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Single sourcing versus multisourcing: The roles of output verifiability on task modularity

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SINGLE-SOURCING VERSUS MULTISOURCING: THE ROLES OF OUTPUT VERIFIABILITY ON TASK MODULARITY

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Abstract:

This paper compares two modes for outsourcing the development of information services projects: single-sourcing (where one vendor handles all outsourced activities) and multisourcing (where multiple vendors handle those activities). We assess the relative efficacy of these two outsourcing modes by identifying the effects of three factors: task modularity, the extent of alignment between a (verifiable) performance metric and project revenue, and the extent to which project revenue is itself verifiable. We find that if tasks are modular then multisourcing strictly dominates single-sourcing—provided the verifiable performance metric and project revenue are not completely aligned. Yet if tasks are integrated, then the choice of sourcing mode is more nuanced: the best choice depends on trade-offs among the alignment between performance metric and project revenue, the verifiability of project revenue, and moral hazard. If the verifiable performance metric and project revenue are perfectly aligned, or if project revenue is completely verifiable, then firms prefer single-sourcing because it entails less moral hazard than does multisourcing. Comparative statistics for the effects of task interdependence costs and vendors' risk aversion reveal that multisourcing (single-sourcing) should be preferred when there are interdependence costs (/when vendors are strongly risk averse).

Keywords:

IT outsourcing, single-sourcing, multisourcing, effort interdependence, task modularity, revenue verifiability, revenue–metric alignment

Introduction

Practitioners and theorists have recognized the challenges of outsourcing tasks to single versus multiple vendors (Aron et al. 2005). The potential problems associated with committing to a single vendor include supplier lock-in, bad vendor selection, and limited domains of competence. Hence, firms have increasingly relied on multisourcing, where (for example) information technology activities are outsourced to multiple vendors. Multisourcing enables the firm to choose "best of breed" vendors, to lower costs through vendor competition, and to improve agility and adaptability to dynamic environments (Cohen and Young 2006). Using the Interactive Data Corporation (IDC) services contracts database, Bapna et al. (2010) report that there was $7.2 billion (U.S.) worth of multisourcing contracts in information technology (IT) and IT-enabled services (ITES) worldwide in 2007; these authors argue that "multisourcing is a long-term phenomenon rather than a short-term fad" (p. 786).

Although the use of multisourcing has grown rapidly, that strategy has several pitfalls stemming from such issues as effort interdependence between parties, the formal incentive structure, and alignment of performance measures (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 client encounters moral hazard issues with only one supplier, a client that multisources must coordinate (and properly incentivize) the actions of multiple vendors. And, just as in the single-sourcing case, it may not be possible to write formal contracts based on project revenues because those revenues are often either unverifiable or only partially verifiable.

This paper develops a model of outsourcing the development of an IT project to either one vendor (single-sourcing) or two vendors (multisourcing). In this model, 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 and vendors are agents. The revenue of the project is a joint function of the efforts of the client and the vendor—or vendors, owing to effort interdependence in IT outsourcing (Bapna et al. 2010). Yet the outsourcing endeavor is complicated by agency issues due to the decentralized decision making of self-interested firms. As emphasized by Bapna et al., codevelopment efforts undertaken by multiple parties make it impossible to verify such efforts and the resulting project revenue; hence, no contracts can be based on them (Bhattacharya et al. 2014). When efforts in codevelopment are unverifiable, a simultaneous-move game may be rendered inefficient by the free-rider problem (Bhattacharyya and Lafontaine 1995; Holmstrom 1982). Therefore, the client must resort to contracting based on objectively verifiable project signals or metrics (e.g., a predefined service level agreement) that in all likelihood are not perfectly aligned with project revenue. For example, software quality may serve as a verifiable performance metric (Dey et al. 2010). The number of bugs in a software application can be objectively verified and is therefore contractible. It also depends on the efforts of both client and vendor(s). Additional factors that affect the trade-off between single-sourcing and multisourcing include the cost of managing task interdependence, in either setting (Itoh 1994), and vendor attitudes toward risk (Holmstrom and Milgrom 1991). Finally, as suggested by Bapna et al., the modularity of interdependent tasks may also alter the relative efficacy of single- and multisourcing. We model modularity by allowing the verifiable performance metric to be a function of vendor efforts and independent of client effort.[1]

Our objective is to establish whether the environments better suited to single-sourcing or multisourcing modes can be identified from the perspective of the client (the principal). In particular, we seek to answer these questions:

1. How does task modularity influence the effectiveness of single-sourcing versus multisourcing?

2. What is the corresponding effect on these outsourcing modes when project revenue is only partially verifiable (measurable) and when project revenue and the verifiable metric are only partially aligned?

