, $\tilde{x}$. Another more direct method is a "buy out" (e.g. Harris and Raviv (1979)) of the procurer by the forecaster. The forecaster purchases the buyer's assets, (assuming they're transferable) and thereby becomes the residual claimant of all net surplus. This leads the supplier to produce efficiently.

A special case of interest arises when only the expert receives an informative signal, and the non expert always forecasts, $\hat{x}$, the ex ante mean cost. Previous studies (e.g. Cremer et al (1998a)) and Lewis and Sappington(1993, 1994) have focused exclusively on this setting. In this case the solution to the buyer's problem is readily characterized in,

Proposition 1: *When the non expert is completely uninformed the buyer implements the first best contract with*

(a) $\{T^n(\tilde{x}) = \hat{x}C(q^*(\hat{x})), q^n(\tilde{x}) = q^*(\hat{x})\}$ *for* $\tilde{x} \in X$

(b) $\{q^e(\tilde{x}) = q^*(\tilde{x})\}$ *for* $\tilde{x} \in X$ *and* $\int_X [T^{i*}(\tilde{x}) - \tilde{x}C(q^{i*}(\tilde{x}))]\, dF^i(\tilde{x}) = 0$

Two interesting findings emerge from Proposition 1. One holds generally and the other is specific to this setting. The first finding is that the non expert is delegated less decision making authority, than the expert. Here the non expert has only one choice, to supply $q^*(\hat{x})$ where $\hat{x}$ is the ex ante expected unit cost of supply. More generally, when the non expert receives some informative forecasts, we will continue to find her purchase authority is restricted relative to the expert's. Second, the buyer is able to implement the first best allocation, without ceding any rent to the expert supplier The expert is precluded from earning rent because he is unable to use his superior forecasting abilities when the non expert's contract calls for a constant level of service. This result is special. As we demonstrate below it does not generalize to settings where the non expert receives informative forecasts.

Now returning to the buyer's problem for the general setting, we make the following assumption for the rest of the analysis to follow (unless indicated otherwise)

Assumption: *Continuous Distributions with Common Support (CDCS)*:

For $i = e, n$, $F^i(\tilde{x})$ *is absolutely continuous and strictly increasing with density* $dF^i(\tilde{x}) = f^i(\tilde{x}) > 0$ *for all* $\tilde{x} \in X$.

CDSC implies that all suppliers receive the same set of forecasts, but with different frequencies. This enables us to analyze and interpret the optimal contracts more easily.

It is instructive to rewrite the buyer's problem (4) as,

$$\max_{\{T^i(\tilde{x}),q^i(\tilde{x})\}_{i=e,n}} \mu \int_X (V(q^e(\tilde{x})) - T^e(\tilde{x}))\, dF^e(\tilde{x}) + (1-\mu) \int_X (V(q^n(\tilde{x})) - T^e(\tilde{x}))\, dF^n(\tilde{x}) - \mu R \tag{7}$$

According to (7) the buyer selects services to maximize total net surplus minus the expected information rent accruing to the expert supplier. The rent S^e earns is,

$$\begin{aligned} R &= U^e(M^n) - U^n(M^n) \\ &= \int_X (T^n(\tilde{x}) - \tilde{x}C(q^n(\tilde{x})))\,(dF^e(\tilde{x}) - dF^n(\tilde{x})) \\ &= \int_X C(q^n(\tilde{x}))(F^e(\tilde{x}) - F^n(\tilde{x}))dx \end{aligned} \tag{8}$$

where the third line follows from the second by integrating by parts and recognizing the constraint in (d) binds for S^n. After substituting for the rent expression into (7) and rearranging terms, the buyer's problem becomes,

$$\max_{\{q^i\}_{i=e,n}} \mu \int_X AW^e(\tilde{x}, q^e(\tilde{x}))dF^e(\tilde{x}) + (1-\mu)\int_X AW^n(\tilde{x}, q^n(\tilde{x}), \mu)dF^n(\tilde{x}) \tag{9}$$

where,

$$AW^e(\tilde{x}, q^e(\tilde{x})) = V(q^e(\tilde{x})) - \tilde{x}C(q^e(\tilde{x})) \tag{10}$$

$$AW^n(\tilde{x}, q^n(\tilde{x}), \mu) = V(q^n(\tilde{x})) - \tilde{x}C(q^n(\tilde{x})) - \frac{\mu}{1-\mu}C(q^n(\tilde{x}))\frac{F^e(\tilde{x}) - F^n(\tilde{x})}{f^n(\tilde{x})} \tag{11}$$

are the adjusted (for information rent) welfare expressions for the S^e and S^n suppliers respectively.

3.2 Characterization of Optimal Supply Contracts

The solution to (9) is characterized in the following Proposition (whose proof is in the appendix). To avoid unnecessary complications we assume the solution satisfies monotonicity, constraint (b).[11]

Proposition 2: *Given CDCS, in the solution to* (9), $q^i(\tilde{x}) = \arg\max AW^i(\cdot)$ *with*

(a) $V'(q^e(\tilde{x})) - \tilde{x}C'(q^e(\tilde{x})) = 0$

[11] We demonstrate in the appendix that the solution satisfies monotonicity whenever μ is not too large, or the distribution functions $F^i(\tilde{x})$ are sufficiently similar so that $\left|\frac{F^e(\tilde{x})-F^n(\tilde{x})}{f^n(\tilde{x})}\right|$ and $\left|\frac{d}{d\tilde{x}}\frac{F^e(\tilde{x})-F^n(\tilde{x})}{f^n(\tilde{x})}\right|$ are small for all $\tilde{x} \in X$. When the monotonicity condition is violated, the quantity schedule undergoes an ironing process, (see Rochet and Chone (98) for details), which restricts the schedule to being nonincreasing. Although this alters the optimal supply schedule, it does not alter the qualitative properties of the optimal contract.

