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Metric-Outcome Misalignment,
and Incentive Design

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Single Sourcing versus Multisourcing: The Role of Effort Interdependence, Metric-Outcome Misalignment, and Incentive Design

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We compare two strategies for outsourcing the development of information services projects: multisourcing and single-sourcing. We model these sourcing strategies when incentive contracts are based on a verifiable project metric that may or may not be aligned with the project outcome. We also model the interdependence of client and vendor efforts so that the verifiable metric may or may not be separable in these efforts. When the verifiable metric and the project outcome are aligned, single-sourcing performs better than multisourcing if the client and vendor efforts are interdependent, and as well as multisourcing if the efforts are independent. When the metric and outcome are misaligned: (i) multisourcing performs better than single-sourcing if the client effort is independent of the vendor efforts; (ii) the choice of sourcing strategy is nuanced based on the trade-off between the degree of misalignment and moral hazard if the client and vendor efforts are interdependent.

Key words: IT outsourcing, single sourcing, multisourcing, effort interdependence, incentive alignment

History:

1. Introduction

Practitioners and theorists have long recognized the importance of outsourcing business processes, activities, and functions for lowering costs and risks and for improving efficiency, flexibility, and quality. Several studies (see, e.g., Dibbern et al. 2004) have demonstrated the potential value and challenges that arise from outsourcing processes and activities in the information technology

(IT) domain. However, the results of such undertakings have been mixed (Aron et al. 2005). Although there are advantages to outsourcing the development of IT services, committing to a single vendor involves many risks: supplier lock-in, bad vendor selection, and limited domains of competence. Hence firms have increasingly sourced their IT activities to multiple firms; this has the advantages of a choice among "best of breed" vendors, lower costs resulting from vendor competition, and improved agility and adaptability to dynamic environments (Cohen and Young 2006). Multisourcing has also been found as a determinant of quality and flexibility in response to a competitive environment (Levina and Su 2008) because it increases the firm's options when responding to any change in their supply chain.

However, while multisourcing is a rapidly growing trend in practice, there are a number of pitfalls to this strategy; they stem from such issues as effort interdependence between parties, the formal incentive structure, and the alignment of metrics (in the contracts that govern these multisourcing relationships) with the client's overall objectives. These issues make the management of such arrangements a challenging endeavor (Bapna et al. 2010). In contrast to single-sourcing environments—where the supplier encounters moral hazard issues with only one supplier—clients that multisource must coordinate (and properly incentivize) the actions of multiple vendors, many of whose tasks are performed across firm interfaces. And just as in the single-sourcing case, it may not be possible to write formal contracts based on project outcomes, which are often unverifiable. Client and vendors must therefore resort to incentive mechanisms based on objectively measurable metrics such as predefined service level agreements (SLAs). For all these reasons, and as documented in the literature, the management of multisourcing projects is critical to their success.

An illustration of the issues faced in multisourcing is provided by Schaffhauser (2006), who summarizes the transition in the outsourcing of IT services at General Motors (GM) from a single-sourced to a multisourced mode. The automaker moved from having EDS as its sole vendor to having six suppliers consisting of the incumbent EDS in addition to HP, Capgemini, IBM, Compuware Covisint, and Wipro. The outsourced tasks consisted of application integration management, infrastructure, and application development and sustenance. The transition was expected

to take a few months, and the main vendors were involved in GM's strategic planning and in designing the service-oriented architecture. The suppliers also helped manage subsidiary vendors in many cases (a role more typically retained by the outsourcing client). General Motors had to make decisions on the performance metrics and the payment schemes to incentivize its vendors in this endeavor. The plan was for GM to retain the role of "systems integrator" in the new multisourcing model, and the automaker was to roll out other outsourcing projects dynamically—over the next five years—as it assessed spending on software and hardware acquisition and on new development and deployment of information systems. This case study highlights the issues that need to be addressed *prior to* embarking on a transition from single-sourcing to multisourcing systems: effort interdependence, the role of each party, contract design, and the assessment of vendor performance.

A second account of the change from single sourcing to multisourcing is provided by Brigden (2011), who documents the migration of National Rail Enquiries (NRE) to a multisourcing strategy. This enterprise provides call center, speech recognition, Internet, mobile, and text services to the traveling public and also provides business-to-business services for train companies and other third parties. It operates the website www.nationalrail.co.uk, which is the most visited travel site in the United Kingdom. Previously, NRE had employed a single-sourcing strategy whereby journey planning, dynamic data, static data, hosting, and design were all handled by one vendor. The service was gradually moved to a multisourcing arrangement, and different vendors operated under different contracts for journey planning, user interface, real-time data, design, and static data maintenance. Brigden (2011) lists the advantages of the multisourced strategy at NRE as better risk allocation across multiple vendors, lower costs and increased accountability of vendors, and faster changes when needed. However, the new strategy also engenders a need for a higher level of governance, management, and coordination of vendor efforts. Bapna et al. (2010) refer to this interdependence of efforts of the client and different suppliers, and they posit that effort interdependence and the inherent unverifiability of the project outcome make the governance of multisourcing relationships a challenging problem.

In this paper, we develop a model of outsourcing the development of an information services project to either one vendor (single sourcing) or two vendors (multisourcing); both the client and the vendor(s) exert costly effort in the joint development process. The problem is modeled as a simultaneous-move game in the principal–agent framework, where the client is the principal. In most IT outsourcing partnerships, the client has more resources and is closer to the customer; this is why the client is typically modeled as the principal (Dey et al. 2010). The success of such outsourcing partnerships requires optimal efforts by both client and vendor(s). Yet the endeavor is complicated by agency issues due to the decentralized decision making of self-interested firms. In the IT domain, it is extremely costly to monitor and coordinate efforts made by the vendor(s) (Bapna et al. 2010). Hence the client does not usually invest in observing efforts and focuses instead on designing contracts based on verifiable SLAs. When efforts are unobservable, the simultaneous-move game may be rendered inefficient by the free-rider problem (Bhattacharyya and Lafontaine 1995, Holmstrom 1982). Furthermore, and contrary to assumptions in the contracting literature (Bhattacharyya and Lafontaine 1995), the outcomes of an IT development project are frequently not verifiable (Bapna et al. 2010) and may not be aligned with the SLAs designed by the client. Finally, owing to effort interdependence — neither the outcome nor the verifiable metric may be separable in the efforts of the client vis-a-vis the vendor(s). In this case, only the total verifiable project metric is observed and not the contributions from each party. That is why, given the agency issues endemic to such cases, the design of optimal contracts is critical for effective governance of joint development partnerships.

Our objective is to find whether the environments that are better suited to single-sourcing or multisourcing strategies can be demarcated from the perspective of the principal (client). Specifically, we ask: (i) What is the impact of effort interdependence on the effectiveness of single-sourcing versus multisourcing strategies? (ii) What are the respective impacts when the project outcome and the verifiable metric are misaligned? (iii) When is each strategy preferable to the other?

Our findings are presented in terms of two factors: the alignment (or not) between the project outcome and the verifiable project metric; and the interdependence (or not) of client and vendor

efforts—that is, whether or not the verifiable metric is dependent on the client effort. On the one hand, if the outcome and the verifiable metric are aligned then single sourcing Pareto-dominates multisourcing. That is, from the client's perspective: (i) the single-sourcing strategy performs as well as multisourcing if the verifiable metric is independent of the client's effort; and (ii) single sourcing performs better than multisourcing if the client and vendor efforts are interdependent (inseparable). This result is counterintuitive because, a priori, one would expect aligning the unverifiable project outcome and the verifiable project metric to have advantages for multisourcing as well (owing perhaps to reduced distortion of effort). Nonetheless, we show that such benefits are more strongly associated with the single-sourcing strategy.

On the other hand, if the project outcome and the verifiable metric are not aligned, then multisourcing may perform better than single sourcing. Under such misalignment and the resulting effort distortion[1], it follows (again from the client's perspective) that: (i) multisourcing always performs better than single sourcing if the verifiable metric is independent of the client's effort; and (ii) if the client and vendor efforts are interdependent, then we show that multisourcing (resp., single sourcing) performs better when the extent of misalignment, or effort distortion, is high (resp., low). These results are surprising given that, a priori, one would not be able to predict the interaction effects of misalignment and effort interdependence.

We now review the extant literature and discuss how this paper adds to that literature.

