

Contracting Structures for Custom Software Development: The Impacts of Informational Rents and Uncertainty on Internal Development and Outsourcing

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Custom software development projects have special informational attributes that have challenged managers for many years: they are associated with information asymmetries regarding user valuation and developer costs, relationship-specific investments, and a resulting likelihood of positive externalities for the user or the developer from the other party's investment. Furthermore, in a custom project, market prices for software are not helpful in solving either the valuation or the cost problems. In this paper we analyze the unique nature of the software development agreements that can be reached between the user and the developer in such a setting. We compare the value of using internal and external developers, with the goal of better understanding the factors relevant to the outsourcing decision. For internal development, we derive a new mechanism that achieves the first-best system whenever the project has positive expected net value, while achieving ex ante budget balance. In contrast, the optimal mechanism for an external developer will not in general yield the first-best system. This implies that when internal and external developers have identical cost functions, internal development definitely yields the larger net value. More generally, this implies that an external developer must have considerable cost advantages over an internal developer in order to have the larger net value. Numerical results indicate that this difference in net values can be very large, as much as a 100% increase for internal development over external development. This is consistent with the strong bias in favor of internal custom development found in recent empirical studies. We also explain why the efficient levels of investment can be achieved only when there are no externalities, and we show that the presence of positive externalities results in underinvestment. Since using an external developer will typically yield a system that is not first-best, inefficient investments result with or without externalities. We present examples showing that uncertainty about system value is not a significant factor in choosing between internal and external development. However, uncertainty about the development costs is highly significant, with greater uncertainty making outsourcing less attractive.

(Software Development; Outsourcing; Bargaining; Revelation Principle; Relationship-specific Investment; Externalities; Informational Asymmetry)

Research on software development outsourcing has been minimal. Richmond et al. (1992) provide a model that attempts to characterize the conditions under which an organization will outsource its software enhancements. They differentiate internal and external development by assuming that the internal developer will be paid a flat salary whereas an external developer will be paid by an incentive scheme (profit sharing). Their model, however, ignores the dominant role that central management can play when a project is to be developed internally.

Richmond and Seidmann (1993) develop a model consisting of two stages, system design and system development, that allows them to compare two outsourcing contractual forms: stage-by-stage contracting and two-stage contracting. Their model has two limitations that need to be addressed. First, the "design" of the system is not explicitly modeled; it is assumed that the expected value of system design is increasing in the vendor's specific investment. This leaves nothing for the contractual parties to bargain for other than the prices for designing and developing the system. Second, the presence of informational asymmetries plays a minor role in their model, since the decisions are made either in expectation or with complete information. Consequently, some essential elements of bargaining are lost in the contracting process.

Whang's model (1992) is probably the most elaborate formal analysis of software contracting in the IS literature thus far. By assuming that the external developer and a hypothetical in-house developer have the same production technology and informational characteristics, Whang formulates a "viable" software contract for external development that implements the same equilibrium outcome as in the hypothetical case of in-house development. In his model, the software development is composed of N phases, and the uncertainties about development costs are progressively resolved as the project advances. Whang then derives a "viable" contract which is *efficient*, *Pareto optimal*, *incentive compatible*, and *individually rational*. Nonetheless it is unclear how this contract can be reached in a bilateral bargaining situation if each party's main interest is to maximize its own payoff instead of the combined payoff.

The property rights approach would appear to be promising since it provides a useful theory of vertical

and lateral integration, and it has also produced several novel studies in the IS field, e.g., Alstyne et al. (1995), Brynjolfsson (1994), Lacity et al. (1995), Loh and Venkatraman (1995). It lacks, however, elements of hierarchical control that are central to our analysis when systems are to be developed internally, especially the role of the central management in prescribing and enforcing mechanisms for directing, regulating, and coordinating business activities. Since the sourcing decision of system development is basically a "make or buy" problem, transaction cost economics (TCE) would seem to provide an appropriate analytical foundation for analyzing it (Williamson 1975, 1985). However, the basic TCE analysis is unsuitable for custom software development since this problem violates the key assumption of TCE models, namely that the basic unit of analysis, the transaction, must be characterized independent of the governance structure (Dow 1987, p. 18). This assumption is violated in our case since the developer's skill and business knowledge, and the functions and quality of the system, and thereby the value and cost of developing the system, are unlikely to remain invariant with different sources or providers.

Banker and Kemerer (1992) develop a principal-agent model that provides a set of decision criteria for the principal to use to develop an incentive-compatible contract for the agent. Built upon the work by Banker and Datar (1989), the "goodness" of a performance metric is judged by its *precision* and *sensitivity*. Since we do not explicitly address the difficulties of deriving and choosing effective software development performance metrics, this research is a good complement to ours.

The basic structure of our model is similar to the two-stage contracting of Richmond and Seidmann (1993), with an emphasis on software development bargaining outcomes under informational asymmetries, relation-specific investments, and investment externalities. This emphasis substantially differentiates our work from the studies reviewed above. Bargaining is the process of arriving at a mutual agreement on the provisions of a contract. With informational disparities, the contractual parties' incentives for strategic behavior and the necessity of communication must be explicitly recognized and studied. Moreover, our focus on two-stage contracts is justified by noting that, other things being equal, a long-term contract can always be structured to

mimic a series of short-term contracts, and it thereby replicates the performance generated by short-term contracts.

The plan of the paper is as follows. Our model is introduced in §2. We examine the internal development case in §3 and then turn to the outsourcing case in §4. Section 5 presents a numerical example, and §6 contains managerial implications and concluding remarks.

Glossary of Symbols

α	Initial investment by the user
β	Initial investment by the developer
$m(\alpha)$	User's investment cost function
$n(\beta)$	Developer's investment cost function
ω	Parameter representing the user's private information about system value
Ω	Set of feasible values for ω
$F(\omega)$	Probability distribution representing the user's prior beliefs about ω
θ	Parameter representing the developer's private information about costs
Θ	Set of feasible values for θ
$G(\theta)$	Probability distribution representing the developer's prior beliefs about θ
$T(\hat{\omega})$	User's expected payment for the system when reporting $\hat{\omega}$
$B(\hat{\theta})$	Payment the developer expects to receive when reporting $\hat{\theta}$
\mathcal{K}	Set of feasible system specifications
q	Scalar representing the system specification
q^*	First-best (efficient) system specification
q''	Optimal system specification under outsourcing
$V(q, \omega \alpha, \beta)$	User's value function

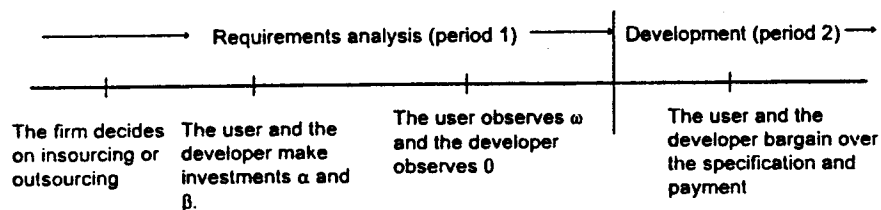
$C(q, \theta \alpha, \beta)$	Developer's cost function
$U(\hat{\omega}; \omega)$	User's expected net value from the system when ω is the true valuation parameter and $\hat{\omega}$ is reported (period 2)
$\Pi(\hat{\theta}; \theta)$	Developer's expected profit from the system when θ is the true cost parameter and $\hat{\theta}$ is reported (period 2)
r^o	Marginal-cost-of-requirements-effort parameter for the outsourcer (numerical example)
r	Marginal-cost-of-requirements-effort parameter for the internal developer (numerical example)

2. The Model

The events and timing of the model are summarized in Figure 1. Before a custom development project can begin, the user firm must decide either to have the system developed internally or to outsource it to an external developer, since the specificity of the investment implies that switching developers once the project is underway will be prohibitively costly. (Our model can easily accommodate switching developers by adding switching costs, as in Richmond and Seidmann 1993, and making appropriate modifications to the user's investment function if the investment is not completely specific to the previous relationship.)