(b) $V'(q^n(\tilde{x})) - \tilde{x}C'(q^n(\tilde{x}))) \leq \frac{\mu}{1-\mu}C'(q^n(\tilde{x}))(\frac{F^e(\tilde{x})-F^n(\tilde{x})}{f^n(\tilde{x})})$ $(=)$ if $q^n(\tilde{x}) > 0$.

(c) $U^n(M^n) = 0$, $U^e(M^e) > 0$

Proposition 2 indicates the optimal supply contract offers the expert forecaster S^e the first-best, surplus maximizing menu, M^* as there is no need to distort service to reduce his rents. S^e is delegated the choice of the efficient level of service for each cost realization. This contract is implemented either through a "buy out" of the buyer's assets, or by offering S^e the first best menu satisfying (5).

In contrast, part (b) indicates the non expert S^n is offered a contract that distorts his supply choice. As usual with incentive contracts, these distortions are induced to mitigate the expert's incentive to misrepresent his forecasting ability. However, unlike the usual Baron-Myerson type of quantity reducing distortions, here $S^{n\prime}s$ supply is distorted above or below efficient levels depending on how likely it is that the expert S^e would have forecast a lower cost. The rationale for these distortions is that each supplier type earns rent from their private knowledge of $\tilde{x}$, when they forecast cost. Increasing output for one realization $\tilde{x}$, increases the rent for all realizations $\tilde{x}' < \tilde{x}$, since a supplier with costs $\tilde{x}'$ can claim to have higher costs $\tilde{x}$ and receive greater compensation. Thus, supplier type S^i accrues marginal information rents at the rate of $C'(q^n(\tilde{x}))F^i(\tilde{x})$ when he declares he is a non expert. The difference between the expert's and non expert's marginal rent for some cost $\tilde{x}$ is $\Delta R(q^n(\tilde{x}), \tilde{x}) = C'(q^n(\tilde{x}))(F^e(\tilde{x}) - F^n(\tilde{x}))$. Therefore to dissuade S^e from imitating S^n, the buyer lowers $q^n(x)$ for all $\tilde{x}$ where $\Delta R(q^n(\tilde{x}), \tilde{x})$ is positive and raises $q^n(x)$ for all $\tilde{x}'$ where $\Delta R(q^n(\tilde{x}'), \tilde{x}')$ is negative.

To see more clearly how these distortions effectively constrain the non expert's supply choice consider the following example.

Example 1: Suppose $F^e(\tilde{x})$ is a single MPS of $F^n(\tilde{x})$ such that $F^e(\tilde{x})$ intersects $F^n(\tilde{x})$ once from above at some $x' \in (\underline{x}, \bar{x})$. Roughly this implies the expert forecasts relatively high or low costs more frequently than the non expert.

For this example Proposition 2 indicates that the relative service levels required for the expert and non expert satisfy,

$$q^n(\tilde{x}) \left\{ \begin{array}{c} > \\ = \\ < \end{array} \right\} q^e(\tilde{x}) \text{ as } \tilde{x} \left\{ \begin{array}{c} > \\ = \\ < \end{array} \right\} x' \tag{12}$$

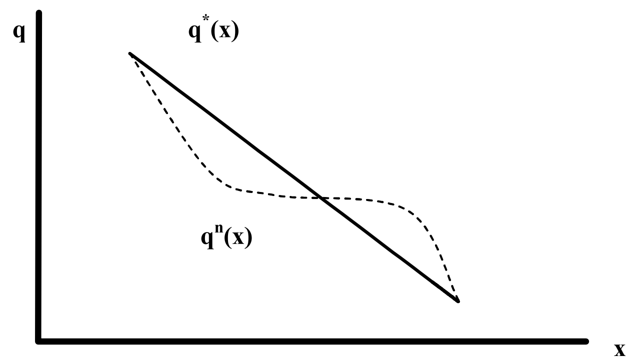

Figure 1:

Notice the expert is free to select the efficient service level based on his forecast of cost. In contrast the non expert is rationed when forecasts are low, and subsidized when forecasts are high. The effect of these distortions is to restrict the variation in service supplied by the non expert. This is illustrated conceptually in Figure 1 below. The Figure shows how the non expert supplies are concentrated around intermediate levels of service. Compared to the expert the non expert is delegated less decision making authority. He is discouraged from adjusting supply in response to updated information received from his forecast of costs. This renders it less attractive for an expert to claim he is non expert, since his delegation authority is reduced as a result.

3.3 Signaling of Forecasting Expertise

An important element, that we have not modeled, is the career concern of forecasters. Suppliers are compensated for their ability to predict costs and prescribe service for buyers. If possible, suppliers will try to establish a reputation as an expert for future employers. Our findings imply that experts will prescribe varying service levels. Therefore non experts may artificially vary their recommendations, when such prescriptions are unwarranted, to signal they are experts. Similar incentives for experts to modify forecasts to signal ability in other settings are noted by Prendergast and Stole (96), Ottaviani and Sorenson (2000) and

Dewatrixpont et al (1999). The signalling of expertise by manipulating forecast will impose coordination costs on the non expert. With randomly forecasting he will occasionally supply large quantities when real costs are high, and small amounts when real costs are low.