1.1. Literature Review

The emergence of strategic multisourcing has been studied in the field of information systems (see Herz et al. 2010). That strategy is often portrayed in the academic literature as a source of competitive advantage, and in fact the practitioner literature has found that multisourcing leads to greater cost efficiency, quality, and flexibility in a competitive environment (Huber 2008, Levina and Su 2008) as well as to growth and increased agility (Charles 2006, Cohen and Young 2006). A documented advantage of multisourcing is its role in mitigating risk (Bapna et al. 2010, Currie 1998). Currie (1998) finds that the benefits of multisourcing—including reduced risk—can be

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[1] Henceforth we use effort distortion and metric-outcome misalignment interchangeably.

realized by clients only when they have sufficiently developed capabilities in contract management and negotiation. Bapna et al. postulate that the risk mitigation benefit from multisourcing is a function of whether a project's possible outcomes are substitutes (decreased risk) or complements (increased risk). It also depends on whether tasks are codifiable (decreased risk) or not (Aron and Singh 2005) and on the ease of switching to another vendor should one fail to perform its tasks. It is widely acknowledged that the contracts governing relationships between clients and vendors influence the relative outcomes of multi- and single-sourced systems. The design and analysis of SLAs (and operational level agreements, OLAs) to be included in the contract will certainly influence the outsourcing endeavor's outcome (Herz et al. 2010), given that the metrics governing the relationship may be aligned to a greater or lesser extent with the client's financial output (Bapna et al. 2010). According to Bapna et al., a key issue in the governance of multisourcing contracts is devising optimal compensation schemes and formal incentives when metrics are verifiable but outcomes are not; these researchers also note the influence of effort distortion and effort interdependence on the efficacy of multisourcing relationships. Our research contributes to this stream of literature by describing performance-based contracts that are commonly used (and optimal in a wide variety of circumstances) to govern both multi- and single-sourced networks and then comparing their performance in terms of the domains in which each mode excels.

Several studies that are focused on single sourcing are relevant to our paper. Susarla et al. (2010b) find that contingent contracts are difficult to design in the presence of task complexity, and Fitoussi and Gurbaxani (2011) find that contract efficiency is strongly affected by the specific types of performance metrics used. Dey et al. (2010) show that fixed-price, cost-plus, and performance-based contracts are optimal under different conditions, while Sarkar and Ghosh (1997) study vendor certification under uncertainty. Gopal and Sivaramakrishnan (2008) study contract design from the vendor's perspective; they find that a vendor prefers fixed-price contracts when it can leverage adverse selection but prefers time-and-materials contracts when the risk of employee attrition is high. Chellappa and Shivendu (2010) study the contract design problem for personalization services

under information asymmetry. Our paper contributes to this stream of literature by analyzing the contract design problem as a function of sourcing modes.

In the exploratory phase of the research in this area, many factors are relevant for their impact on multisourcing. These factors include the breadth and depth of the supplier base, theoretical and practical utility considerations, transaction costs, the mission criticality of the outsourced tasks, and client-created barriers to suppliers entering the product market. Su and Levina (2011) find that the depth and the breadth of the client's supplier base influences the relative outcomes of outsourcing via single and multiple vendors, and they propose a framework that uses these findings to organize the supplier base. In a case study, Pries-Heje and Olsen (2011) combine theories of utility, risk, and transaction costs to estimate how much reduction in risk and transaction costs could be effected by multisourcing. Heitlager et al. (2010) examine the relation between multisourcing and mission criticality of the outsourced tasks. The existence of multiple suppliers, who act as self-satisficing agents also influences the efficacy of joint development efforts (Singh and Tan 2010). Lin et al. (2008) find that—when outsourcing results in imitation— multisourcing helps to deter entry by suppliers into the final goods market and enhances the client's profitability. Our research contributes to this stream of literature by assessing the impact of effort interdependence, metric–outcome alignment, and contractual governance mechanisms on the relative efficacy of multisourcing and single sourcing.

A number of other factors also influence the outcomes of multisourcing: modularity of the outsourced tasks (Aron et al. 2005), extent of task specialization, and vendor competition (Bapna et al. 2010, Flinders 2010). Task modularity has important implications not only for the strategic motivation behind outsourcing but also for its incentive structure. Susarla et al. (2010a) show that modularity increases verifiability of the outsourced tasks, in which case fixed-price contracts may replace variable-price contracts. Herz et al. (2011) propose a mechanism for the disaggregation of tasks to be performed by multiple vendors. Finally, multisourcing allows the client to take advantage of vendor task specialization and may also induce competition among them; however, it makes protecting intellectual property rights more difficult (Bapna et al. 2010). Our paper contributes to

this stream of literature by comparing the efficacy of multi- and single-sourcing in the case when interdependent client and vendor efforts determine the project outcome and the verifiable metric.

The balance of this paper is organized as follows. In Section 2, we describe the model and state our assumptions formally. Section 3 contains the model's formulation, analysis, and results as well as the paper's main contributions. Section 4 concludes with a discussion of the findings.

2. Model Description and Assumptions

In this section we describe the formal mathematical model in detail and state our assumptions. The problem is modeled as a simultaneous game between the client and one or more vendor(s). There are three tasks, $i \in \{1,3\}$, which must be performed if the IT outsourcing project is to succeed. We assume without loss of generality that the client always performs task 3 by exerting an effort of e_3 and that tasks 1 and 2 are performed either by one vendor (single sourcing) or two vendors (multisourcing). The vector $\mathbf{e}$ captures the effort exerted by the vendor(s) and client in performing tasks i; thus, $\mathbf{e} = [e_1, e_2, e_3]$. Define the vector $\mathbf{e}_{-i} = \{e_j : j \neq i\}$. Efforts are costly, and $c_i(e_i)$ denotes the cost for performing each task i. We assume task-specific (rather than vendor-specific) cost functions in order to isolate the effects of effort interdependence and effort distortion on the client's sourcing strategy[2]. The outcome of the joint development project between the client and the vendor(s) is given by $v(\mathbf{e})$. This outcome is not verifiable, and v may or may not be separable in the efforts exerted by the parties. The model also includes a verifiable scalar project metric $s(\hat{e})$, which is a function of the efforts exerted by the parties involved. This metric may capture either the efforts of all parties ($\hat{e}=\mathbf{e}$) or only the efforts of the vendor(s) ($\hat{e}=[e_1, e_2]$). The verifiable project metric is therefore dependent on the efforts of the vendor(s),[3] but the verifiable metric may or may not be independent of client efforts. In practice, the verifiable project metric is given by the set of service level agreements that the client specifies in the contracts with the vendor(s).

[2] Assuming vendor-specific cost functions would trivially make task specialization by vendor(s) favor the multisourcing strategy. Similarly, including the costs and benefits of coordination between tasks would trivially favor single sourcing. We have discussed the implications of these effects in Section 4.

[3] We assume that vendor efforts are always interdependent because assuming the contrary (i.e., independent vendor efforts) leads to decoupled principal–agent problems with moral hazard that do not capture effort interdependence, and trivially yield equivalence between multi- and single sourcing.

Without loss of generality, vendor reservation value from the outsourced project is normalized to zero.

Our model describes the sequence of events illustrated in Figure 1. In the initial stage (at $t = 0$), the client proposes a contract $f(s(\cdot))$ to the vendor(s), where f is based on the verifiable project metric $s(\hat{e})$. Next, the client and vendor(s) simultaneously exert effort while developing the IT project (at $t = 1$) and incur the costs related to that development effort. Finally, the outcome of the project is realized (at $t = 2$) and, simultaneously, the verifiable metric is observed by all parties.

Figure 1   Sequence of Events in Model.
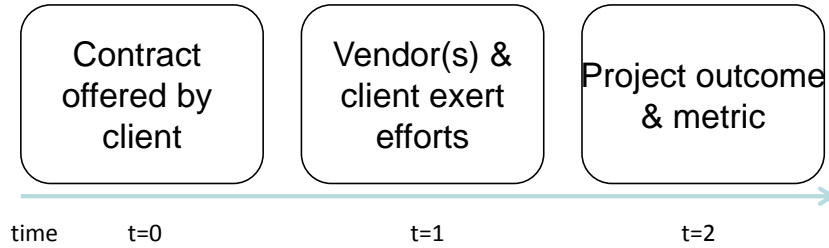
We make the following four assumptions about the model parameters.