A search and screening process is typically needed before an organization can identify outsourcers who are good candidates (Klepper 1993). Although the price of an outsourcing deal is an important factor in making the selection, a provider's track record and its business knowledge appear to be at least as important as price (Collins and Millen 1995, Livingston 1992). This is usual for applications development outsourcing,

Figure 1 Timeline of the Model



which requires outsourcers to have domain knowledge and industry know-how of the client's business. Hence we assume that there is only one potential outsourcer who has been selected based on its track record and business knowledge, so the contract bidding process is not modelled explicitly in this paper. (For bidding models see McAfee and McMillan 1986, 1987.)

After the sourcing decision is made, the user and the developer make relationship-specific investments α and β , respectively. These can be thought of as the effort expended on the requirements analysis (Kuo and Wang 1995). In this paper, we will focus on cases where α and β are not contractible. The effect of contractibility will be discussed briefly in §6; a fuller exposition can be found in Wang et al. (1994). We assume that the system's value is affected by a parameter, ω , which captures the user's private valuation information; the user's own investment, α , the developer's investment, β ; and the system specification, $q \in \mathcal{K}$, where \mathcal{K} is the set of feasible specifications. Similarly, the developer's cost to develop the system is affected by a parameter, θ , which captures the developer's private cost information, as well as α , β , and q . Features represented by q include functionality, reliability and response time as well as less tangible attributes, such as the degree of user-friendliness, the completeness of the database design, and the accuracy of the system's stored data and outputs. More generally, we may consider q to be the level (of quality) of service provided through the target system, as in Barua et al. (1991). For concreteness, q may be thought of as the number of function points represented by a system specification.

Neither the user nor the developer knows the realization of ω or θ when they make investments in period 1. However, they do have prior beliefs about ω and θ , represented by the probability distributions $F(\omega)$ and $G(\theta)$ with positive supports over $\Omega = [\underline{\omega}, \bar{\omega}]$ and $\Theta = [\underline{\theta}, \bar{\theta}]$, respectively. After the investment has been made, the user (developer) learns the realized ω (θ) but not the realized θ (ω). Thus at the bargaining stage the user possesses private information about the system's value, while the developer possesses private information about the system's development cost. We assume that the realized ω and θ are not correlated, so the user's

(developer's) beliefs about θ (ω) will not change after learning ω (θ).²

Given the investments made and the private information learned in period 1, the user and the developer bargain over the desired system specification, q , to be put into the (internal or outsourcing) contract and the corresponding payment for developing the system in period 2. While creating a cooperative or strategic partnership with the outsourcer is important if outsourcing is chosen (Klepper 1993, Willcocks and Choi 1995), outsourcers appear to be primarily driven by profit motives (Lacity and Hirschheim 1993a, 1993b). Even for internal development, IS staff often have private incentives that conflict with those of the organization as a whole (Beath and Straub 1989, Gurbaxani and Kemerer 1989, Wang and Barron 1995). Consequently, instead of relying on the Shapley values of a cooperative game as is done in Alstyne et al. (1995), we adopt a noncooperative bargaining game approach.

The "revelation principle" (Myerson 1979) implies that a bargaining game can be specified as a direct revelation game with the bargaining parties' truth-revelation as an equilibrium. Each bargaining party chooses the report to provide to a mediator depending on what he or she knows initially; incentive compatibility restricts the outcomes resulting from each pair of reports to ensure that truth-revelation is optimal³ for each party. When a "principal" or mechanism designer is introduced into a bargaining game with private information, we are dealing with a game of mechanism design, in which the principal designs a "mechanism," "contract," or "incentive scheme" to maximize her expected payoff (Fudenberg and Tirole 1996, Ch. 7). Although a game of mechanism design can have many

² A third-party budget balancer implies the existence of an efficient bargaining mechanism when the value and the cost are correlated, provided that the conditional distribution functions satisfy certain properties (McAfee and Reny 1992). However, an efficient mechanism with correlated information still requires a budget balancer who can break-even on average, but not for all realizations, thus a trade that is not closed. Since introducing correlated information into our model provides no additional qualitative results and complicates our derivations greatly, we focus on the uncorrelated case.

³ One of the references in the literature states that the revelation mechanism provides only epsilon truthfulness; an agent who derives satisfaction from lying will lie.

stages, the revelation principle implies that the principal can obtain her highest expected payoff through a static Bayesian game with all agents simultaneously and truthfully revealing their private information in equilibrium.

In this paper, the central management of an organization is modelled as the mechanism designer for deriving software development contracts. Depending on the central management's preferences, different revelation mechanisms may be chosen with different weights that the central management puts on the "welfare" of the user and the developer. We differentiate internal and external development by assuming that the central management can serve as a mediator as well as a budget balancer when the system is developed internally. When the system is developed externally, we assume the user (or the organization) has all the bargaining power to make a take-it-or-leave-it offer to the external developer. Although this assumption is primarily used to highlight that a different "welfare weight" is placed on the external developer's profit, it can also partially reflect the fact that external software contracts still contain many hierarchical elements (Ang and Beath).

Our model assumes that the user's investment will increase the system's value at a diminishing rate, while the developer's investment may or may not affect the system's value. When it does, it creates positive investment externalities and also increases the system's value at a diminishing rate. Similarly, the developer's investment will reduce the system's cost at the development stage at a diminishing rate. The user's investment may or may not affect the development cost. When it does, it creates positive investment externalities and decreases the system's cost at a diminishing rate. Also, the marginal value of the system with respect to q is increasing in α and nondecreasing in β and ω . Similarly, the marginal cost of the system with respect to q is decreasing in β and nonincreasing in α and θ . Other properties are typical regularity requirements for deriving unambiguous solutions. To avoid repeated descriptions, we assume that all the functions are sufficiently smooth, so that all differentiability requirements are satisfied. These considerations lead to the following assumptions.

ASSUMPTION 1. *The investment cost functions, $m(\alpha)$ and $n(\beta)$, are increasing and convex.*

ASSUMPTION 2. 1. *The user's value function, denoted by $V(q, \omega | \alpha, \beta)$, is concave in q with $V_{q\omega} \geq 0$, $V_\alpha > 0$, $V_{\alpha\alpha} < 0$, $V_{q\alpha} > 0$, $V_\beta \geq 0$, $V_{\beta\beta} \leq 0$, $V_{q\beta} \geq 0$, and $V_{\omega q\eta} \leq 0$. 2. *The developer's cost function, denoted by $C(q, \theta | \alpha, \beta)$, is convex in q with $C_{q\theta} \geq 0$, $C_\beta < 0$, $C_{\beta\beta} > 0$, $C_{q\beta} < 0$, $C_\alpha \leq 0$, $C_{\alpha\alpha} \leq 0$, $C_{q\alpha} \leq 0$, and $C_{\theta q\eta} \geq 0$.**

For regularity, we make the following assumption regarding the distribution functions $F(\omega)$ and $G(\theta)$.

ASSUMPTION 3. *For all ω in Ω and all θ in Θ , $F(\omega)/f(\omega)$ is increasing in ω and $G(\theta)/g(\theta)$ is increasing in θ .*

This is the monotone hazard rate condition, which is satisfied by many families of probability distributions, including the normal, the exponential, the Poisson, and the uniform (Milgrom 1982). The purpose of this assumption is technical; without it convexification is required to ensure global incentive compatibility of the bargaining solution that we derive later (see Guesnerie and Laffont 1984).

Because developers differ in experience and business and technical knowledge, the costs of communication, identification of requirements, and project monitoring can be quite different for internal and external development. Thus, the functions used for these two alternatives can be quite different in general, and one alternative may clearly dominate the other. Usually outsourcers specialize in a particular industry, thus developing specific industry know-how. Under these circumstances, economies of specialization and technical expertise make it likely that outsourcers can deliver an effective system at a significantly lower cost. This may be why many practitioners argue that both internal and external alternatives have to be carefully evaluated before a good sourcing decision can be made (Benko 1993).