3.4 Implication for Combining Prescription with Supply

The conventional wisdom that it is beneficial for buyers to obtain diagnosis and supply of service from independent parties is not borne out here. By bundling the prescription and provision of services with one supplier, the buyer is able to screen experts from non experts more easily. As we demonstrated above the buyer offers different supply schedules that afford varying degrees of delegation authority according to the supplier's reported expertise. This will induce suppliers with different abilities to select distinct contracts. This self selection is not possible if diagnosis is independent of supply. In that case the buyer is unable to verify the accuracy of the forecaster without observing actual production costs.[12] Naturally though, it may be preferable to separate diagnosis from supply provided production costs can be observed.[13]

3.5 Implication for Acquisition of Expertise and Firm Boundaries

Our analysis to this point has assumed a supplier is exogenously endowed with expertise. In reality, suppliers may need to invest resources to acquire expertise. Suppliers will only acquire additional information if the rewards from being a better forecaster yield a high enough return to their investment. Suppose, for instance, that a supplier must invest $I > 0$ to become a expert and that the buyer is unable to observe this investment. Then for any feasible contract $\{T(\tilde{x}), q(\tilde{x})\}$ the seller is offered, the additional surplus, $R_I(T(\tilde{x}), q(\tilde{x}))$, from being an expert (instead of a non expert) is,

$$\begin{aligned} R_I(T(\tilde{x}), q(\tilde{x})) &= \int_X (T(\tilde{x}) - \tilde{x}C(q(\tilde{x})))(dF^e(\tilde{x}) - dF^n(\tilde{x})) \\ &= \int_X (C(q(\tilde{x})))(F^e(\tilde{x}) - F^n(\tilde{x}))\, d\tilde{x} \end{aligned} \tag{13}$$

[12] Our findings suggest one rationale for bundling tasks. There are other reasons as well. When multiple complementary products are to be supplied, a double marginalization of information rents is avoided by assigning production to a single supplier. See Baron and Besanko (1992) and Gilbert and Riordan (1995)

[13] See Lewis and Sappington (1997).

where the second line of (13) follows from the first after integrating by parts. A buyer wishing to purchase from an expert supplier must offer a supply contract $\{T(\tilde{x}), q(\tilde{x})\}$ providing sufficient reward for the seller to invest in expertise. This requires $R_I(T(\tilde{x}), q(\tilde{x})) \geq I$.

The optimal schedule that induces seller acquisition of expertise is the solution to,

$$\max_{\{T(\tilde{x}), q(\tilde{x})\}} \int_X (V(q(\tilde{x})) - T(\tilde{x}))dF^e \tag{14}$$

subject to $\{T(\tilde{x}), q(\tilde{x})\}$ being feasible and $R_I\ (T(\tilde{x}), q(\tilde{x})) \geq I$. Employing familiar arguments from analysis of Proposition 2, one can show the optimal contract in (14) is characterized by the following, (where $\rho \geq 0$ is the Lagrange multiplier attached to $R_I(T(\tilde{x}), q(\tilde{x})) - I \geq 0$)

Proposition 3: *In the solution to* (14)

(*a*) $V'(q(\tilde{x})) - \tilde{x}C'(q(\tilde{x}))) \leq -\rho C'(q(\tilde{x}))(\frac{F^e(\tilde{x}) - F^n(\tilde{x})}{f^e(\tilde{x})})$; (=) if $q(\tilde{x}) > 0$,

(*b*) $R_I(T(\tilde{x}), q(\tilde{x})) \geq I$,$\rho \geq 0$

Proof: The proof, which follows Proposition 2, is omitted.

The optimal contract in Proposition 3 calls for too much output when $F^e(\tilde{x}) - F^n(\tilde{x}) > 0$ and too little output when $F^e(\tilde{x}) - F^n(\tilde{x}) < 0$. These distortions provide the necessary reward for the seller to acquire forecasting skill. To understand this recall the difference in the rate experts and non experts acquire rent is $\Delta R(q(\tilde{x},)\tilde{x}) = C'(q(\tilde{x}))(F^e(\tilde{x}) - F^n(\tilde{x}))$. Therefore the reward from investing in expertise comes from increasing supply when the expert's marginal rent difference is positive, and by decreasing it when the rent difference is negative.

This suggests firms will contract out for those services that are most difficult to prescribe. The core of our argument is that arrangements involving expost inefficiencies are required to induce suppliers to gain expertise. Such arrangements are more difficult to enforce within a firm, than when the firm contracts outside for supply. To induce an internal division in the firm to acquire expertise, requires a distortion of the supply allocation so that it is ex post inefficient. There is ample evidence and compelling arguments (e.g.Williamson (75)) to suggest that inefficient arrangements between internal divisions of a firm are more difficult to enforce than contracts with outside parties. This is because renegotiation of inefficient terms occurs more readily within a firm, than when the arrangement is between separate entities contracting at arms length. We conclude these types of expost inefficient arrangements will likely transcend the boundary of the firm. Firms will be more likely to self provide products not requiring expert diagnosis.

4 Buyer's Preferences for Contracting with Expert Forecasters

What are the buyer's preferences for contracting with sellers having different diagnostic abilities? The answer depends on two factors. The first is the timing of contracting. Are contracts negotiated sequentially or only after experts have observed costs? Second, is the seller aware of his forecasting ability ex ante?

4.1 Buyer Preferences for Contracting with Informed Sellers

Suppose suppliers know their forecasting abilities ex ante. An expert forecaster can perform more effectively for the buyer by recognizing opportunities to provide greater service when costs are small. However this advantage may be negated by the increased information rents the expert commands. To investigate this trade-off we define a forecaster of type μ, S^{μ} as one who draws the expert distribution, F^e,with probability μ and the non expert distribution, F^n, with probability $1-\mu$. We assume B knows only the likelihood, μ, that the seller is an expert at the time of contracting.