(A1) The project outcome v is not verifiable and is jointly concave in the set of efforts $\mathbf{e}$: $\frac{\partial v(\mathbf{e})}{\partial e_i} < \infty$ as $e_i \to \infty, \forall \mathbf{e}_{-i}$; $\frac{\partial v(\mathbf{e})}{\partial e_i} > 0 \ \forall e_i \in [0, \infty) \forall \mathbf{e}_{-i}$.

(A2) The verifiable metric $s(\cdot)$ of the project is jointly concave in the set of efforts $\hat{e}$. $\frac{\partial s(\hat{e})}{\partial e_i} < \infty$ as $e_i \to \infty, \forall\{i : e_i \in \hat{e}\}, \forall\{e_j : e_j \in \hat{e}, j \neq i\}$; $\frac{\partial s(\hat{e})}{\partial e_i} > 0 \ \forall e_i \in [0, \infty), \forall\{i : e_i \in \hat{e}\}, \forall\{e_j : e_j \in \hat{e}, j \neq i\}$.

(A3) The cost of effort $c_i(e_i)$ is strictly convex and increasing in the individual efforts: $c_i(e_i) = 0 \forall \mathbf{e}_{-i}$; $c_i'(0) = 0$; $c_i'(\infty) = \infty$. Our assumption on the cost function rules out $e_i = 0$ as the system-optimal effort level for $i \in 1, 2, 3$.

(A4) To rule out the unrealistic case of efforts converging to ∞ in the optimal solution, we impose the following boundary condition: $\lim_{e_i \to \infty} v(\mathbf{e}) - \sum_{i=1}^{3} c_i(e_i) < 0 \forall \mathbf{e}_{-i}$.

3.   Model Formulation and Analysis

In this section, we describe the contractual structures capable of yielding optimal outcomes (for the client) under two scenarios: (i) when a single vendor performs tasks 1 and 2; and (ii) when

two vendors are used—that is, each task is assigned to a dedicated vendor. We then examine the efficacy of the single-sourcing and multisourcing, by comparing the optimal profits of the client under the two strategies.

We begin with the simultaneous game in which the client and the vendor(s) coordinate their efforts to maximize joint profits. Because each party's efforts are exerted simultaneously in a coordinated fashion, optimal efforts may be determined via the following mathematical statement of the problem:

$$e_i^* = \arg\max_{e_i \geq 0} v(\mathbf{e}) - c_i(e_i) \tag{1}$$

This equation determines the first-best efforts (e_i^*) in the coordinated problem of maximizing the development effort's joint profits. We now present results based on two cases: whether or not the verifiable project metric s is independent of the client's effort.

3.1. Verifiable Project Metric Independent of Client Effort

Here we examine the case where the verifiable metric is independent of the client's effort (this assumption does not preclude interdependence between multiple vendors), and dependent only on vendor efforts. Thus we model the frequent occurrence in practice of clients outsourcing mainly noncore activities and using the project metric only to measure vendor effort, not its own effort, in the development project; hence $s(e_1, e_2)$ is a function of vendor effort only. Because the project metric $s(\cdot)$ is verifiable and the project's outcome is not, only the former is used as a criterion in contracts between the client and the vendor(s). We first consider the single-sourcing case, in which one vendor performs both tasks 1 and 2.

3.1.1. Single Sourcing
If the client seeks to offer the vendor a contract f based on the verifiable project metric $s(e_1, e_2)$, then the client's contract design problem can be stated as follows:

$$\max_{f(\cdot)} \Pi_{SS} = v(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3) - c_3(\tilde{e}_3) - f(s(\tilde{e}_1, \tilde{e}_2)) \tag{2}$$

$$\text{s.t.} \tilde{e}_3 = \arg\max_{e_3 \geq 0} v(\tilde{e}_1, \tilde{e}_2, e_3) - c_3(e_3) - f(s(\tilde{e}_1, \tilde{e}_2)) \tag{3}$$

$$\tilde{e}_1, \tilde{e}_2 = \arg \max_{e_1, e_2 \geq 0} f(s(e_1, e_2)) - c_1(e_1) - c_2(e_2) \tag{4}$$

$$f(s(\tilde{e}_1, \tilde{e}_2)) - c_1(\tilde{e}_1) - c_2(\tilde{e}_2) \geq 0 \tag{5}$$

Inequality (5) is the participation constraint for the vendor; equation (4) captures the vendor's determination of its effort in performing tasks 1 and 2, while equation (3) represents the analogous problem for the client effort. Equation 2 represents the contract design problem for the client.

The decisions made by the client and the vendor are simultaneous; that is, the respective parties solve (3) and (4) simultaneously because each party bases its best response on the other party's reaction function.

Proposition 1. *If both of the development tasks are outsourced to a single vendor then, a linear contract that provides for a fixed-fee and a payment contingent on the verifiable metric (of the form $T + \alpha s(\cdot)$) is optimal.*

In this case, the client prefers linear contracts because they incentivize the vendor to invest optimally in the joint development effort. Such contracts have the advantage of sharing the upside between the client and the vendor. Linear contracts are also easy to implement: the client incurs no monitoring costs because the SLAs (on which the project metric is based) are easily observable and verifiable in practice. Note that the linear contract's optimality here does not result from any double-sided moral hazard, since the verifiable metric is independent of the client effort. Rather, the client faces (i) single-sided moral hazard (from the vendor's incentive to lower its effort that can be mitigated by using the variable payment contingent on the verifiable metric) and (ii) effort distortion from misalignment between verifiable metric and project outcome. The fixed fee ensures that the vendor's participation constraint (inequality (5)) is tight.

The literature on contract design in the IT domain includes examples of performance-based contracts leading to optimal outcomes; for example, Dey et al. (2010) show that performance-based contracts keyed to quality level agreements can achieve the optimal solution. We add to this stream of literature by showing that—when the client and a single vendor combine their efforts to develop an information service project—linear performance-based contracts achieve the client's optimal

solution in the presence of single-sided moral hazard and effort distortion. Yet we should also like to know whether the optimal solution is also the client's *first-best* solution, which is defined (in a principal–agent framework) as follows: (i) the principal and the agent (client and vendor) make system-optimal efforts; and (ii) the principal attains the maximum profits possible.

Proposition 2. *If both of the development tasks are outsourced to a single vendor then, from the client's perspective, the first-best outcome can be attained if and only if the following equality holds:*

$$\frac{\frac{\partial v(e_1, e_2^*, e_3^*)}{\partial e_1}\big|_{e_1^*}}{\frac{\partial s(e_1, e_2^*)}{\partial e_1}\big|_{e_1^*}} = \frac{\frac{\partial v(e_1^*, e_2, e_3^*)}{\partial e_2}\big|_{e_2^*}}{\frac{\partial s(e_1^*, e_2)}{\partial e_2}\big|_{e_2^*}}.$$

The linear contract is optimal for the client, but it is not first-best because it fails to resolve completely the moral hazard (vis--vis the vendor) stemming from misalignment between the verifiable metric and the project outcome. Proposition 2 states the condition under which such misalignment goes to zero and thus alignment is achieved. Observe that this condition is more general than requiring the project outcome to be a linear function of the verifiable metric. Proposition 2 shows that if a particular ratio—the rate of improvement in the project outcome with respect to vendor effort divided by the rate of improvement in the verifiable metric with respect to vendor effort—is equal for each task evaluated at e_1^*, e_2^* respectively, then the client's first-best outcome can be achieved. We remark that this finding differs from the standard result in the literature (Bhattacharyya and Lafontaine 1995) that linear contracts between the client and the vendor attain only the second-best outcome. Because the verifiable metric is independent of the client's effort, there can be no double moral hazard. A single vendor performs tasks 1 and 2, and the client approaches the first-best solution to the extent that it mitigates effort distortion, or the misalignment between the project outcome and the verifiable metric. In this case, then, both the client and the vendor make optimal efforts and will achieve the first-best outcome (in the absence of effort distortion).

If there is misalignment between the project outcome and the verifiable project metric, then the *optimal* solution obtained by linear SLA-based contracts is only *second-best*. Hence, in the presence of single-sided moral hazard and effort distortion, no contract can attain the first-best solution. That is, the issues raised by metric-outcome misalignment cannot be resolved.

We next analyze the multisourcing case, in which each task (1 and 2) is assigned to a different vendor.