Property rights over the system developed is another key difference between internal development and outsourcing. Although IS innovations may be in the "weak regime of appropriability" (Teece 1987), so that the strategic advantages generated by a proprietary system are unlikely to last very long, the well-established property rights of internally developed systems can reduce management's fear that what they thought was a competitive advantage is being sold on the open market. Even though an organization may team up with an

outsourcer to produce systems that are to be put on the open market, the rights to grant, to own, to sell, and to modify the systems may only be established through costly negotiations.

Compressing system development time and reducing the development backlog usually are important factors that motivate firms to seek external help. In addition, the contracting and contract management costs may also consume significant management time and organizational resources (Earl 1996). These considerations can also be captured by the user's valuation since the effects of outsourcing on these factors must be properly evaluated and estimated at the beginning of the sourcing decision.

Based on this model, we evaluate internal development and outsourcing. The net value that can be generated by internal development can then serve as a benchmark for the firm to decide whether to outsource the development. The analysis is conducted by applying the mechanism design approach introduced earlier.

3. Internal Development

Within an organization, the central management should have all the bargaining power, so it can prescribe any coordination or bargaining mechanism it sees fit. Moreover, since it can also serve as a communication mediator and budget balancer, the "trade" between the user and the internal developer is not financially closed. Thus, the user's payment for the system need not equal the payment received by the developer, i.e., we allow budget-breaking when the system is developed internally. The central management's objective is assumed to be to maximize the system's expected net value.

When budget-breaking is feasible, it is well-known that a Clarke-Groves-type scheme—"user pays C , developer receives V "—can achieve the first-best outcome, since the transfers do not depend on the parties' private information and therefore provide no incentives for misrepresentation (Groves). However, under this scheme the central management will have to make up the balance, and therefore it will always incur a budget deficit equal to the total gains of the system. This double counting of the system's net value may distort performance measures significantly. To minimize this, the central management on average should be able to at

least balance its own budget, while both the user and the developer can earn "fair returns" or informational rents to their expertise due to their superior information about their local environment. Even though the compensations of employees are largely governed by the labor market, this sort of rent can stem from the employees' firm-specific human capital and are unlikely to be competed away in any long-term relationship. Thus, it is reasonable to consider these rents to be the user's and the developer's "fair return" to their expertise in so far as the internal performance evaluation is concerned.

3.1. Period 2: Internal Bargaining

We work backward and first study the bargaining outcomes in period 2 of the model. At this point, investments α and β have been made, and the user (developer) knows the realized ω (θ) but not the realized θ (ω). This is a bargaining problem with two-sided incomplete information, and the central management's objective is to maximize $V(q, \omega) - C(q, \theta)$. It is clear from Assumption 2 that $V(q, \omega) - C(q, \theta)$ is concave in q and thereby admits a unique solution.

The revelation principle allows us to focus on the set of direct revelation mechanisms without loss of generality (Myerson 1979). We now derive the optimal truth-revelation mechanism as well as the condition under which the central management can expect not to incur a budget deficit ex ante. Let

1. $T(\hat{\omega}, \hat{\theta})$: the user's payment to the central management for the system when the user reports $\hat{\omega}$ and the developer reports $\hat{\theta}$;
2. $B(\hat{\omega}, \hat{\theta})$: the payment received by the developer from the central management when the user reports $\hat{\omega}$ and the developer reports $\hat{\theta}$.

Since the central management need not balance its budget ex post, T need not equal B . Given the equilibrium investments $(\bar{\alpha}, \bar{\beta})$ from period 1 and the realizations (ω, θ) , the system's net value is⁴

$$W(q, \omega, \theta) = V(q, \omega) - C(q, \theta). \quad (3.1)$$

Then the efficient (first-best) software specification is

⁴ For notational clarity, we suppress the equilibrium investments whenever doing so would not cause any confusion.

$$q^*(\omega, \theta) \equiv \arg \max_{q \in \pi} W(q, \omega, \theta).$$

Let

$$W(\omega, \theta) \equiv V(q^*, \omega) - C(q^*, \theta),$$

$$T(\omega) \equiv \int_{\Theta} T(\omega, \theta) dG(\theta),$$

$$B(\theta) \equiv \int_{\Omega} B(\omega, \theta) dF(\omega).$$

The revelation principle implies that we can confine our attention to the set of truth-revelation mechanisms without loss of generality. Then the user's expected payoff is

$$U(\hat{\omega}; \omega) \equiv \int_{\Theta} V(q^*(\hat{\omega}, \theta), \omega) dG(\theta) - T(\hat{\omega}),$$

when the realization is ω and she reports $\hat{\omega}$, and the developer's expected payoff is

$$\Pi(\hat{\theta}; \theta) \equiv B(\hat{\theta}) - \int_{\Omega} C(q^*(\omega, \hat{\theta}), \theta) dF(\omega),$$

when the realization is θ and he reports $\hat{\theta}$. Thus, the central management's problem is to set the software specifications, the user's charges, and the developer's payment that will maximize the system's net value. The following well-known lemma characterizes the set of incentive-compatible and individually rational mechanisms (see Wang et al. 1994 for a proof).

LEMMA 1. *A direct mechanism is feasible if and only if*

$$T(\omega) = \int_{\Theta} \left\{ V(q^*, \omega) - \frac{1 - F(\omega)}{f(\omega)} V_{\omega}(q^*, \omega) \right\} dG(\theta) - U(\underline{\omega}), \quad (3.2)$$

$$B(\theta) = \int_{\Omega} \left\{ C(q^*, \theta) + \frac{G(\theta)}{g(\theta)} C_{\theta}(q^*, \theta) \right\} dF(\omega) + \Pi(\bar{\theta}), \quad (3.3)$$

where $U(\underline{\omega}) \geq m(\bar{\alpha})$ and $\Pi(\bar{\theta}) \geq n(\bar{\beta})$.

Although the investments are sunk at the bargaining stage, the overall mechanism must compensate for the costs of the investments so that both the user and the

developer are willing to participate at the beginning of the project. Thus $U(\underline{\omega})$ and $\Pi(\bar{\theta})$ can be set to be the central management's equilibrium beliefs about the investment costs, i.e., $U(\underline{\omega}) = m(\bar{\alpha})$ and $\Pi(\bar{\theta}) = n(\bar{\beta})$, where $\bar{\alpha}$ and $\bar{\beta}$ are the equilibrium investments. Also, because the user and developer are both players with private information at the bargaining stage, the central management must independently consider all possible realizations of the value and cost parameters in choosing a mechanism.

From Lemma 1, the user's expected payment before learning the realized ω is

$$\begin{aligned} & \int_{\Omega} T(\omega) dF(\omega) \\ &= \int_{\Omega} \int_{\Theta} \left\{ V(q^*, \omega) - \frac{1 - F(\omega)}{f(\omega)} V_{\omega}(q^*, \omega) \right\} \\ & \quad \cdot dG(\theta) dF(\omega) - m(\bar{\alpha}), \end{aligned}$$

and the developer's expected revenue before learning the realized θ is

$$\begin{aligned} & \int_{\Theta} B(\theta) dG(\theta) \\ &= \int_{\Theta} \int_{\Omega} \left\{ C(q^*, \theta) + \frac{G(\theta)}{g(\theta)} C_{\theta}(q^*, \theta) \right\} \\ & \quad \cdot dF(\omega) dG(\theta) + n(\bar{\beta}). \end{aligned}$$

In order to induce the user and developer to reveal their private information, not all of the user's expected gross value is taxed away, and some premium over expected cost is paid to the developer. Thus, the second term in brackets of each of the above equations represents the user's and the developer's informational rents that the central management will not extract.

If the expected system net value is large enough to cover both the user's and the developer's informational rents as well as their investment costs, the central management can expect on average not to incur a budget deficit. The following theorem uses McAfee's results to characterize the condition under which this property can be satisfied.