4.1.1 Sequential Contracting

To illustrate the importance of the timing of negotiations, first consider the sequential contract setting. Define $W(\mu)$ to be the buyer's expected utility from contracting with seller type S^{μ} as,

$$W(\mu) = \max_{\{q^i\}_{i=e,n}} \mu \int_X AW^e(\tilde{x}, q^e) dF^e + (1-\mu) \int_X AW^n(\tilde{x}, q^n, \mu) dF^n \qquad (15)$$

where AW^i, the adjusted welfare expression for S^i, is given in (10) and (11)

Lemma 4 characterizes a key property of $W(\mu)$.

Lemma 4: *$W(\mu)$ is convex.*

Proof: Let

$$W(\mu \mid \{q^i\}) = \mu \int_X AW^e(\tilde{x}, q^e)dF^e + (1-\mu)\int_X AW^n(\tilde{x}, q^n, \mu)dF^n \tag{16}$$

and denote $\{q^i_\mu\}$ as the quantity menu maximizing $W(\mu \mid \{q^i\})$. Note, for $\mu \in (0,1)$

$$\begin{aligned} W(\mu \quad \mid \quad \{q^i_\mu\}) &= \mu \int_X AW^e(\tilde{x}, q^e_\mu)dF^e + (1-\mu)\int_X AW^n(\tilde{x}, q^n_\mu, \mu)dF^n \\ &< \mu \int_X AW^e(\tilde{x}, q^e_\mu)dF^e + (1-\mu)\int_X AW^n(\tilde{x}, q^n_\mu, 0)dF^n \\ &\leq \mu \int_X AW^e(\tilde{x}, q^e_1)dF^e + (1-\mu)\int_X AW^n(\tilde{x}, q^n_0, 0)dF^n \\ &= \mu W(1 \mid \{q^i_1\}) + (1-\mu)W(0 \mid \{q^i_0\}) \end{aligned} \tag{17}$$

where the second line follows because AW^n is decreasing in μ, the third line is implied by the fact q^e_1 and q^n_0 maximize AW^e and AW^n respectively, and the last line follows after some rearranging of terms. QED

Suppose $\mu = 0$ so the seller draws distribution F^n with certainty. The effect on $B's$ expected surplus from a slight increase in μ is given by

$$\begin{aligned} W'(0) &= \frac{d}{d\mu}_{|\mu=0}\left\{\mu \int_X AW^e(\tilde{x}, q^e_\mu)dF^e + (1-\mu)\int_X AW^n(\tilde{x}, q^n_\mu, \mu)dF^n\right\} \\ &= \int_X AW^e(\tilde{x}, q^e_0)dF^e - \int_X AW^n(\tilde{x}, q^n_0, 0)dF^n - \int_X C\left(q^n_0\right)\left(F^e - F^n\right)d\tilde{x} \\ &= \int_X C\left(q^n_0\right)\left(F^e - F^n\right)d\tilde{x} - \int_X C\left(q^n_0\right)\left(F^e - F^n\right)d\tilde{x} = 0 \end{aligned} \tag{18}$$

where the third line follows after integrating by parts and recognizing $q^e_0 = q^n_0$. QED

Combining Lemma 4 and (18), we can establish :

Proposition 4 $W(\mu)$ *is increasing in* μ. *Buyers prefer contracting with sellers who are more likely to be experts.*

The intuition for Proposition 4 is that B prefers contracting with experts, because of the first order effect that they generate greater total surplus for the buyer and seller to split. This is partially negated by the fact that seller's earn greater profits when they are well informed. Infact one can readily show when buyers employ the first-best efficient contract, that $W'(\mu) = 0$ as the supplier captures all the additional surplus from being a better forecaster. However, by distorting contracts to reduce information rents, the buyer manages to capture some portion of the benefits of better forecasting for himself.

4.1.2 Contracting After Costs are Known

Now to highlight the importance of contract timing in shaping buyer preferences we turn to a setting where contracting occurs after the supplier observes his forecast. In this case the buyer can do no better than to offer a single schedule $\{T(\tilde{x}), q(\tilde{x})\}$. Otherwise the supplier will just select the schedule containing his best option given his cost, $\tilde{x}$,when multiple schedules are offered.[14] Further, to guarantee the supplier produces, he must earn positive surplus whatever his cost.

Under these conditions the buyer may prefer contracting with a non expert. To illustrate, suppose costs $\tilde{x} \in \{x_L, x_H\}$ are "low" or "high" with probability $\frac{1}{2}$. Assume buyer's surplus is $V(q) = (a - bq)q$ and the seller's costs $C(\tilde{x}, q) = \tilde{x}q$ where $a, b > 0$. Further suppose $x_H < a$ so it is efficient to produce at all costs. The non expert always forecasts the ex ante expected cost $\hat{x} = \frac{x_H + x_L}{2}$. The expert forecasts actual costs.

Suppose the buyer knows the seller's forecasting ability. Then when contracting with a non expert the buyer optimally offers a single take it or leave it contract $\left\{T = \hat{x}q^2, q = \frac{a-\hat{x}}{2b}\right\}$. The non expert accepts this contract and breaks even on average. The buyer acquires a net surplus $V(q^n) - T^n = \frac{(a-\hat{x})^2}{4b}$ with this arrangement.