3.1.2. Multisourcing If each task is assigned to a different vendor, then in principle the client can offer a different contract to each vendor. Let f_1 and f_2 denote the contracts given to the vendors performing task 1 and task 2, respectively. If each contract is based on the verifiable metric $s(e_1, e_2)$, then the client's contract design problem is

$$\max_{f(\cdot)} \Pi_{MS} = v(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3) - c_3(\tilde{e}_3) - f_1(s(\tilde{e}_1, \tilde{e}_2)) - f_2(s(\tilde{e}_1, \tilde{e}_2)) \tag{6}$$

$$\text{s.t. } \tilde{e}_3 = \arg\max_{e_3 \geq 0} v(\tilde{e}_1, \tilde{e}_2, e_3) - c_3(e_3) - f_1(s(\tilde{e}_1, \tilde{e}_2)) - f_2(s(\tilde{e}_1, \tilde{e}_2)) \tag{7}$$

$$\tilde{e}_1 = \arg\max_{e_1 \geq 0} f_1(s(e_1, \tilde{e}_2)) - c_1(e_1) \tag{8}$$

$$\tilde{e}_2 = \arg\max_{e_2 \geq 0} f_2(s(\tilde{e}_2, e_2)) - c_2(e_2) \tag{9}$$

$$f_1(s(\tilde{e}_1, \tilde{e}_2)) - c_1(\tilde{e}_1) \geq 0 \tag{10}$$

$$f_2(s(\tilde{e}_1, \tilde{e}_2)) - c_2(\tilde{e}_2) \geq 0 \tag{11}$$

In this problem, (10) and (11) are the participation constraints for the two vendors; equations (8) and (9) capture the respective vendors' determination of their efforts in performing tasks 1 and 2, while equation (7) represents the analogous problem for client effort. Equation (6) represents the contract design problem for the client. As before, each party bases its best responses on the reaction functions of (i.e., the efforts exerted by) the other parties.

Proposition 3. *If development tasks are outsourced to different vendors, then the client should optimally offer each vendor a differentiated linear contract consisting of a fixed fee and an additional payment based on the verifiable metric (the contracts to the two vendors have the form $T_1 + \alpha_1 s(\cdot)$ and $T_2 + \alpha_2 s(\cdot)$). In this case, the client can obtain the first-best solution regardless of any misalignment between the verifiable metric and the project outcome.*

The first insight from Proposition 3 is that the effect of effort distortion, which arises from the misalignment between the project outcome and the verifiable metric, can be eliminated by using differentiated linear contracts with the two vendors. This is an important result because, in the

presence of effort distortion, using the same proportion of the verifiable project metric as the variable payment for both vendors prevents the client from obtaining both vendors' best efforts. That is, the vendors have an incentive to free-ride when the client's use of the same contract fails to differentiate between them: each vendor can exert a lower effort yet still receive the same compensation from the client. If the client uses differentiated linear contracts, however, then it can always adequately incentivize the vendors to exert their first-best efforts by using a combination of variable payments and fixed fees. Because such differentiated contracts allow the client to distinguish between the two vendors' efforts, no vendor can free-ride on the other.

Note that there is no moral hazard on part of the client in this case, since the verifiable metric is independent of the client's effort. Hence, the client can use linear differentiated contracts to resolve two-agent moral hazard and effort distortion issues simultaneously. As in the previous case, the client uses the fixed fee to ensure that the vendors attain their reservation values. This ensures (i) the first-best efforts from both client and vendors and (ii) attainment of the first-best solution by the client (the principal).

We now analyze the case where the client and vendor efforts are interdependent. Hence, in this scenario, the verifiable project metric is thus dependent on the client and vendor efforts.

3.2. Verifiable Project Metric Dependent on Client and Vendor Efforts

The verifiable metric now depends not only on the vendor efforts but also on the client effort. Thus we model the practice of a client outsourcing some of its core activities; hence $s(e_1, e_2, e_3)$ is a function of all the parties' efforts. As before, the client offers a contract that is contingent on the verifiable project metric. We first consider the single-sourcing case, where one vendor performs both tasks 1 and 2.

3.2.1. Single Sourcing If the client offers the vendor a contract f based on the verifiable project metric $s(e_1, e_2, e_3)$, then the client's contract design problem can be stated as follows:

$$\max_{f(\cdot)} \Pi_{SS} = v(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3) - c_3(\tilde{e}_3) - f(s(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3)) \tag{12}$$

$$\text{s.t. } \tilde{e}_3 = \arg\max_{e_3} v(\tilde{e}_1, \tilde{e}_2, e_3) - c_3(e_3) - f(s(\tilde{e}_1, \tilde{e}_2, e_3)) \tag{13}$$

$$\tilde{e}_1, \tilde{e}_2 = \arg\max_{e_1,e_2} f(s(e_1, e_2, \tilde{e}_3)) - c_1(e_1) - c_2(e_2) \tag{14}$$

$$f(s(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3)) - c_1(\tilde{e}_1) - c_2(\tilde{e}_2) \geq 0 \tag{15}$$

Here (15) is the vendor's participation constraint, while (14) and (13) capture (respectively) the vendor and client problem of determining their effort. Equation (12) represents the contract design problem for the client.

Lemma 1. *Under single sourcing and interdependent efforts of the client and vendor, it is optimal for the client to offer the vendor a linear contract consisting of a fixed fee plus a variable payment based on the verifiable project metric. Such an optimal contract attains the second-best outcome for the client under single sourcing.*

The result that linear contracts are optimal also when client–vendor efforts are interdependent is due to the presence of double-sided moral hazard as regards client and vendor efforts, given that Bhattacharyya and Lafontaine (1995) have shown linear contracts to be optimal in cases of double-sided moral hazard. Here the verifiable metric is dependent on the efforts of both the client and the vendor; hence the client cannot eliminate moral hazard and so cannot attain the first-best solution. In the coordinated problem, the first-best effort by the client and the vendor is obtained by satisfying equation (1), which optimizes the expected reward from the joint development effort minus the cost of client and vendor efforts in performing the required tasks ($c(\mathbf{e})$). Observe that the vendor will be induced to exert its first-best effort, per equation (1), only if it receives all the upside from the joint development effort. But then the client would have no incentive to invest its own effort in performing task 3. Because no contract can adequately incentivize both firms to invest their first-best efforts, the first-best solution cannot be attained.

3.2.2.   Multisourcing Suppose now that tasks 1 and 2 are performed by different vendors. Then, just as in Section 3.1.2, the client offers the vendors performing task 1 and task 2 the respective contracts f_1 and f_2, both of which are based (as before) on the verifiable metric $s(e_1, e_2, e_3)$. In this case, the client's contract design problem is

$$\max_{f(\cdot)} \Pi_{MS} = v(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3 - c_3(\tilde{e}_3) - f_1(s(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3)) - f_2(s(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3)) \tag{16}$$

$$\text{s.t. } \tilde{e}_3 = \arg\max_{e_3} v(\tilde{e}_1, \tilde{e}_2, e_3) - c_3(e_3) - f_1(s(\tilde{e}_1, \tilde{e}_2, e_3)) - f_2(s(\tilde{e}_1, \tilde{e}_2, e_3)) \tag{17}$$

$$\tilde{e}_1 = \arg\max_{e_1} f_1(s(e_1, \tilde{e}_2, \tilde{e}_3)) - c_1(e_1) \tag{18}$$

$$\tilde{e}_2 = \arg\max_{e_2} f_2(s(\tilde{e}_1, e_2, \tilde{e}_3)) - c_2(e_2) \tag{19}$$

$$f_1(s(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3)) - c_1(\tilde{e}_1) \geq 0 \tag{20}$$

$$f_2(s(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3)) - c_2(\tilde{e}_2) \geq 0 \tag{21}$$

The problem statement is analogous to the previous cases. We now characterize the optimal contracts to be offered by the client.

Proposition 4. *Under multisourcing and interdependent efforts, it is optimal for the client to offer each vendor a differentiated linear contract, with different variable payments based on the verifiable project metric and fixed fees. Such optimal contracts obtain the second-best outcome for the client under multisourcing.*

Proposition 4 states that, in the presence of effort distortion and n-sided moral hazard (where n is the number of parties in the joint development effort; $n = 3$ in the multisourcing case), linear contracts that are differentiated by vendor mitigate the effect of that distortion. This insight is related to that of Proposition 3; here, the effort distortion arising from the metric-outcome misalignment is eliminated by offering a differentiated linear contract to each vendor. However, the three-sided moral hazard problem still exists, and is exacerbated compared to the free rider problem with double-sided moral hazard (present in the single sourcing case).