THEOREM 1. *The central management can implement $q^*(\omega, \theta)$ and on average at least balance the budget if*

$$\int_{\Theta} \int_{\Omega} W(\omega, \theta) dF(\omega) dG(\theta) + m(\bar{\alpha}) + n(\bar{\beta})$$

$$\leq \int_{\Theta} W(\underline{\omega}, \theta) dG(\theta) + \int_{\Omega} W(\omega, \bar{\theta}) dF(\omega). \quad (3.4)$$

Thus whenever (3.4) holds, the central management can expect to at least balance the budget while at the same time inducing truth revelation and achieving bargaining efficiency. Although the direct revelation mechanism leaves the details of the bargaining process unspecified, we may imagine that the user and the developer can bargain effectively over the system specification until all the potential gains from developing the system are exhausted. Note that the main purpose of this mechanism is not to balance the budget per se—it may not be balanced ex post anyway. Instead, its main purpose is to minimize the distortion of performance measures while maintaining efficiency. Thus, the (sunk) investment costs that the user and the developer make in period 1 can be covered by the extra budget allocation based on the central management's equilibrium beliefs about their investments even when the investments are not enforceable.

3.2. Period 1: Investment

First consider the case where the specific investments create no externalities, i.e., $V_{\beta} = 0$ and $C_{\alpha} = 0$.⁵ The efficient investments are

$$(\alpha^*, \beta^*) \equiv \arg \max_{\alpha, \beta} \int_{\Theta} \int_{\Omega} \{V(q^*, \omega | \alpha, \beta) - C(q^*, \theta | \alpha, \beta)\} dF(\omega) dG(\theta) - m(\alpha) - n(\beta).$$

The efficient investments are given by the following first-order conditions:

$$0 \equiv \int_{\Theta} \int_{\Omega} V_{\alpha}(q^*, \omega | \alpha^*, \beta^*) dF(\omega) dG(\theta) - m'(\alpha^*);$$

$$0 \equiv - \int_{\Theta} \int_{\Omega} C_{\beta}(q^*, \theta | \alpha^*, \beta^*) dF(\omega) dG(\theta) - n'(\beta^*).$$

Given Assumption 2, the first-order conditions are also

⁵ Relatively standard systems such as transaction processing or networking using standard protocols (POS, EOS, MRP, EDI, accounting, etc.) would tend to fall in this category.

sufficient. The following theorem characterizes the efficiency of the relationship-specific investments.

THEOREM 2. *Given the efficient mechanism in period 2 (development), the ex ante investments are also efficient regardless of whether the investments are contractible, provided that the investments create no externalities.*

The intuition behind this result is simple. Given that the central management's beliefs are set at $(\bar{\alpha}, \bar{\beta})$, the user can predict the resulting specification of the new system. Moreover, since the user also knows her own optimal reporting strategy perfectly, she can again predict the exact specification as a function of θ . Since the central management's belief about $\bar{\alpha}$ is fixed, the user internalizes all of the benefits in terms of incremental value and therefore will always be induced to make an efficient level of investment based on the expected specification.

The way that the mechanism works can be described as follows. At the outset, the central management displays a mechanism (or a contract) defined as

$$(q^*(\cdot), T^*(\cdot), B^*(\cdot)).$$

It also instructs the user and the developer to make investments equal to α^* and β^* , respectively. Knowing that they can fully appropriate the extra informational rents generated by their investments at the bargaining stage, they realize that the optimal action is to follow the central management's instruction through their private calculations. After making the investments and obtaining their private information, the parties bargain over the system specification and payment according to the rules specified in the mechanism. Since, by the construction of the mechanism, truth-revelation is the dominant strategy for both parties, the efficient software specification q^* is implemented.

Our result shows that under-investment will not arise when the investments generate no positive externalities. If the investments do generate positive externalities, under-investment occurs.⁶ This is because $T^*(\cdot)$ and $B^*(\cdot)$ only depend on the central management's beliefs, $(\bar{\alpha}, \bar{\beta})$, and consequently neither the user nor the

⁶ Such systems are typically less standard and frequently associated with business innovations with a potential strategic impact.

developer will internalize the externalities, which leads to inefficient investments. Investment externalities cause problems simply because each party is only interested in its own expected payoff and thus has no incentive to take account of those externalities in its own optimization. As a result, the overall level of investment will be lower than the efficient level for both parties. So, unless a mechanism internalizes both parties' potential gains due to their investments, efficiency will not be achieved at the investment period. This problem of incontractibility is typically less severe for internal development than for outsourcing since close monitoring is less costly and over time the user is likely to develop a better understanding of the internal IS staff's performance and efforts.

The mechanism proposed here is not coalition-proof. This quality is desirable, since if the direct revelation mechanism is used regularly, users and the developer would have incentives to collude to inflate the overall informational rent that they can extract. Considering this possibility, however, introduces an additional layer of private bargaining between users and developer for deciding how the extra informational rent should be divided, and thus it is beyond the scope of the paper.

4. Outsourcing

Under outsourcing, there is no third party to serve as mediator and budget balancer. In our model the user has all of the bargaining power—the user can make a take-it-or-leave-it offer to the developer—since this assumption provides the upper bound of the user's expected payoff from outsourcing. The problem then becomes a model with one-sided incomplete information with all the welfare being put on the user's net gains from the system, and the solution that we derive at the bargaining period is the user's *neutral bargaining solution* (Myerson 1985). Of course, the welfare weights on the parties' net gains can be appropriately adjusted to reflect the bargaining power of the parties in case of more balanced bargaining power. However, with such a modification, all the qualitative results are unchanged except for making outsourcing a less desirable alternative.

4.1. Period 2: External Bargaining

Given $(\bar{\alpha}, \bar{\beta})$ and the fact that the user has all the bar-

gaining power, the revelation principle implies that the user's problem in period 2 for a realized ω can be formulated without loss of generality as:

$$\max_{q(\cdot), T(\cdot)} \int_{\Theta} \{V(q, \omega) - C(q, \theta) - T(\theta)\} dG(\theta), \quad (4.1)$$

subject to the developer's participation constraints

$$\Pi(\theta) \geq \Pi(\hat{\theta}; \theta), \quad \forall \hat{\theta}, \theta \in \Theta, \quad (4.2)$$

$$\Pi(\theta) \geq 0, \quad \forall \theta \in \Theta, \quad (4.3)$$

where the user's expected payoffs are

$$U(\hat{\theta}; \theta) \equiv T(\hat{\theta}) - C(q(\hat{\theta}), \theta).$$

The incentive compatible and individually rational payment is (Guesnerie and Laffont):

$$T(\theta) = C(q(\omega, \theta), \theta) + \int_{\underline{\theta}}^{\theta} C_{\theta}(q(\omega, \hat{\theta}), \hat{\theta}) d\hat{\theta} - n(\bar{\beta}). \quad (4.4)$$

So, given a realized θ , the extra cost term in (4.4),

$$\int_{\underline{\theta}}^{\theta} C_{\theta}(q(\omega, \hat{\theta}), \hat{\theta}) d\hat{\theta},$$

is the extra real dollars that the user has to pay the developer ex post. Further, by pointwise optimization the optimal system specification for outsourcing, q^* , is the solution to the following identity:

$$0 \equiv V_q(q^*, \omega) - C_q(q^*, \theta) - \frac{G(\theta)}{g(\theta)} C_{\theta q}(q^*, \theta). \quad (4.5)$$

This equation manifests the incentive constraints that the mechanism designer must take into account. The term

$$\frac{G(\theta)}{g(\theta)} C_{\theta q}(q^*, \theta)$$

represents the informational rent required for inducing truth-revelation. Since the user has to account explicitly for the developer's informational rents in choosing a system specification, she will choose a specification that is not socially efficient.