When dealing with an expert, the buyer optimally offers a single take it or leave it contract $\left\{T = x_L q,\ q = \frac{a-x_L}{2b}\right\}$provided $a \leq 2x_H - x_L$.[15] The expert accepts this contract whenever his costs are x_L .Otherwise when costs are high he rejects it. The buyer's expected surplus from this arrangement is $V(q^e) - T^e = \frac{(a-x_L)^2}{8b}$.

One can readily show that $(V(q^n) - T^n) - (V(q^e) - T^e) = \frac{(a-\hat{x})^2}{4b} - \frac{(a-x_L)^2}{8b} \geq 0$ whenever $\frac{x_H - x_L}{2(\sqrt{2}-1)} \leq a$. In this the buyer earns a greater surplus contracting with the non expert. Although the expert can tailor production to cost conditions, it's too costly to induce him

[14] That is when several schedules $\left\{T^i(\tilde{x}), q^i(\tilde{x})\right\}$ for $i = 1, 2, , N$ are offered, a supplier will select the schedule j such that $T^j(\tilde{x}), q^j(\tilde{x}) = \arg\max_{T,q,x} T^i(\tilde{x}) - \tilde{x}q^i(\tilde{x})$. So without loss of generality the buyer may consolidate these choices by simply offering the schedule $T(\tilde{x}), q(\tilde{x}) = \arg\max_{T,q,x} T^i(\tilde{x}) - \tilde{x}q^i(\tilde{x})$ for all $\tilde{x}$.

[15] When the buyer induces the expert to produce q when $\tilde{x} = x_H$ he earns extra net surplus equal to $(a - bq)q - x_H q - (x_H - x_L)q$. The last term is the information rent the expert earns. This expression is negative for all $q \geq 0$ provided $a \leq 2x_H - x_L$.

to produce when costs are high. In contrast, the non expert supplies the buyer under all conditions. Therefore when the buyer's value of consumption, a, is large compared to variations in cost, $x_H - x_L$, he derives greater value from the non expert supplier. This follows because the benefit of predicting cost to adjust production is small when there is little variation in costs. However the benefit from always being supplied is high.

Comparing the buyer's preferences in this setting with his preferences in the sequential contracting setting reveal the important benefits of gradual contracting. It's more difficult to control experts' rents when they are fully informed at contracting time. At this point the buyer can only offer a single contract, and suppliers must always expect positive profits, otherwise they will not produce. The expert's ability to extract large rents is greater here than when contracting is sequential and the buyer can employ more instruments to limit experts' rents. In that case, a supplier need only break even on average to insure he produces. And different ability suppliers are managed under separate contracts. This allows the buyer to tailor agreements to the supplier's type, so that expert advice is more valuable to the buyer under these conditions.

4.2 Buyer's Preference for Ex Ante Knowledge of Seller

According to Proposition 4, B prefers contracting with more capable forecasters. But this presumes sellers know their forecasting ability ex ante. Suppose instead, the seller is uncertain whether he is an expert or nonexpert predictor of the buyer's costs. Would the buyer prefer contracting with a forecaster who is uncertain of his predictive abilities? This questions is not entirely academic, as settings exist where the buyer may offer or conceal information regarding the service he desires that would inform the seller about his forecasting ability.[16]

To pursue this question we compare the buyer's expected utility when contracting with an informed seller, $W(\mu)$ defined in (18), with his expected utility contracting with an uninformed seller, $W^u(\mu)$, defined by,

$$W^u(\mu) = \max_{\{q\}} \int_X V(q(\tilde{x})) - \tilde{x}C(q(\tilde{x}))\,(\mu dF^e + (1-\mu)\,dF^n). \tag{19}$$

Without knowing whether he is an expert or nonexpert, the uninformed seller's prior on his

[16] As an example, the procurer of health care services may provide or conceal information on the demographic characteristics of the patient population that would inform the provider about the likely costs of treatment.

distribution is the mixture $\mu F^e+(1-\mu)F^n$. Accordingly, B designs a quantity menu, $\{q\}$, to maximize expected utility given the seller's perceived forecast distribution $(\mu dF^e + (1-\mu)\, dF^n$.

The buyer's preferences depend on how valuable the expert's information is for planning production. To illustrate, imagine $F^e(\tilde{x})$ is the expert's signal distribution and suppose there exists a much less informative distribution, $\widetilde{F}(\tilde{x})$, providing such poor information that the buyer would not purchase from a forecaster predicting with $\widetilde{F}(\tilde{x})$, so that,[17]

$$\max_{\{q\}} \int_X (V(q(\tilde{x})) - \tilde{x}C(q\,(\tilde{x})))d\widetilde{F}(\tilde{x}) \leq 0 \tag{20}$$

Let $F^n_\lambda = \lambda F^e + (1-\lambda)\widetilde{F}$ represent the second, less informative distribution S may draw. This distribution is a mixture of F^e and $\widetilde{F}$ with the weight, $\lambda \in [0,1]$ being the measure of similarity between the informative and uninformative information structures. For λ close to 1 there is little additional information gained from structure F^e, whereas there is significant information gained from structure F^e when λ is close to 0. Employing this gauge of the value of a better forecast permits us to partially characterize $B's$ preferences.

Proposition 5: *There exists a λ_H and λ_L satisfying $0 < \lambda_L < \lambda_H < 1$ such that*

(a) B prefers contracting with an uninformed seller for $\lambda \geq \lambda_H$ and,

(b) B prefers contracting with an informed seller for $\lambda \leq \lambda_L$.