Next we compare the client rewards from the single-sourcing and multisourcing strategies (Π_{SS} and Π_{MS}) when the verifiable metric is dependent on client and vendor efforts. In this case, the interdependence of client and vendor efforts leads to n-sided moral hazard (where n refers to the number of parties in the co-operative effort, and is equal to 2 if only one vendor is used, and 3 if two vendors are used). Hence, the first-best outcome cannot be attained by the client under both single and multisourcing strategies (Bhattacharya et al. 2011, Bhattacharyya and Lafontaine 1995). In the single-sourcing strategy the sources of inefficiency are the 2-sided moral hazard and effort distortion; whereas, in the multisourcing strategy the source of inefficiency is the 3-sided moral

hazard. To compare the second-best outcomes attained using the single-sourcing and multisourcing strategies, we use functional forms for the dependence of the project outcome and the verifiable metric on the client and vendor effort. For mathematical tractability, we assume the functional forms $v(\mathbf{e}) = e_1 + e_2 + e_3$ and $s(\mathbf{e}) = \theta(e_1 + \gamma e_2 + e_3)$, where $\gamma \in (0, \infty)$. Note that γ is a parsimonious representation of the misalignment effect (effort distortion), as $\gamma = 1$ represents complete alignment between the project outcome and the verifiable metric. Values of γ that are close to zero or are very high represent high misalignment, while values of γ that are close to 1 represent low misalignment. The scalar $\theta > 0$ is a constant that normalizes the effect of the parties' efforts on the verifiable metric with respect to the project outcome $v(\mathbf{e})$.

Proposition 5. (i) *Under interdependent efforts, if the verifiable metric is aligned with the project outcome then the single-sourcing strategy attains higher profits for the client than the multisourcing strategy.*

(ii) *Under interdependent efforts, if the verifiable metric and the project outcome are not aligned, then the client should employ the following sourcing strategy: use multisourcing in cases of high metric-outcome misalignment (i.e., when $\gamma < \underline{\gamma}$ or $\gamma > \bar{\gamma}$) and use single sourcing in cases of low misalignment (when $\gamma \in (\underline{\gamma}, \bar{\gamma})$. If $\gamma = \{\underline{\gamma}, \bar{\gamma}\}$ then the client is indifferent between the two strategies. Here $\underline{\gamma} = 0.5$ and $\bar{\gamma} = 5.5$.*

Proposition 5(i) shows that, if effort distortion is eliminated in the single-sourcing case (i.e., if the project outcome and the verifiable metric are aligned and so $\gamma = 1$), then the only distinction—from the client's perspective—between single- and multisourcing strategies is the extent of n-sided moral hazard. Because the client faces three-sided moral hazard when there are two vendors, the single-sourcing strategy (with only two-sided moral hazard) can be expected to dominate. Thus Proposition 5(i) confirms that three-sided moral hazard engenders higher inefficiency for the client than does two-sided moral hazard. We are aware of no other study that explicitly posits these differences.

Proposition 5(ii) shows that, under interdependent efforts and metric-outcome misalignment, the client should trade off the effects of effort distortion and n-sided moral hazard when choosing

its sourcing strategy. The intuition behind Proposition 5(ii) is as follows. When the client and the vendors efforts are interdependent, the presence of n-sided moral hazard favors the single-sourcing strategy because the effect of n-sided moral hazard is increasing in n. Yet multisourcing can mitigate the effort distortion resulting from misalignment between the project outcome and the verifiable metric, since vendors can be incentivized by linear contracts that are differentiated. In contrast, under single sourcing the client cannot eliminate this effort distortion because both outsourced tasks are performed by a single vendor (and so are governed by a single linear contract).

Proposition 5(ii) shows that, if the effect of the effort distortion is low ($\gamma \in (\underline{\gamma}, \bar{\gamma})$), then the n-sided moral hazard dominates the sourcing strategy trade-offs. In other words, below this threshold misalignment value (given by $\underline{\gamma} < \gamma < \bar{\gamma}$), the single-sourcing strategy dominates because the free-rider problems stemming from double-sided moral hazard and effort distortion are less severe than those from three-sided moral hazard. Thus the impact of misalignment (which normally favors multisourcing) is not enough to overcome the negative effects of 3-sided moral hazard. In sum, beyond the threshold values of $\gamma \in (\underline{\gamma}, \bar{\gamma})$, multisourcing dominates single sourcing.

For the case of interdependent efforts, the difference between the client profits from the single-sourcing and multisourcing strategies ($\Pi_{SS} - \Pi_{MS}$) is illustrated in Figure 2. The figure shows that, under low levels of effort distortion ($0.5 < \gamma < 5.5$), the single-sourcing strategy yields higher profits for the client than does the multisourcing strategy. Under high levels of effort distortion ($\gamma \in (0, 0.5)$ or $\gamma \in (5.5, \infty)$), however, the multisourcing strategy yields higher profits.

Studies in the information systems literature have addressed the question of what domains are most appropriate for single-sourcing versus multisourcing strategies (Bapna et al. 2010, Herz et al. 2010). Our paper is among the first to provide a basis for modeling the two strategies' benefits for the purpose of comparing their efficiency. This model is both parsimonious and able to capture the trade-offs—when choosing between these two strategies—among effort interdependence, formal incentive structures, and metric-outcome misalignment. We show not only that the impact of n-sided moral hazard favors single sourcing but also that the impact of effort distortion favors

Figure 2   Difference in Client Profits from Single Sourcing and Multisourcing.
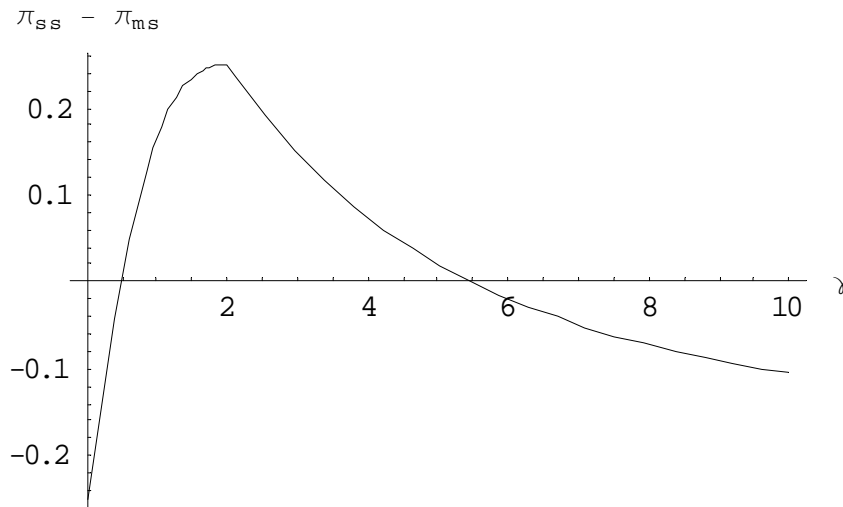
multisourcing. When both factors are important, a more nuanced approach to strategy choice must be adopted.

4.   Conclusions and Future Research

This paper develops a model for outsourcing the development of an information services project to either a single vendor (single sourcing) or two vendors (multisourcing) in order to determine which strategy is best for what environments. The problem is modeled as a simultaneous-move game in a principal–agent framework, where the client is the principal. Following our observations in practice, we model both client and vendor efforts as unobservable and the project outcome as unverifiable. However, a project metric that is based on predefined SLAs is both observable and verifiable, although the extent of its alignment with the project outcome does vary. We model vendor efforts as being interdependent; hence the verifiable metric is always dependent on the vendor efforts but may be independent of the client's effort.

We find that if the verifiable metric is *independent* of the client's effort, then multisourcing performs better than single sourcing—but only if the project outcome and the verifiable metric are not aligned (if they are aligned, then the two sourcing strategies perform equally well). If the verifiable metric is *dependent* on vendor and client efforts, then the single sourcing strategy

outperforms multisourcing strategy provided the project outcome and the verifiable metric are aligned. But if they are not aligned, then single sourcing (resp., multisourcing) is preferable when the degree of metric-outcome misalignment is low (resp., high). These findings are summarized in Figure 3.

Figure 3   Summary of Model Findings.