4.2. Period 1: Investment

Since the user has perfect control over her own investment, she can offer a contract based on the realized ω ,

her investment, α , and her beliefs about the developer's investment, $\bar{\beta}$. We first consider the case with no externalities. Letting $q^o(\omega, \theta | \alpha, \bar{\beta})$ denote the user's optimal system specification given $\bar{\beta}$, using the argument in the previous section we can show that, with the developer's beliefs about the user's investment fixed at $\bar{\alpha}$, his optimal investment decision is

$$\beta^o \equiv \max_{\beta} \int_{\Theta} \int_{\Omega} \left\{ C(q^o, \theta | \bar{\alpha}, \bar{\beta}) + \frac{G(\theta)}{g(\theta)} C_{\theta}(q^o, \theta | \bar{\alpha}, \bar{\beta}) - C(q^o, \theta | \bar{\alpha}, \hat{\beta}) \right\} dF(\omega) dG(\theta) - n(\hat{\beta}).$$

In his private calculation the developer's investment can only affect his own development cost, not the payment, which is fixed at the user's beliefs. Consequently, the developer's optimal investment decision is determined by the solution to the following first-order condition:

$$-\int_{\Theta} \int_{\Omega} C_{\beta}(q^o, \theta | \bar{\alpha}, \hat{\beta}) dF(\omega) dG(\theta) = n'(\hat{\beta}). \quad (4.6)$$

Since $C_{\beta\beta} > 0$ and $n''(\beta) > 0$, this necessary condition is also sufficient. Again in equilibrium the beliefs must be correct, so the developer will always minimize his own costs of development for a given system specification.

Similarly, given her beliefs about the developer's investment, $\bar{\beta}$, the user's optimal investment decision is

$$\alpha^o \equiv \max_{\alpha} \int_{\Theta} \int_{\Omega} \left\{ V(q^o, \omega | \hat{\alpha}, \bar{\beta}) - C(q^o, \theta | \hat{\alpha}, \bar{\beta}) - \frac{G(\theta)}{g(\theta)} C_{\theta}(q^o, \theta | \hat{\alpha}, \bar{\beta}) \right\} dF(\omega) dG(\theta) - m(\hat{\alpha}).$$

Since, in the absence of the externalities, the user's investment has no effect on the system's development cost, and thus no effect on the developer's informational rents, she will make her investment based on its effect on the system's value alone. Then, by the envelope theorem, the necessary condition for the user's investment problem is

$$\int_{\Theta} \int_{\Omega} V_{\alpha}(q^o, \omega | \bar{\alpha}, \bar{\beta}) dF(\omega) dG(\theta) = m'(\bar{\alpha}), \quad (4.7)$$

in the absence of investment externalities. Since $V_{\alpha\alpha}$

< 0 and $m''(\alpha) > 0$, this necessary condition is also sufficient. So in equilibrium,

$$m'(\alpha^o) \equiv \int_{\Theta} \int_{\Omega} V_{\alpha}(q^o, \omega | \alpha^o, \beta^o) dF(\omega) dG(\theta),$$

$$n'(\beta^o) \equiv -\int_{\Theta} \int_{\Omega} C_{\beta}(q^o, \theta | \alpha^o, \beta^o) dF(\omega) dG(\theta).$$

Thus (α^o, β^o) are "efficient" in the sense that α^o always maximizes the user's expected value and β^o always minimizes the developer's cost for the expected system specification, q^o . However, since q^o itself is not efficient, due to the effect of the developer's informational rents, the investments fail to be efficient. The following result shows that both parties' investments are socially deficient.

THEOREM 3. *When the relationship-specific investments are not contractible, the user's and developer's investments are both socially deficient for external development even in the absence of positive investment externalities.*

Obviously, if the value and cost of developing the system are the same for internal development and outsourcing, the only difference between these two cases is how the cost is evaluated. Using internal development, the extra ex post cost, $\int_{\Theta} C_{\theta}(q, \theta) d\theta$, is part of internal accounting, and no real resources have been transferred out of the organization. For example, even though the internal IS department is evaluated as a profit center, the profit it generates typically is used to evaluate its performance, to signal the business value of its services, and to justify its expenditures and investments for internal resource allocation. However, for outsourcing, the extra cost is the outsourcer's profit margin, real dollars that the organization has to pay out. As Wendell Jones, the general manager of McDonnell-Douglas Aerospace Information Services, puts it, "the real difference between in-house support and outsourcing is that in-house support involves only internal accounting, whereas outsourcing involves real dollars going outside the corporation" (James 1993, p. 75). Consequently, the assumption that the central management puts full welfare weights on their informational rents is reasonable for the internal development case. This difference motivates the organization to distort the

system specification in order to make a tradeoff between the functionality of the system and the informational rents, or profit, that the outsourcer can command. This kind of evaluation is important, since it is common practice for outsourcers to charge excess fees for additional or optional system functions.

When investment creates externalities, because the payment is set based on the user's equilibrium beliefs about the developer's investment, the developer's optimal investment decision can again be derived by solving an equation similar to (4.6), which fails to account for the effect of his investment on the user's value. Consequently, the developer's optimal investment is further distorted.

For the user, the optimal investment is characterized by the identity:

$$\int_{\theta} \int_{\Omega} \left\{ V_{\alpha}(q^{\circ}, \omega | \alpha^{\circ}, \bar{\beta}) - C_{\alpha}(q^{\circ}, \theta | \alpha^{\circ}, \bar{\beta}) - \frac{G(\theta)}{g(\theta)} C_{\theta\alpha}(q^{\circ}, \theta | \alpha^{\circ}, \bar{\beta}) \right\} dF(\omega) dG(\theta) = m'(\alpha^{\circ}).$$

Thus, the user internalizes the effect of her investment

on the reduction of the developer's expected development cost as well as the virtual informational rent, since $C_{\alpha} < 0$ and $C_{\theta\alpha} \leq 0$. Hence if $C_{\theta\alpha} < 0$ and the developer invests at the socially efficient level, the user's investment will turn out to be higher than the socially efficient level. On the other hand, if the user invests at the socially efficient level, the developer's investment will be lower than the socially efficient level.

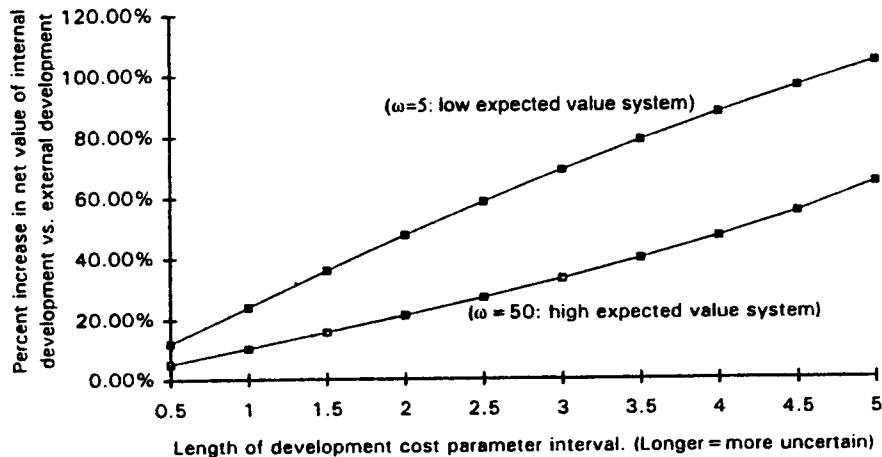
5. Numerical Example

We present a numerical example illustrating some of the magnitudes of the economic differences between outsourcing and internal development. Due to space constraints we consider only the case of no externalities. Let $V(q, \omega | \alpha, \beta) = \alpha + 2\omega q^{1/2}$, $C(q, \theta | \alpha, \beta) = \theta q \beta^{-1/2}$, $m(\alpha) = k\alpha^3/3 + s$, $n(\beta) = r\beta^3/3 + t$, and $n^o(\beta) = r^o\beta^3/3 + t^o$, where o refers to the outsourcer. We assume here $k = 1$, $s = 2$, $t = 1$, and $t^o = 1$. Also, uniform distributions are assumed for ω and θ throughout the example.

As proved earlier, when the internal and external developers have identical cost functions, the net value of

Figure 2 The Percentage Increase in Expected Net Value Using Internal Development Over External Development, as a Function of the Degree of Uncertainty About the Development Cost Parameter, θ , When Their Cost Functions are Identical.

Internal development (using our mechanism) yields a larger expected net value than external development. In the upper curve $\Omega = [5, 5]$, and $\Omega = [50, 50]$ in the lower. Uncertainty in the value parameter has little effect on the percentage differences. $\bar{\theta} = 6$ and $\underline{\theta} = (6 - \text{the value on the } x\text{-axis})$ for both developers. (Uniform distributions are used for both the value and the cost parameters.)



the system produced by an internal developer governed by our mechanism will be no worse than that for the outsourcer. Thus it is instructive to have an example of such a case as a baseline. Figure 2 shows a typical case where the developers have identical costs functions; clearly the difference in net value can be substantial. It is evident from Figure 2 that the benefit of internal development increases significantly with greater uncertainty about the development costs.