The buyer faces a trade off between reducing information rent and increasing allocative efficiency. When the seller is informed, the buyer could increase efficiency by offering the expert forecaster S^e a more flexible supply schedule. However, S^e would capture rents from his private knowledge. When a seller is uninformed the buyer cannot tailor the supply schedule to the quality of his information. Nonetheless, the buyer may fully extract the seller's expected rents.

When λ is close to 1, there is little difference between the expert and non expert information structures. The efficiency gained from an informed seller is small compared to the additional rent the seller captures. Thus B prefers contracting with an uninformed seller. When λ is close to 0, the expert forecasts are much more informative than the non expert forecasts. Performance improves significantly by knowing the quality of the seller's information. Further, the rents an informed expert may command are small, since the buyer may credibly commit not to employ a seller who declares he is a non expert. In this case, the buyer prefers informed sellers.

[17] This would arise if there were fixed costs to employing the supplier.

5 Conclusion

Most studies of optimal procurement presume the seller is privately and perfectly informed of his costs at the time of contracting. In contrast this paper explores how contracts are optimally planned and designed for suppliers with different expertise who acquire information gradually over time. We have discovered interesting variations in contracts arise when suppliers differ in their ability to prescribe service. For instance we show experts receive more varied forecasts of costs than non experts. The supply schedules offered to the expert and non expert differ by the ability of the expert to adjust supply to different forecast costs. Fitting supply schedules to the relative frequency of cost forecasts mitigates the supplier's incentives to misrepresent his ability to prescribe service. Further we find buyers are more likely to benefit from delegating decisions to suppliers, when they can tailor supply agreements to the seller's level of expertise.

While our analysis suggests some ways that the quality of advice may be accounted for in supply contracts, we have ignored or barely mentioned several other potentially important factors that may shape the procurement process. For example accounting for the career concerns of experts in the optimal design of purchase arrangements warrants further attention. It would also be useful to more carefully explore what factors, other than supplier expertise, determine a firm's decision to outsource. [18]The strategic disclosure of pre-contracting information also warrants investigation. The rationale for buyer's to withhold information from suppliers may fruitfully be analyzed in the context of our model.

Our central insights about contracting with experts may be relevant for the design of optimal procurement auctions. For example, suppliers bidding to acquire the rights to develop a mineral deposit or an oil field are likely to vary in their ability to forecast value. Our model suggests that the handicapping of bidders by ability and the strategic disclosure of pre bid information are two instruments sellers may use to maximize their expected revenues.[19] Other prescriptions for designing optimal selling mechanism ranging from decentralized auctions to bilaterally negotiated agreements may be addressed by our model as well.

[18] For instance the ability of the firm to observe inputs or output from production may influence it's decision to outsource. Khalil and Lawaree (1995) provide an interesting analysis of the relative advantages of monitoring outputs.

[19] The impact of bidders with unknown abilities to predict value in First-Price Auctions is explored by Piccione and Tan (1996) Other analysis of the benefits of informing agents about their valuations include Persico(2000) and Ottaviani and Prat (2001).

6 Appendix

Proof of Proposition 2

The necessary first-order conditions for problem (9) are given by (a) and (b) of Proposition 2 in the text. These conditions are also sufficient provided AW^n is strictly quasai concave which is guaranteed if $\frac{\mu}{1-\mu}\frac{F^e(\tilde{x})-F^n(\tilde{x})}{f^n(\tilde{x})}$ is not too large in absolute value for $\tilde{x}\in[\underline{x},\bar{x}]$. This same condition insures the solution identified in (a) and (b) of Proposition 2 satisfies monotonicity. When $q^n(\tilde{x})>0$,monotonicity requires

$$\frac{dq^n(\tilde{x})}{d\tilde{x}}=-\frac{-\left(1-\frac{\mu}{1-\mu}\frac{d}{d\tilde{x}}\frac{F^e(\tilde{x})-F^n(\tilde{x})}{f^n(\tilde{x})}\right)C'(q^n(\tilde{x}))}{V''(q^n(\tilde{x}))-C''(q^n(\tilde{x}))\left(\tilde{x}-\frac{\mu}{1-\mu}\frac{F^e(\tilde{x})-F^n(\tilde{x})}{f^n(\tilde{x})}\right)}\leq 0$$

which is satisfied provided$\frac{\mu}{1-\mu}\frac{d}{d\tilde{x}}\frac{F^e(\tilde{x})-F^n(\tilde{x})}{f^n(\tilde{x})}$ is not too large.

Proof of Proposition 5

Part (a)

Let $W^u_\lambda(\mu)$ and $W_\lambda(\mu)$ represent $B's$ expected surplus when contracting with an uninformed and informed seller respectively, given $F^n_\lambda=\lambda F^e+(1-\lambda)\widetilde{F}$ where

$$W^u_\lambda(\mu)=\max_{q(\tilde{x})}\mu\int_Z[V(q(\tilde{x}))-\tilde{x}C(q(\tilde{x}))]\,dF^e(\tilde{x})+(1-\mu)\int_Z[V(q(\tilde{x}))-\tilde{x}C(q(\tilde{x}))]\,dF^n_\lambda(\tilde{x}) \tag{A1}$$

and

$$\begin{aligned}W_\lambda(\mu) \;=\; & \max_{q^e_\mu(\tilde{x}),q^e_\mu(\tilde{x})}\mu\int_X\left[V(q^e_\mu(\tilde{x}))-\tilde{x}C(q^e_\mu(z))\right]dF^e(z) \qquad \text{(A2)}\\ & +(1-\mu)\int_X\left[V(q^n_\mu(\tilde{x}))-\tilde{x}C(q^n_\mu(\tilde{x}))-\frac{\mu}{1-\mu}C(q^n_\mu(\tilde{x}))\frac{(F^e(\tilde{x})-F^n_\lambda(\tilde{x}))}{f^n_\lambda(\tilde{x})}\right]dF^n_\lambda(\tilde{x})\end{aligned}$$