	Verifiable metric aligned to project outcome	Verifiable metric not aligned to project outcome
Client task independent of vendor(s)	SS=MS	SS<MS
Client task interdependent on vendor(s)	SS>MS	SS>MS (low metric-outcome misalignment) SS<MS (high metric-outcome misalignment)

Our results have a number of implications. Note first of all that, when the verifiable project metric is independent of the client's effort, multisourcing performs at least as well as single sourcing. This finding is in line with the literature and is borne out by our observations in practice. Cohen and Young (2006) and Levina and Su (2008) find the greatest use of multisourcing in the banking and manufacturing sectors. In both cases, the IT specific tasks are not core activities of the client. While the final outcome of the project may depend on the joint efforts of the client and the vendor(s), the IT project specific verifiable metric is solely dependent on the vendor efforts. Our previously cited examples of General Motors and NRE lie within this domain.

Second, single-sourcing performs well when client and vendor efforts are interdependent (non-separable). This, too, is in line with the literature (Bapna et al. 2010), which has postulated that

such interdependence makes it difficult for the client to eliminate moral hazard (Bhattacharyya and Lafontaine 1995, Holmstrom 1982). If client–vendor relations involve any moral hazard, then free-rider problems arise—and even more so when there are multiple vendors. Therefore, single sourcing should be used when the likelihood of moral hazard increases owing to a larger number of vendors exacerbating the moral hazard problem.

Finally, if under interdependent efforts there is also misalignment between the verifiable metric and the project outcome (effort distortion), then the client should use the single-sourcing (resp., multisourcing) strategy if the extent of effort distortion is low (resp., high). In cases of high effort distortion, a single vendor will require more incentives than will multiple vendors, because the former will lower its efforts to take advantage of the higher effort distortion. In cases of low effort distortion (i.e., good metric–outcome alignment), the client should prefer a single-sourcing strategy so that moral hazard will be minimized.

We remark that these results are *not* intuitive in the sense that effort distortion and n-sided moral hazard affect both single- and multisourcing strategies. We first show that linear contracts are optimal in all cases of effort interdependence and metric–outcome misalignment; we then show that any choice between the single-sourcing and multisourcing should account for the trade-off between effort distortion and n-sided moral hazard. The advantage of multisourcing is that it can mitigate the effects of effort distortion via linear contracts that are differentiated by vendor, which is an important result of this paper; while the advantage of single sourcing is that there is less moral hazard to overcome. This trade-off makes the choice of strategy a nuanced decision, and Figure 3 serves as a useful guide in this respect.

Our results contribute to the extant literature in a number of ways. First, this paper describes (what to the best of our knowledge is) a unique modeling effort in the area of multisourcing that aims to assess the impact of effort interdependence, incentive structure, and the alignment between project outcomes and verifiable metrics (SLAs) on the choice of sourcing strategy. We show that the performance-based contracts studied in the IT literature (Dey et al. 2010, Fitoussi and Gurbaxani 2011, Gopal and Sivaramakrishnan 2008, Susarla et al. 2010b) are optimal for both single sourcing

and multisourcing. Our second contribution consists of adding to this literature by (i) addressing which sourcing strategy should be adopted by the client, (ii) showing that our results—together with anecdotal observations in the literature (Bapna et al. 2010, Herz et al. 2010)—have nuanced ramifications on the choice of strategy, and (iii) identifying the conditions under which each strategy performs better for the client.

This research is in its early phases, so it is easy to identify a number of potential avenues for additional work. Since we have considered the impact only of formal incentive structures, effort interdependence, and metric–outcome alignment, future research should consider empirically the extent of the roles played by coordination costs, task specialization, and by the competitive bidding for project parts among vendors (as opposed to competitive bidding for the entire project). We have investigated for the effects of these factors theoretically on the choice of sourcing strategy, and find that including the latter two factors would further favor multisourcing over single sourcing. Similarly, the inclusion of coordination costs would trivially favor single sourcing. For example, if multisourcing is preferable over single sourcing, the inclusion of coordination costs attenuates the domain of preference of the multisourcing strategy, while the inclusion of task specialization accentuates the domain of preference of multisourcing. Since these effects have obvious results, we have chosen not to include them in the body of the paper. In contrast, the effects of effort interdependence, metric-outcome alignment and the resultant incentive design problem are more nuanced. Finally, we have studied only the pure strategies of single sourcing and multisourcing; future research should thus consider hybrid systems of both strategies.

In this paper we look at the practice of outsourcing the development of IT service projects and then model the impact of different agency and task-specific, client–vendor issues concerning the choice of outsourcing strategy. Our findings lead us to posit that clients could make better decisions when choosing such a strategy, and the framework proposed here offers guidance on that score.

Appendix

Proof of Proposition 1: Let us assume that a contract $f_0(\cdot)$ is optimal and that it induces $\tilde{e}_1$ and $\tilde{e}_2$ as the optimal efforts by the vendor. Hence the vendor's problem can be represented as,

$$\max_{e_1, e_2 \geq 0} f_0(s(e_1, e_2)) - c_1(e_1) - c_2(e_2).$$

The FOC for the vendor's problem as stated above are

$$f_0'(s(\tilde{e}_1, \tilde{e}_2))\frac{\partial s(e_1, \tilde{e}_2)}{\partial e_1}|_{e_1 = \tilde{e}_1} = c_1'(\tilde{e}_1), \tag{22}$$

$$f_0'(s(\tilde{e}_1, \tilde{e}_2))\frac{\partial s(\tilde{e}_1, e_2)}{\partial e_2}|_{e_2 = \tilde{e}_2} = c_2'(\tilde{e}_2). \tag{23}$$

Note that equations (22) and (23) can be implemented by a linear contract $\alpha s(e_1, e_2) + T$, where $\alpha = f_0'(s(\tilde{e}_1, \tilde{e}_2))$. Note that the second order conditions are trivially met by assumptions *A1–A3*. Also note that the fixed payment T does not influence the vendor's effort and hence can be chosen such that the vendor's participation constraint is tight.

Proof of Proposition 2: The FOC for the first-best efforts on the outsourced tasks as defined in equation (1) are

$$\frac{\partial v(e_1, e_2^*, e_3^*)}{\partial e_1}|_{e_1 = e_1^*} = c_1'(e_1^*), \tag{24}$$

$$\frac{\partial v(e_1^*, e_2, e_3^*)}{\partial e_2}|_{e_2 = e_2^*} = c_2'(e_2^*). \tag{25}$$

Since Proposition 1 has established that the linear contract is optimal, in this proof we need only to restrict our attention to linear contracts. It is easy to see from equations (22)–(25) that the vendor will exert the first-best efforts if and only if

$$\alpha = \frac{\frac{\partial v(e_1, e_2^*, e_3^*)}{\partial e_1}|_{e_1 = e_1^*}}{\frac{\partial s(e_1, e_2^*)}{\partial e_1}|_{e_1 = e_1^*}} = \frac{\frac{\partial v(e_1^*, e_2, e_3^*)}{\partial e_2}|_{e_2 = e_2^*}}{\frac{\partial s(e_1^*, e_2)}{\partial e_2}|_{e_2 = e_2^*}}$$