Figures 3 and 5 show the effect of varying the marginal-cost-of-requirements-effort parameters (i.e. r and r^o). Figures 3 and 5 differ in Θ and Θ^o . In Figure 3, $\Theta = \Theta^o = [5, 6]$, while in Figure 5 $\Theta = [5, 6]$ and $\Theta^o = [3.5, 5.5]$. The latter case corresponds to the situation in which central management feels more certain about internal development costs, but believes it is likely that the outsourcer under consideration has lower costs (i.e., smaller θ). Naturally, the expected net values of the optimal systems are decreasing in r and r^o . In Figure 3, we know that the internal developer must yield the higher net value whenever $r = r^o$ since they then have identical requirements and development cost functions. However, note that if the developers differ enough in requirements marginal costs, outsourcing can be preferable. In Figure 5 central management's beliefs about the outsourcer's expected development costs are low

enough to make outsourcing preferable. However, if the internal developer has enough of an advantage in requirements gathering (i.e., low enough r) it can be preferred. Not shown in the figures are the optimal amounts of requirements effort on the part of the developer (i.e., β^* , β^o); these also decrease in r and r^o , respectively.

Figures 4 and 6 show the optimal expected system specifications as functions of r and r^o ; the parameter values are the same as in Figures 3 and 5, respectively. While the optimal sourcing decision changes between Figures 3 and 5, internal development results in a higher specification (e.g., more function points) in both cases. This appears to be a consequence of the central management's ability to distort only the system specification in minimizing the outsourcer's information rent, whereas relaxation of the balance-of-trade requirement in dealing with the internal developer permits more freedom in reducing that rent.

Somewhat surprisingly, we found that uncertainty about the system value parameter, ω , has very little impact on the sourcing decision. The mean value of ω is a significant factor as Figure 2 shows, but the length of Ω is not very significant. Finally, extensive numerical experiments with this model failed to yield a case where a deficit occurred.

Figure 3 Expected Net Values (at Investment Time) as a Function of the Requirements Marginal Cost Parameters, r and r^o .

$\Omega = [25, 25]$ and $\Theta = [5, 6]$ for both. Between the two dotted lines is a range where external development can yield the higher expected net value, corresponding to the case where the external developer is much more efficient in requirements gathering. That is, when $1.6 < r$, there are values of $r^o, 1 \leq r^o \leq 1.2$ that cause external development to have the higher net value.

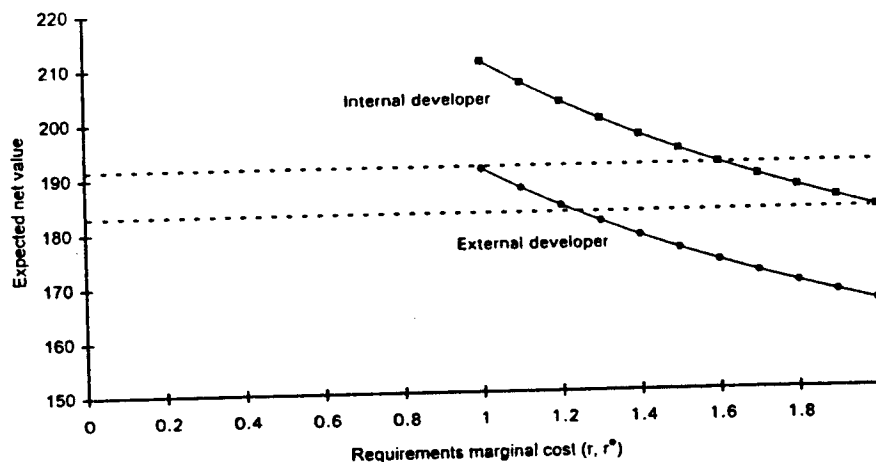
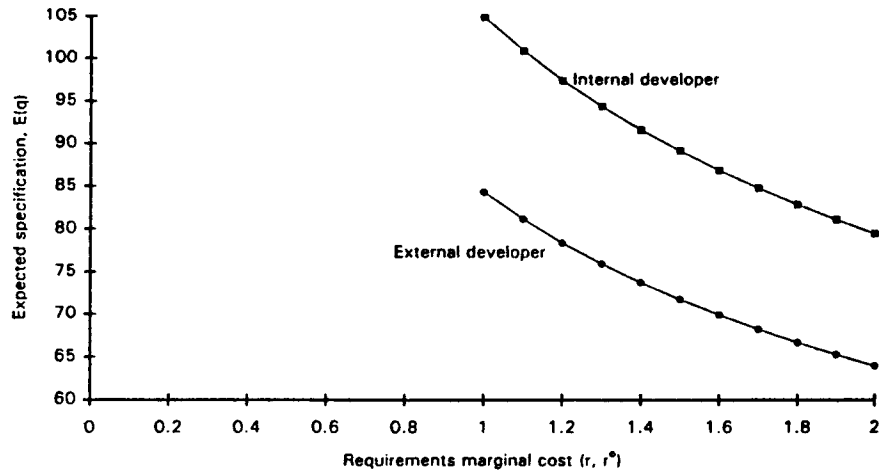


Figure 4 A Comparison of the Expected System Specifications (at Investment Time) Using the Same Parameter Set as in Figure 3



6. Managerial and Research Implications

Comparison with Nelson et al. (1996). Our modeling and numerical experiments indicate that an internal developer can be expected to have a substantial advantage over an outsourcer when both are governed optimally. Thus in a sample of sourcing decisions one would expect to see a significant bias in favor of internal development. Nelson et al. (1996) studied 186 projects from five firms and found that 64% were custom/insourced, 17% were custom/outsourced, 11% were package/insourced, and 8% were package/outsourced. Nelson et al. present the "not invented here" syndrome and empire-building as possible explanations for this bias. Our model indicates that such explanations are not needed; a rational firm will behave in just this way.

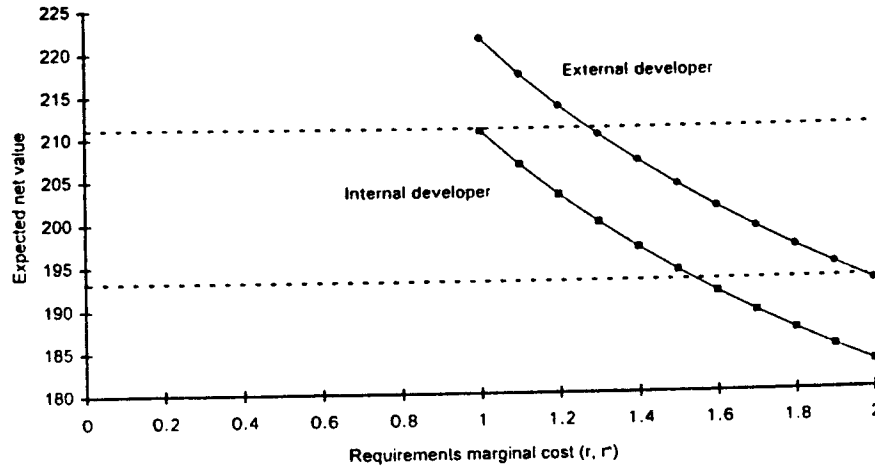
Our model makes no direct distinction between strategic and non-strategic systems, although this distinction has been made by many other researchers. Instead, in our model software must be characterized via its (expected) value, hence by ω , and the costs for both internal and external developers. As numerical experiments indicate, neither the expected value of ω nor uncertainty about it has much effect on the decision (Figure 2); the choice is driven by cost differences. Thus our model says that the sourcing of strategic systems depends on a case-by-case analysis, so that any attempt to predict sourcing as a function of a system's strategic value will

find no clear pattern. This is precisely what Nelson et al. find: "There is little support for the hypothesis that strategic systems are more likely to be insourced and/or custom-developed."