3. How do risk aversion and the cost of coordinating interdependent tasks affect each outsourcing mode?

Our main findings are as follows.

• If project revenue and the verifiable metric are perfectly aligned then single-sourcing Pareto-dominates multisourcing. So, from the client's perspective, single-sourcing performs as well as (better than) multisourcing if project tasks are modular (integrated). This result is counterintuitive because one would expect that aligning project revenue with the verifiable performance metric also would have advantages for multisourcing (due perhaps to reduced distortion of vendor effort resulting from the perfect alignment between revenue and metric). Nonetheless, we show that such benefits are more strongly associated with the single-sourcing mode.

• If project revenue and the verifiable metric are just partially aligned, then multisourcing may perform better than single-sourcing. Under such partial alignment, it follows (again from the client's perspective) that multisourcing always performs better than single-sourcing if the tasks are modular. However, if the tasks are integrated, then these outsourcing modes have nuanced domains of dominance; we characterize the conditions under which each mode performs better. These results, too, are surprising given that the interaction effects of partial alignment, task modularity, and verifiable project revenue seem not to be

[1] If all such tasks were completely modular, then individual contracts could be written to cover individual task outcomes. In that event, the multisourcing environment would be equivalent to a single-sourcing setup (Bapna et al. 2010).

predictable ex ante. Yet in all cases we find linear contracts—which are also the most easily implemented—to be optimal.

We now review the extant literature and discuss how our paper contributes to that research. We shall streamline the presentation by often using the abbreviations "SS" and "MS" for single-sourcing and multisourcing (respectively) as well as "VPM" for the verifiable performance metric.

Literature review

Our aim is to compare single- and multisourcing, so we start with a brief summary of the relevant literature on these sourcing modes. We then highlight this paper's contributions, which are based in large part on that comparison. The literature on IT outsourcing has received considerable attention in the SS setting. Examples include studies on the effects of task complexity and the holdup phenomenon (Susarla et al. 2010), performance metrics (Dey et al. 2010; Fitoussi and Gurbaxani 2011), adverse selection (Chellappa and Shivendu 2010; Gopal and Sivaramakrishnan 2008), incentive contracting on output quality (Liu and Aron 2014), risk mitigation (Gefen et al. 2008), and vendor certification under uncertainty (Sarkar and Ghosh 1997). See Bapna et al. (2010) for a comprehensive review of the research in this field.

Previous comparisons of single-sourcing and multisourcing in the practitioner IT literature highlight the cost efficiency resulting from specialization and the flexibility benefits of multisourcing (Huber 2008), which include increased agility (Cohen and Young 2006) and its role in mitigating risk (Currie 1998). A number of factors affect the firm's choice of outsourcing mode: the codifiability of tasks and the ease of switching vendors (Aron and Singh 2005), utility considerations and transaction costs (Pries-Heje and Olsen 2011), the mission criticality of outsourced tasks (Heitlager et al. 2010), the presence of third parties that encourage cooperation among vendors (Wiener and Saunders 2014), governance and coordination of the efforts made by multiple suppliers (Jin et al. 2014; Plugge and Janssen 2014), client-created barriers to suppliers entering the product market (Lin et al. 2008), modularity of the outsourced tasks (Aron et al. 2005; Herz et al. 2011), extent of task specialization and coordination costs (Bapna et al. 2010), and vendor competition (Flinders 2010).

The outsourcing of tasks to single versus multiple vendors is the subject of studies in the economics literature as well. For example, Itoh (1991, 1994) and Schöttner (2007) consider when to outsource different tasks to different vendors (multisourcing) and when to outsource the tasks to the same vendor (single-sourcing); however, those authors consider a different set of trade-offs from the ones that we examine. In particular, Itoh (1991, 1994) does not consider metric-revenue misalignment, which we show to be an important factor in determining the optimal sourcing strategy. In his earlier work, Itoh considers the trade-off between outsourcing tasks to dedicated vendors and the inclination of vendors to cooperate in their efforts; that paper shows how the preferred sourcing strategy depends on the complementarity of efforts among vendors. In contrast, we focus on whether—when tasks are outsourced completely—it is preferable for the client firm to contract with a single vendor or with multiple vendors.