Proof of Proposition 3: Assume that the client offers the contract $\{\alpha_i, T_i\}$ to vendor i, where α_i

is the variable term of the linear contract and T_i is the fixed term. Given this the vendors' optimal efforts are given by

$$\tilde{e}_1 = \arg\max_{e_1} \alpha_1 s(e_1, \tilde{e}_2) - c_1(e_1) + T_1,$$

$$\tilde{e}_2 = \arg\max_{e_2} \alpha_2 s(\tilde{e}_1, e_2) - c_2(e_2) + T_2.$$

Note that T_1 and T_2 do not influence the vendors' effort decision, and so T_1 and T_2 can be freely adjusted to ensure that the vendors participation constraints are tight. Therefore to complete this proof, we need to show that $\exists \{\alpha_1, \alpha_2\}$ such that $\tilde{e}_i = e_i^*$ is the unique Nash equilibrium for the vendors' effort decision. Set $\alpha_1 = \frac{\frac{\partial v(e_1, e_2^*, e_3^*)}{\partial e_1}|_{e_1 = e_1^*}}{\frac{\partial s(e_1, e_2^*)}{\partial e_1}|_{e_1 = e_1^*}}$ and $\alpha_2 = \frac{\frac{\partial v(e_1^*, e_2, e_3^*)}{\partial e_2}|_{e_2 = e_2^*}}{\frac{\partial s(e_1^*, e_2)}{\partial e_2}|_{e_2 = e_2^*}}$. It is easy to check that $\{e_1^*, e_2^*\}$ is a Nash equilibrium outcome. This is because for vendor i's first-order condition is satisfied at e_i^* when vendor j chooses e_j^*. Finally we need to show that $\{e_1^*, e_2^*\}$ is a unique Nash equilibrium. For this we compute the Hessian. We can check that

$$
\begin{aligned}
|\mathbf{H}| &= \begin{vmatrix} \alpha_1 \frac{\partial^2 s(e_1, e_2)}{\partial e_1^2} - \frac{\partial^2 c_1(e_1)}{\partial e_1^2} & \alpha_1 \frac{\partial^2 s(e_1, e_2)}{\partial e_1 \partial e_2} \\ \alpha_2 \frac{\partial^2 s(e_1, e_2)}{\partial e_2 \partial e_1} & \alpha_2 \frac{\partial^2 s(e_1, e_2)}{\partial e_2^2} - \frac{\partial^2 c_2(e_2)}{\partial e_2^2} \end{vmatrix} \\
&= \alpha_1 \alpha_2 \left(\frac{\partial^2 s(e_1, e_2)}{\partial e_1^2} \frac{\partial^2 s(e_1, e_2)}{\partial e_2^2} - \left(\frac{\partial^2 s(e_1, e_2)}{\partial e_1 \partial e_2} \right)^2 \right) - \sum_{i=1}^{2} \alpha_i \frac{\partial^2 s(e_1, e_2)}{\partial e_i^2} \frac{\partial^2 c_i(e_i)}{\partial e_i^2} + \frac{\partial^2 c_1(e_1)}{\partial e_1^2} \frac{\partial^2 c_2(e_2)}{\partial e_2^2} \\
&> 0.
\end{aligned}
$$

Therefore we conclude that $\{e_1^*, e_2^*\}$ is a unique Nash equilibrium.

Proof of Lemma 1: While in this section we have assumed particular functional forms for $v(\cdot)$ and $s(\cdot)$, we are able to maintain the general functional form for this proof. Let us assume that a contract $f_0(\cdot)$ is optimal and that it induces $\tilde{e}_1$ and $\tilde{e}_2$ as the optimal efforts by the vendor, and $\tilde{e}_3$ by the client. The FOC for the vendor's problem are

$$f_0'(s(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3)) \frac{\partial s(e_1, \tilde{e}_2, \tilde{e}_3)}{\partial e_1} |_{e_1 = \tilde{e}_1} = c_1'(\tilde{e}_1), \tag{26}$$

$$f_0^{'}(s(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3))\frac{\partial s(\tilde{e}_1, e_2, \tilde{e}_3)}{\partial e_2}|_{e_2=\tilde{e}_2} = c_2^{'}(\tilde{e}_2). \qquad (27)$$

Note that equations (26) and (27) can be implemented by a linear contract $\alpha s(e_1, e_2, e_3) + T$, where $\alpha = f_0^{'}(s(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3))$. Note that the second order conditions are trivially met by assumptions *A1–A3*. Also note that the fixed payment T does not influence the vendor's effort and hence can be chosen such that the vendor's participation constraint is tight. Therefore a linear contract will replicate the outcome of any optimal contract, and hence is optimal. We now need to show that the outcome of the optimal linear contract cannot be the first-best outcome for the client. Assume that is not true and that the outcome is the first-best. This implies that $\tilde{e}_i = e_i^* \ \forall i \in \{1, 2, 3\}$. For $\tilde{e}_1 = e_1^*$and $\tilde{e}_2 = e_2^*$ we require that

$$\alpha = \frac{\frac{\partial v(e_1, e_2^*, e_3^*)}{\partial e_1}|_{e_1=e_1^*}}{\frac{\partial s(e_1, e_2^*, e_3^*)}{\partial e_1}|_{e_1=e_1^*}} = \frac{\frac{\partial v(e_1^*, e_2, e_3^*)}{\partial e_2}|_{e_2=e_2^*}}{\frac{\partial s(e_1^*, e_2, e_3^*)}{\partial e_2}|_{e_2=e_2^*}}. \qquad (28)$$

Therefore a necessary condition for the first-best outcome is

$$\frac{\frac{\partial v(e_1, e_2^*, e_3^*)}{\partial e_1}|_{e_1=e_1^*}}{\frac{\partial s(e_1, e_2^*, e_3^*)}{\partial e_1}|_{e_1=e_1^*}} = \frac{\frac{\partial v(e_1^*, e_2, e_3^*)}{\partial e_2}|_{e_2=e_2^*}}{\frac{\partial s(e_1^*, e_2, e_3^*)}{\partial e_2}|_{e_2=e_2^*}}. \qquad (29)$$

Let us assume that (29) holds. The FOC for the client's effort decision is

$$\frac{\partial v(e_1^*, e_2^*, e_3)}{\partial e_3}|_{e_3=e_3^*} - \alpha \frac{\partial s(e_1^*, e_2^*, e_3)}{\partial e_3}|_{e_3=e_3^*} = c_3^{'}(e_3^*). \qquad (30)$$

Note that from (28) we have that $\alpha > 0$. As in this case the verifiable signal $s(\cdot)$ is a function of all three efforts $\mathbf{e} = [e_1, e_2, e_3]$, from A2 we have $\frac{\partial s(e_1^*, e_2^*, e_3)}{\partial e_3}|_{e_3=e_3^*} > 0$. This implies that (30) leads to a contradiction as by definition of e_3^*we have $\frac{\partial v(e_1^*, e_2^*, e_3)}{\partial e_3}|_{e_3=e_3^*} = c_3^{'}(e_3^*)$. Therefore in this case the optimal contract will not yield the first-best solution.

Proof of Proposition 4: We will first proof the optimality of linear contracts. Let us assume that contracts $f_i(\cdot)$ for vendor i are optimal and that they induces $\tilde{e}_1$and $\tilde{e}_2$ as the optimal efforts by the vendor, and $\tilde{e}_3$ by the client. The FOC conditions for the vendors are

$$f_1'(s(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3)) \frac{\partial s(e_1, \tilde{e}_2, \tilde{e}_3)}{\partial e_1} |_{e_1 = \tilde{e}_1} = c_1'(\tilde{e}_1), \tag{31}$$

$$f_2'(s(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3)) \frac{\partial s(\tilde{e}_1, e_2, \tilde{e}_3)}{\partial e_2} |_{e_2 = \tilde{e}_2} = c_2'(\tilde{e}_2). \tag{32}$$

Note that equations (31) and (32) can be implemented by a linear contract $\alpha_i s(e_1, e_2, e_3) + T_i$, where $\alpha_i = f_i'(s(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3))$. Also note that the fixed payment T does not influence the vendor's effort and hence can be chosen such that the vendor's participation constraint is tight. Therefore a linear contract will replicate the outcome of any optimal contract, and hence is optimal. All second order conditions are satisfied because of A1–A3. This completes our proof.

Proof of Proposition 5: First we compute the profit for the client under the specific functional forms of $v(\cdot)$ and $s(\cdot)$. Restricting to linear contracts, the client's problem can be written as

$$\max_{\alpha, T} \Pi_{SS} = \tilde{e}_1 + \tilde{e}_2 + \tilde{e}_3 - \frac{\tilde{e}_3^2}{2} - \alpha\theta(\tilde{e}_1 + \gamma\tilde{e}_2 + \tilde{e}_3) - T$$

$$\text{s.t. } \tilde{e}_3 = \arg\max_{e_3 \geq 0} \tilde{e}_1 + \tilde{e}_2 + e_3 - \frac{e_3^2}{2} - \alpha\theta(\tilde{e}_1 + \gamma\tilde{e}_2 + e_3) - T$$

$$\tilde{e}_1, \tilde{e}_2 = \arg\max_{e_1, e_2 \geq 0} \alpha\theta(e_1 + \gamma\tilde{e}_2 + \tilde{e}_3) + T - \frac{e_1^2}{2} - \frac{e_2^2}{2}$$

$$\alpha\theta(\tilde{e}_1 + \gamma\tilde{e}_2 + \tilde{e}_3) + T - \frac{\tilde{e}_1^2}{2} - \frac{\tilde{e}_2^2}{2} \geq 0$$