Comparison with Lacity et al. (1996). Based on case studies of organizations that have outsourced, Lacity et al. (1996) identify four types of systems, *critical commodity*, *critical differentiator*, *useful commodity*, and *useful differentiator*, and recommend a sourcing decision for each one. They define a *critical commodity* to be a system that is necessary to do business in a particular industry, but does not differentiate one firm from another. Thus an outsourcer that concentrates on a particular industry could be expected to have lower requirements costs due to reuse of requirements knowledge, and perhaps lower development costs as well. Lacity et al. recommend "best source" for such systems, that is, either internal or external development can be optimal depending on the particular features of a project. Figure 3 leads us to the same conclusion, while Figure 5 says outsourcing is best whenever the outsourcer has lower requirements costs. Thus relative development costs are a key piece of information in making the decision. A *critical differentiator* is idiosyncratic to an organization, differentiating it from its competitors. Lacity et al. recommend internal development in this case. Here we would expect the internal IS department to be at least as efficient as an outsourcer in requirements costs due to its familiarity

Figure 5 When the Developers Differ Enough in Their Cost Functions, External Development can be Preferred.

$\Omega = [25, 25]$, $\Theta = [5, 6]$, and $\Theta^o = [3.5, 5.5]$, corresponding to central management being more certain about the internal developer's costs, but believing that the external developer is probably cheaper in the development phase. As in Figure 3, between the dotted lines there are cases where the internal developer will have a higher net value if it is more efficient in requirements gathering.



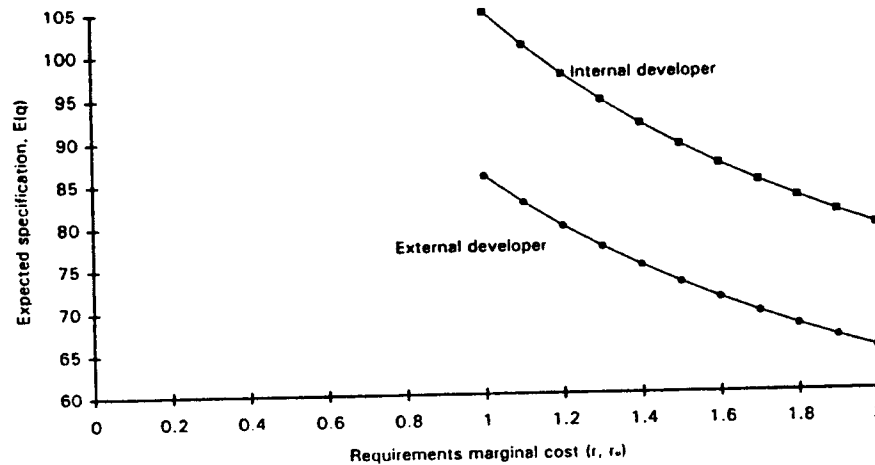
with existing business processes. However, development costs could go either way. In Figure 3, where development costs are the same, internal development is the dominant choice. In Figure 5, internal development is the most likely choice, but outsourcing could be optimal if the internal department is not sufficiently cheaper in requirements. A *useful commodity* is a relatively low value system common to many firms. Lacity et al. recommend outsourcing for such systems. Our model's recommendations are the same as those for a critical commodity, above. Their final category is *useful differentiator*, a type of system they say shouldn't exist, being a failed attempt to produce a critical differentiator. Their recommendation is to either eliminate the system or move it to one of the other categories. Our model would permit such a system, corresponding to one that has relatively low value (i.e., ω), and is idiosyncratic. This leads to the same conclusions that we arrived at for a critical differentiator. Thus we find the distinction between *critical* and *useful* to be irrelevant to the sourcing decision, while the *commodity* and *differentiator* distinction enters through the cost functions, and thus is relevant.

Using the Proper Objective Function and Correctly Measuring Costs. Although it may seem trivial, our model focuses attention on the proper objective in the

sourcing decision, namely maximizing the system's net value, and properly measuring costs. However, Nelson et al. argue: "When comparing internal and external acquisition, system value does not differ, because both teams are expected to deliver the same system." As our model demonstrates, the optimal systems produced by internal and external development will in general *not* be the same, with the internally developed system tending to have a larger specification (i.e., more "function points"). As a result, both the system gross values and costs will differ at optimum. Further, our model emphasizes that costs must be taken to include informational rents for the developer and user.

Importance of Incentives for Software Development. Although incentive- and performance-based contracts for outsourcing seem to be common, incentives are at least as important for internal development since central management can select from a broader range of incentive schemes. (See Ein-Dor and Jones 1985.) Using our internal trading mechanism, companies will build systems that achieve the maximum expected organizational net value while at the same time minimizing distortion of performance measures. Efficient levels of investment are also achieved by our approach in the absence of externalities, or when there are externalities and the investments are contractible. Our

Figure 6 Expected System Specifications using the Parameter Set of Figure 5



numerical example suggests that the economic impacts of the sourcing decision can be substantial. An outsourcer must have substantial cost advantages over a properly governed internal developer in order to provide the higher net value choice. While uncertainty about system value is inconsequential, uncertainty about development costs strongly favors internal development. As a result, we concur with Earl's (1996) question for management, "Why should we *not* in-source IT services?"

Choosing an Appropriate Contracting Scheme. We can use the comparison highlighted in Figure 2 to gauge the opportunity loss due to suboptimal governance of the internal department. Since the internal and external developers' cost functions are identical in Figure 2, we can interpret the graphs as showing the percentage loss occurring when the internal department is governed by the mechanism we prescribe for the outsourcer. This mechanism is superior to other kinds of contracts, such as fixed price, because it takes the developer's informational rent into account. Thus we can interpret Figure 2 as giving a lower bound on the increment in (gross) value of governing the internal department optimally, *exclusive of contracting costs*. This value increment must be traded off against the contracting cost involved in implementing our mechanism. Hence if the contracting cost is not very dependent on the project's expected value, Figure 2 suggests that there is some expected

value threshold above which the costs involved in implementing our mechanism are justified.

Effects of Positive Externalities. Externalities are troublesome for both internal development and outsourcing. If the investments are not contractible, an efficient solution for internal development can be achieved only by using a Clarke-Groves mechanism (i.e., the user pays C and the developer receives V). This will overcome the inefficiency caused by externalities, but it will cause the central management to incur a deficit. Thus a tradeoff must be made between distorting performance measures and distorting the system specification due to the externalities. No clear solution is available in the case of outsourcing since the lack of a budget balancer implies that the Clarke-Groves scheme cannot be used. Thus as positive externalities become more pronounced, outsourcing becomes relatively less attractive as compared to internal development. As a result, efforts should be made to make these investments observable and contractible (see below) when externalities are likely to be substantial. This can be done by setting periodic milestones with contractual clauses that hold the external developer legally responsible for meeting all deadlines (Radosevich 1995).

Making Investments Observable or Contractible. Active participation and communication at least in the requirements phase should have the effect of mutual monitoring, making the investments or efforts observable

or even contractible. This can help alleviate externality problems and reduce the uncertainties associated with the development process. Thus, it may be worthwhile to have a preliminary contract specifying the quality and quantity of manpower that each party will devote to the requirements analysis. For instance, the city manager of Richmond, Virginia writes into all contracts the names of the developer's personnel who must work on the project (Rothfeder 1988). In our model the payment associated with such a contract should be interpreted as the fixed transfer based on the central management's beliefs about each party's investment.

Closely related to this are approaches that seek to improve the software development process and the refusal to contract for software development with an organization that does not rate high enough on the method's scale. The best-known process improvement approach is the Software Engineering Institute's (SEI) five-level Capability Maturity Model. A developer's being rated at a particular CMM level makes the investment needed to reach that level observable.