Note $W^u_1(\mu)=W_1(\mu)$ so that

$$W^u_\lambda(\mu)-W_\lambda(\mu)=-\int_\lambda^1\frac{d}{d\lambda}\left(W^u_{\lambda'}(\mu)-W_{\lambda'}(\mu)\right)d\lambda'. \tag{A3}$$

Since

$$-\frac{d}{d\lambda}\left(W_\lambda^u(\mu)-W_\lambda(\mu)\right) = (1-\mu)\int_X \left[V(q_\mu^e(\tilde{x}))-\tilde{x}C(q_\mu^e(\tilde{x}))\right]\left(dF^e(\tilde{x})-d\widetilde{F}(\tilde{x})\right) \tag{A4}$$
$$+\mu\int_X C(q_\mu^n(\tilde{x}))\left(F^e(\tilde{x})-\widetilde{F}(\tilde{x})\right)d\tilde{x}$$
$$-(1-\mu)\int_X \left[V(q(\tilde{x}))-\tilde{x}C(q(\tilde{x}))\right]\left(dF^e(\tilde{x})-d\widetilde{F}(\tilde{x})\right)$$

and $q(\tilde{x})=q_\mu^e(\tilde{x})=q_\mu^n(\tilde{x})=q^e(\tilde{x})$ at $\lambda=1$, we have,

$$-\frac{d}{d\lambda}\left(W_\lambda^u(\mu)-W_\lambda(\mu)\right)_{|\lambda=1} = (1-\mu)\int_X \left[V(q^e(\tilde{x}))-\tilde{x}C(q^e(\tilde{x}))\right]\left(dF^e(\tilde{x})-d\widetilde{F}(\tilde{x})\right) \tag{A5}$$
$$+\mu\int_X C(q^e(\tilde{x}))\left(F^e(\tilde{x})-\widetilde{F}(\tilde{x})\right)d\tilde{x}$$
$$-(1-\mu)\int_X \left[V(q^e(\tilde{x}))-\tilde{x}C(q^e(\tilde{x}))\right]\left(dF^e(\tilde{x})-d\widetilde{F}(\tilde{x})\right)$$
$$= \mu\int_X C(q^e(\tilde{x}))\left(F^e(\tilde{x})-\widetilde{F}(\tilde{x})\right)d\tilde{x} > 0.$$

Since $\frac{d}{d\lambda}\left(W_{\lambda'}^u(\mu)-W_{\lambda'}(\mu)\right)$ is continuous and $\frac{d}{d\lambda}\left(W_\lambda^u(\mu)-W_\lambda(\mu)\right)_{|\lambda=1}<0$, it follows that

$$\frac{d}{d\lambda}\left(W_\lambda^u(\mu)-W_\lambda(\mu)\right)<0 \tag{A6}$$

for λ close to 1. This implies there exists a λ_H sufficiently close to 1 such that

$$W_{\lambda_H}^u(\mu)-W_{\lambda_H}(\mu)=-\int_{\lambda_H}^1 \frac{d}{d\lambda}\left(W_{\lambda'}^u(\mu)-W_{\lambda'}(\mu)\right)d\lambda'>0 \tag{A7}$$

for all $\lambda \in \lambda_H, 1]$. QED

Part (b)

First,

$$\begin{aligned} \mu W^u_\lambda(1) + (1-\mu) W^u_\lambda(0) &= \mu \int_X V(q^e(\tilde{x})) - \tilde{x}C(q^e(\tilde{x}))dF^e(\tilde{x}) \\ &\quad +(1-\mu)\int_X V(q^n(\tilde{x}))) - \tilde{x}C(q^n(\tilde{x}))dF^n_\lambda(x) \\ &> \max_{q(\tilde{x})}[\mu \int_X V(q(\tilde{x})) - \tilde{x}C(q(\tilde{x}))dF^e(\tilde{x}) \\ &\quad +(1-\mu)\int_X V(q(\tilde{x})) - \tilde{x}C(q(\tilde{x}))dF^n_\lambda(\tilde{x})] \\ &= W^u_\lambda(\mu) \end{aligned} \tag{A8}$$

so that $W^u_\lambda(\mu)$ is convex. Further, when the seller is informed about his information structure,

$$W_\lambda(\mu) \geq \mu W_\lambda(1), \tag{A9}$$

as the buyer can always ensure $\mu W_\lambda(1)$ by offering a contract that only a seller with better information will supply. Therefore we have,

$$\begin{aligned} W^u_0(\mu) &< \mu W^u_0(1) + (1-\mu) W^u_0(0) \\ &= \mu W^u_0(1) \\ &= \mu W_0(1) \\ &\leq W_0(\mu) \end{aligned} \tag{A10}$$

where the first line follows from the convexity of $W^u_\lambda(\mu)$, the second line follows from $W^u_0(0) = W_0(0) = 0$, the third line follows from the fact that $W^u_\lambda(1) = W_\lambda(1)$.and the fourth line follows from $(A9)$. Thus, since $W^u_\lambda(\mu)$ and $W_\lambda(\mu)$ are continuous in λ, there exists a λ^L sufficiently close to 0 such that $W_\lambda(\mu) > W^u_\lambda(\mu)$ for all $\lambda \leq \lambda^L$. QED