As mentioned earlier, the fixed payment T does not influence the vendor's decisions, and hence will be set to make the participation constraint tight. Therefore, $T = -\alpha\theta(\tilde{e}_1 + \gamma\tilde{e}_2 + \tilde{e}_3) + \frac{\tilde{e}_1^2}{2} + \frac{\tilde{e}_2^2}{2}$. We can see that $\tilde{e}_1 = \alpha\theta \wedge 0$, $\tilde{e}_2 = (\alpha\theta\gamma) \wedge 0$ and $\tilde{e}_3 = (1 - \alpha\theta) \wedge 0$, where $x \wedge y = \max\{x, y\}$. It is easy to verify that $\alpha\theta > 1$ will not be a solution to the client's profit maximization problem. Therefore the client's problem can we written as

$$\max_{\alpha \geq 0} \ 1 + \gamma\alpha\theta - \frac{(1 - \alpha\theta)^2}{2} - \frac{(\alpha\theta)^2}{2} - \frac{\gamma^2(\alpha\theta)^2}{2}$$

The above optimization problem yields the solution $\alpha = (\gamma + 1)/(\gamma^2\theta + 2\theta)$, and $\Pi_{SS} = (3 + 2\gamma + 2\gamma^2)/(4 + 2\gamma^2)$.

Next we compute the profit for the client under the optimal contract. Restricting to linear contracts, the client's problem can be written as

$$\max_{\alpha_i, T_i} \Pi_{MS} = \tilde{e}_1 + \tilde{e}_2 + \tilde{e}_3 - \frac{\tilde{e}_3^2}{2} - (\alpha_1 + \alpha_2)\theta(\tilde{e}_1 + \gamma\tilde{e}_2 + \tilde{e}_3) - T_1 - T_2 \tag{33}$$

$$\text{s.t. } \tilde{e}_3 = \arg\max_{e_3 \geq 0} \tilde{e}_1 + \tilde{e}_2 + e_3 - \frac{e_3^2}{2} - (\alpha_1 + \alpha_2)\theta(\tilde{e}_1 + \gamma\tilde{e}_2 + e_3) - T_1 - T_2 \tag{34}$$

$$\tilde{e}_1 = \arg\max_{e_1 \geq 0} \alpha_1\theta(e_1 + \gamma\tilde{e}_2 + \tilde{e}_3) + T_1 - \frac{e_1^2}{2} \tag{35}$$

$$\tilde{e}_2 = \arg\max_{e_2 \geq 0} \alpha_2\theta(\tilde{e}_1 + \gamma e_2 + \tilde{e}_3) + T_2 - \frac{e_2^2}{2} \tag{36}$$

$$\alpha_1\theta(\tilde{e}_1 + \gamma\tilde{e}_2 + \tilde{e}_3) + T_1 - \frac{\tilde{e}_1^2}{2} \geq 0 \tag{37}$$

$$\alpha_2\theta(\tilde{e}_1 + \gamma\tilde{e}_2 + \tilde{e}_3) + T_2 - \frac{\tilde{e}_2^2}{2} \geq 0 \tag{38}$$

As mentioned earlier, the fixed payments T_i do not influence the vendors decisions, and hence will be set to make the participation constraint tight. Therefore, $T_i = -\alpha_i\theta(\tilde{e}_1 + \gamma\tilde{e}_2 + \tilde{e}_3) + \frac{\tilde{e}_i^2}{2}$. From (34)–(36) we can see that $\tilde{e}_1 = \alpha_1\theta \wedge 0$, $\tilde{e}_2 = (\alpha_2\gamma\theta) \wedge 0$ and $\tilde{e}_3 = (1 - \alpha_1\theta - \alpha_2\theta) \wedge 0$, where $x \wedge y = \max\{x, y\}$. The client's problem is to choose the maximum of the following two optimization problems

$$\max_{\alpha_1, \alpha_2 \geq 0} 1 - \alpha_2\theta + \gamma\alpha_2\theta - \frac{(1 - \alpha_1\theta - \alpha_2\theta)^2}{2} - \frac{(\alpha_1\theta)^2}{2} - \frac{\gamma^2(\alpha_2\theta)^2}{2} \tag{39}$$

$$\text{s.t. } (\alpha_1 + \alpha_2)\theta \leq 1$$

and

$$\max_{\alpha_1, \alpha_2 \geq 0} \alpha_1\theta + \gamma\alpha_2\theta - \frac{(\alpha_1\theta)^2}{2} - \frac{\gamma^2(\alpha_2\theta)^2}{2} \tag{40}$$

$$\text{s.t. } (\alpha_1 + \alpha_2)\theta \geq 1$$

The optimization problem (39) yields the solution $\alpha_1 = 1/(2\theta)$, $\alpha_2 = 0$, $\Pi_{MS} = 3/4$ when $\gamma < 1/2$; and $\alpha_1 = 1/(2\theta) - (\gamma - 1/2)/(2\gamma^2\theta + \theta)$, $\alpha_2 = (\gamma - 1/2)/(\gamma^2\theta + \theta/2)$, $\Pi_{MS} = (2 - 2\gamma + 5\gamma^2)/(2 + 4\gamma^2)$ when $\gamma \geq 1/2$. The optimization problem (40) yields the solution $\alpha_1 = 1/\theta$, $\alpha_2 = 1/(\gamma\theta)$, $\Pi_{MS} =$

1. Therefore the client will choose $\alpha_1 = 1/\theta$, $\alpha_2 = 1/(\gamma\theta)$ when $\gamma < 2$; and $\alpha_1 = 1/(2\theta) - (\gamma - 1/2)/(2\gamma^2\theta + \theta)$, $\alpha_2 = (\gamma - 1/2)/(\gamma^2\theta + \theta/2)$ when $\gamma \geq 2$.

When the verifiable metric $s(\cdot)$ is aligned with $v(\cdot)$, or in other words when $\gamma = 1$ we can see that $\Pi_{SS} > \Pi_{MS}$. This completes proof of Proposition 5(i).

The difference of the client's profit under the single sourcing strategy and the multisourcing strategy is,

$$\Delta(\gamma) = \Pi_{SS} - \Pi_{MS} = \frac{3 + 2\gamma + 2\gamma^2}{4 + 2\gamma^2} - 1 \text{ if } \gamma < 2$$
$$= \frac{3 + 2\gamma + 2\gamma^2}{4 + 2\gamma^2} - \frac{2 - 2\gamma + 5\gamma^2}{2 + 4\gamma^2} \text{ if } \gamma \geq 2$$

Differentiating Δ with respect to γ yields

$$\frac{d\Delta(\gamma)}{d\gamma} = \frac{2 + \gamma - \gamma^2}{(2 + \gamma)^2} \text{ if } \gamma < 2$$
$$= \frac{-3(-2 + \gamma - \gamma^2 + \gamma^4 - \gamma^5 + 2\gamma^6)}{(2 + 5\gamma^2 + 2\gamma^4)^2} \text{ if } \gamma \geq 2$$

It is easy to see that $\Delta(0) < 0$, $d\Delta(\gamma)/d\gamma > 0$ for $\gamma < 2$, and $\Delta(1/2) = 0$. Therefore $\Delta(\gamma) < 0$ for $\gamma \in [0, 1/2)$ and $\Delta(\gamma) > 0$ for $\gamma \in (1/2, 2)$. We next focus on $\gamma \in [2, \infty)$. It is easy to check that $-3(-2 + \gamma - \gamma^2 + \gamma^4 - \gamma^5 + 2\gamma^6)/(2 + 5\gamma^2 + 2\gamma^4)^2 = 0$ has only one real root, at $\gamma = 1$. Also some algebra shows that $(1 - \gamma)d\Delta(\gamma)/d\gamma > 0 \, \forall \gamma \geq 2$. It can also be verified that $\Delta(2) > 0$ and $\Delta(\gamma) = 0$ at $\gamma = \bar{\gamma} \approx 5.5$. Therefore we conclude that $\Delta(\gamma) < 0$ for $\gamma \in (0, 1/2)$, $\Delta(\gamma) > 0$ for $\gamma \in (1/2, \bar{\gamma})$, $\Delta(\gamma) < 0$ for $\gamma \in (\bar{\gamma}, \infty)$, and $\Delta(\gamma) = 0$ for $\gamma = \{1/2, \bar{\gamma}\}$.

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