Informational Demands and Alternative Approaches. As is standard in game-theoretic analysis, our model assumes a considerable amount of "common knowledge" among the participants, including cost functions, distribution functions of parameters, gross value function, etc. Because of these informational requirements, approaches such as the theory of incomplete contracts and the theory of information assets may offer fruitful alternative ways of analyzing the outsourcing problem, particularly when externalities are substantial. See Brynjolfsson (1994), Richmond and Seidmann (1993), and the references therein for further information.⁷

⁷ We thank the associate editor and three anonymous referees for their detailed and helpful comments, which allowed us to greatly improve the paper.

Appendix A.

Proofs

PROOF OF THEOREM 1. Since $V_4 = C_4$ from the central management's optimization,

$$\frac{d}{d\omega} \{(1 - F(\omega))V\} = -f(\omega)V + (1 - F(\omega))(V_\omega + C_4 q_4^*),$$

and therefore

$$-f(\omega)V + (1 - F(\omega))V_\omega = \frac{d}{d\omega} \{(1 - F(\omega))V\} - (1 - F(\omega))C_4 q_4^*.$$

Taking the integral on both sides yields

$$\begin{aligned} & -\int_{\underline{\omega}}^{\bar{\omega}} (f(\omega)V - (1 - F(\omega))V_\omega) d\omega \\ & = -V(q^*(\underline{\omega}, \theta), \underline{\omega}) + C(q^*(\underline{\omega}, \theta), \theta) \\ & \quad - \int_{\underline{\omega}}^{\bar{\omega}} C(q^*(\omega, \theta), \theta) dF(\omega), \end{aligned}$$

Thus, we get that

$$\begin{aligned} -E\{T(\omega)\} & = -\int_{\underline{\omega}}^{\bar{\omega}} \int_{\underline{\theta}}^{\bar{\theta}} C(q^*(\omega, \theta), \theta) dF(\omega) dG(\theta) \\ & \quad - \int_{\underline{\omega}}^{\bar{\omega}} W(\underline{\omega}, \theta) dG(\theta) + m(\bar{\alpha}). \end{aligned} \tag{A.1}$$

Similarly, since $V_4 = C_4$ from the central management's optimization,

$$\frac{d}{d\theta} [G(\theta)C(q^*, \theta)] = g(\theta)C + G(\theta)(C_\theta - V_4 q_4^*).$$

Then we can show that

$$\begin{aligned} & \int_{\underline{\theta}}^{\bar{\theta}} (g(\theta)C + G(\theta)C_\theta) d\theta \\ & = C(q^*(\omega, \bar{\theta}), \bar{\theta}) - V(q^*(\omega, \bar{\theta}), \bar{\theta}) + \int_{\underline{\theta}}^{\bar{\theta}} V(q^*(\omega, \theta), \theta) dG(\theta), \end{aligned}$$

and thereby

$$\begin{aligned} E\{B(\theta)\} & = \int_{\underline{\omega}}^{\bar{\omega}} \int_{\underline{\theta}}^{\bar{\theta}} V(q^*(\omega, \theta), \theta) dG(\theta) dF(\omega) \\ & \quad - \int_{\underline{\omega}}^{\bar{\omega}} W(\omega, \bar{\theta}) dF(\omega) + n(\bar{\beta}). \end{aligned} \tag{A.2}$$

From (A.2) and (A.1),

$$\begin{aligned} E\{B(\theta)\} - E\{T(\omega)\} & = \int_{\underline{\omega}}^{\bar{\omega}} \int_{\underline{\theta}}^{\bar{\theta}} W(\omega, \theta) dF(\omega) dG(\theta) - \int_{\underline{\omega}}^{\bar{\omega}} W(\underline{\omega}, \theta) dG(\theta) \\ & \quad - \int_{\underline{\omega}}^{\bar{\omega}} W(\omega, \bar{\theta}) dF(\omega) + m(\bar{\alpha}) + n(\bar{\beta}), \end{aligned}$$

proving the theorem. \square

PROOF OF THEOREM 2. Let

$$(q^*(\omega, \theta | \alpha, \beta), T^*(\omega, \theta | \alpha, \beta), B^*(\omega, \theta | \alpha, \beta))$$

denote the efficient mechanism in period 2. Since the investments are not contractible, the mechanism depends on the central management's beliefs about the investments as well as the user's and the developer's beliefs about each other's investment. Suppose that both the central management's and the user's beliefs about the developer's investment

are correct at $\beta = \bar{\beta}$, and that the central management's and the developer's beliefs about the user's investment are $\alpha = \bar{\alpha}$, but the actual investment made by the user is $\hat{\alpha}$ instead. Then, if the user reports $\hat{\omega}$ when the actual realization is ω , the user's expected payoff from the development period is

$$U(\hat{\omega}, \omega | \hat{\alpha}, \bar{\alpha}, \bar{\beta}) = \int_{\omega} [V(q^*(\hat{\omega}, \theta | \bar{\alpha}, \bar{\beta}), \omega | \hat{\alpha}, \bar{\beta}) - T^*(\hat{\omega}, \theta | \bar{\alpha}, \bar{\beta})] dG(\theta). \quad (A.3)$$

The user chooses a reporting strategy, $\sigma_1(\omega, \hat{\alpha}, \bar{\alpha}, \bar{\beta})$, that maximizes (A.3) for each ω . Note that if the central management's beliefs are correct, then $\omega = \sigma_1(\omega, \bar{\alpha}, \bar{\alpha}, \bar{\beta})$ by the construction of $T(\cdot)$. Given the optimal reporting strategy, the user's expected net value (including the costs of investment) is

$$E[NU(\omega | \hat{\alpha}, \bar{\alpha}, \bar{\beta})] = \int_{\omega} U(\sigma_1(\omega, \hat{\alpha}, \bar{\alpha}, \bar{\beta}), \omega | \hat{\alpha}, \bar{\beta}) dF(\omega) - m(\hat{\alpha}).$$

Given a knowledge of the central management's beliefs, $\bar{\alpha}$, the user chooses $\hat{\alpha}$ to maximize $E[U(\omega | \hat{\alpha}, \bar{\alpha}, \bar{\beta})]$. Since from the proof of Theorem 1 the user's expected net payoff is

$$\int_{\omega} \int_{\theta} V(q^*, \omega | \hat{\alpha}, \bar{\beta}) - [C(q^*, \theta | \bar{\alpha}, \bar{\beta}) + V(q^*, \omega | \bar{\alpha}, \bar{\beta}) - C(q^*, \theta | \bar{\alpha}, \bar{\beta})] dF(\omega) dG(\theta) - m(\hat{\alpha}),$$

then a necessary condition for an interior solution to the user's problem is

$$\int_{\omega} \int_{\theta} V_{\omega}(q^*(\omega, \theta | \bar{\alpha}, \bar{\beta}), \omega | \hat{\alpha}, \bar{\beta}) dF(\omega) dG(\theta) = m'(\hat{\alpha}).$$

But in equilibrium, the central management's beliefs must be correct, in which case the user truthfully reports ω , and

$$\int_{\omega} \int_{\theta} V_{\omega}(q^*(\omega, \theta | \bar{\alpha}, \bar{\beta}), \omega | \bar{\alpha}, \bar{\beta}) dF(\omega) dG(\theta) = m'(\bar{\alpha}).$$

This is the same as the condition required for efficient investment, and therefore $\bar{\alpha} = \alpha^*$ if $\bar{\beta} = \beta^*$. Following the same argument, we can show that the developer will also choose an efficient level of investment.

Of course, if the investments are contractible, the central management can direct both the user and developer to invest at the efficient level and pay them $m(\alpha^*)$ and $n(\beta^*)$ respectively. \square

PROOF OF THEOREM 3. Since $V_{\alpha\alpha} < 0$ and $V_{\alpha\beta} > 0$, by the implicit function theorem,

$$\frac{d\alpha}{dq} = \frac{E[V_{\alpha q}]}{-E[V_{\alpha\alpha}] + m''(\alpha)} > 0,$$

and so $\alpha^* < \alpha^*$, the user's socially efficient investment. Similarly, from (4.6), we can show that

$$\frac{d\beta}{dq} = \frac{-E[C_{\beta q}]}{E[C_{\beta\beta}] + n''(\beta)} > 0,$$

so $\beta^* < \beta^*$. Consequently, both parties' investments are deficient. \square

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