7 Reference

1. Aghion, P. and Tirole, J., "Formal and Real Authority," *Journal of Political Economy* 105 (1) (1997) 1-29

2. Armstrong, M., "Delegation and Discretion," Discussion Papers in Economics and Econometrics No 9421, University of Southampton

3. Athey, S. and Levin, J., "The Value of Information in Monotone Decision Problems," MIT working paper (2000)

4. Baron, D. and Myerson, R., "Regulating a Monopolist with Unknown Costs," *Econometrica* 50 (1982): 911-30

5. Baron, D. and Besanko, D., "Information Control and Organizational Structure," *Journal of Economics and Management Strategy*, 1 (1992) 237-75

6. Biglaiser, G., "Middlemen as Experts," *Rand Journal of Economics* 24 (2) (1993) 212-223

7. Chung, T-Y. , "On the Social Optimality of Liquidated Damage Clauses: An Economic Analysis," *Journal of Law, Economics and Organization* 8 (1992) 280-305

8. Courty, P and Li, H., "Sequential Screening," *Review of Economic Studies* 67, (2000) 697-717

9. Cremer, J. and Khalil, F., "Gathering Information Before Signing a Contract," *American Economic Review* 82 (1992): 566-578

10. Cremer, J., Khalil, F. and Rochet,J.C., "Strategic Information Gathering Before a Contract is offered," *Journal of Economic Theory* 81 (1998a): 163-200

11. ———. "Contracts and Productive Information Gathering," *Games and Economic Behavior* 25 (1998b): 174-193

12. Crocker, K and Snow, A., "The Social Value of Hidden Information in Adverse Selection Economies," *Journal of Public Economics*, 48 (1992) 317-347

13. Dewatrixpont, M., Jewitt, I. and Tirole, J, "The Economics of Career Concerns, Part I:Comparing Information Structures," *Review of Economic Studies* 66(1) (1999)

14. Emmons, W., "Credence Goods and Fraudulent Experts," *Rand Journal of Economics 28(1)* (1997)

15. Fudenberg, D. and Tirole, T., *Game Theory* (Cambridge: MIT Press) (1991)

16. Gilbert, R. and Riordan, M. "Regulating Complementary Products: A Comparative Institutional Analysis," *Rand Journal of Economics*, 26 (1995) 243-56

17. Harris, M. and Raviv, A. "Optimal Incentive Contracts with Imperfect Information," *Journal of Economic Theory* 20 (1979): 231-259

18. Holmstrom, B "On the Theory of Delegation" in Boyer, M and Khilstrom,

R. (eds) *Bayesian Models in Economic Theory* (Elsevier Science Publishers B.V.) (1984)

19. Khalil, F. and Lawaree, J. "Input versus Output Monitoring: Who is the Residual Claimant?," *Journal of Economic Theory* 6(1) (1995) 139-157

20. Kim, S.K. "Efficiency of an Information System in an Agency Model," *Econometrica* 63(1) (1995) 89-102

21. Laffont, J and Tirole, J. *A Theory of Incentives in Procurement and Regulation.* MIT press (1992)

22. Lewis, T., and Sappington, D. "Choosing Worker's Qualifications: No Experience Necessary," *International Economic Review* 34 (1993a): 479-502

23. ———. "Ignorance in Agency Problems," *Journal of Economic Theory* 17(1993b): 169-183

24. ———. "Supplying Information to Facilitate Price Discrimination," *International Economic Review* 35 (1994): 309-327

25. ———. Information Management in Incentive Problems, *Journal of Political Economy* 105 (1997): 796-821

26. Ottaviani, M. and Prat, A. "The Value of Public Information In Monopoly," *Econometrica* 69 (2001): 1673-1683

27. Ottaviani, M and Sorenson P "Herd Behavior and Investment: Comment," *American Economic Review*, (2000) 99(3) 695-704

28. Persico, N. "Information Acquisition in Auctions," *Econometrica* 68 (2000): 135-148

29. Piccione, M. and Tan, G., "A Simple Model of Expert and Non-expert Bidding in First Price Auctions," *Journal of Economic Theory* 70 (1996) 501-15

30. Prendergast, C. and Stole, L., "Impetuous Youngsters and Jaded Old-Timers: Acquiring a Reputation for Learning," *Journal of Political Economics*, 104 (6) (1996) 1105-1134

31. Riordan, M. and Sappington, D., "Information, Incentives and Organizational Mode," *Quarterly Journal of Economics*," 102 (1987) ,243-263

32. Rochet, J.C and Chone, P. "Ironing, Sweeping and Multidimensional Screening," *Econometrica* 66 (1998),783-826

33. Rothschild, M. and Stiglitz, J.E. "Increasing Risk:I, *Journal of Economic Theory*, 2 (1970) 225-243

34. Scotchmer, S., (1999) "On the Optimality of the Patent Renewal System," *Rand Journal of Economics*, Vol. 30, No. 2, Summer 1999.

35. Sobel, J,. "Information Control in the Principal-Agent Problem," *International Economic Review,* 34 (1993) 250-69

36. Stole, L,. "The Economics of Liquidated Damage Clauses in Contractual Environments with Private Information," *Journal of Law Economics and Organization*, 8 (1992) 582-606

37. Szalay, D,. "On the One-handed Economist," *Review of Economic Studies* (1993)

38. Taylor, C., "The Economics of Breakdowns, Checkups and Cures," *Journal of Political Economics*, 103 (1995) 53-74

39. Williamson, O ,*Markets and Hierarchies, Analysis and Antitrust Implications*, New York (Free Press) (1975)

40. Wolinsky, A. "Competition in a Market for Informed Experts' Services," *Rand Journal of Economics* 24(3) (1993) 380-98