In his later work, Itoh considers the trade-off between SS and MS in his study of the optimal sourcing strategy when there is division of labor and a delegation pattern of jobs. Neither of Itoh's papers considers metric–revenue misalignment when determining the optimal sourcing decision, although that is the key factor studied here. Schöttner's model does incorporate metric–revenue misalignment and the outsourcing of all tasks, but there is no client effort in that model. In contrast, our model's inclusion of client effort allows us to study the role played by integrated versus modular systems in the optimal sourcing decision. Holmstrom and Milgrom (1991) model a system in which vendor efforts generate a vector of verifiable signals, each of which is independently contractible; such a setting should always yield the first-best outcome for the client (independent of the sourcing strategy) unless additional agency issues prevent it. In that paper, the authors impose additional costs to reflect vendor risk aversion and the possibility of signals being measured with error. They find that if vendors devote different amounts of attention to the tasks, then the most (least) attentive vendor should be assigned tasks that require relatively more (less) monitoring. Che and Yoo (2001) study the effect of group incentives on the propensity of multiple vendors to cooperate on tasks in a multiperiod setting; they find that, in the long run, group incentives can mitigate the effects of moral hazard. Our paper compares the SS and MS outsourcing modes in an IT context, but the results are not specific to the IT domain and can be applied to a wider set of industries. One stream of the economics literature addresses similar problems in settings that involve task division, a field to which our findings should also apply.

In the IT context, Bapna et al. (2010) note that, although ‘‘incentive and coordination issues have been studied in the context of a single service provider, the literature on multisourcing is in its nascent stages" (p. 788). However, many factors (e.g., risk diversification, coordination costs, task specialization) that affect the firm's preference for an outsourcing mode can be inferred from the literature just cited. Yet Bapna et al. pose several research questions of extreme importance:

• What is the role of contract design in governing the multisourcing relationship? (RQ1)

• What roles are played by partial verifiability and interdependence of efforts? (RQ2A and RQ2B)

• What are the effects of task modularity and metric-revenue misalignment? (RQ6B)

These questions must be thoroughly studied if we are to improve our understanding of single- and multisourcing strategies.

This paper addresses a subset of Bapna et al.'s research questions. Specifically, we identify the client's optimal sourcing mode by assessing three factors: (1) task modularity and the cost of coordinating tasks, (2) the extent of misalignment between project revenue and the verifiable performance metric, and (3) vendor risk aversion. In order to conduct a meaningful comparison between the two types of outsourcing, we must first determine the client's optimal contract (i.e., the contract that maximizes the client's profit conditional on the sourcing mode). We therefore derive optimal contract policies for both the single-sourcing mode and the multisourcing mode.

Model Description and Assumptions

In this section, we detail the model's mathematical formalization and stipulate our assumptions. The development of the model will be illustrated by way of two case studies and also by other examples from practice.

Schaffhauser (2006) documents the transition in the outsourcing of IT services at General Motors (GM) from a single-sourced to a multisourced mode. The automaker moved from using Electronic Data Systems (EDS) as its sole vendor to using six suppliers: the incumbent EDS in addition to Hewlett-Packard (HP), Capgemini, International Business Machines (IBM), Compuware Covisint, and Wipro. Some of these vendors were involved in GM's strategic planning and in designing the service-oriented architecture of the multisourced mode. General Motors had to make decisions about performance metrics and payment schemes that together would incentivize its vendors to participate, and GM intended to retain its "systems integrator" role in the new multisourcing mode of operation. This case study highlights the issues to be addressed before embarking on any transition from single-sourcing to multisourcing: effort interdependence, the role of each party, contract design, and the assessment of vendor performance.

Wang (2015) provides examples of single-sourcing's practical benefits. He reports that, in China, firms working with multiple small- and medium-sized enterprise (SME) vendors encounter a lack of accountability on the part of individual vendors, which leads to increased moral hazard. Also, the risk aversion typical of smaller vendors leads to an increased risk premium for variations in outcome-based project payments. We use the observations made in these two case studies—along with other practice-based observations—to develop our model.

The problem in this paper is modeled as a simultaneous game between the client and one or more vendor(s). There are three tasks, $i \in \{1, 2, 3\}$, that 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 e captures the effort exerted by client and vendor(s) when performing tasks i; thus $e = [e_1, e_2, e_3]$. Define the vector $e_{-i} = \{e_j: j \neq i\}$. Efforts are costly, and $c_i(e_i)$ denotes the cost for performing each task i (the cost model is based on the notion that tasks are "chunkified" vertically; see Aron et al. 2005). We assume task-specific (rather than vendor-specific) cost functions in order to isolate the effects of (1) task modularity and (2) the partial alignment of project revenue with a verifiable performance metric.[2]

In our model, the revenue from the development project undertaken jointly by client and vendor(s) is partially verifiable. Dey et al. (2010) note that project revenue tends to have both verifiable and unverifiable components; in their paper, the verifiable component is a scaled measure of the project's quality. Dey et al. (p. 95) note that the quality of software used by a client whose outsourcing involves a performance-based contract may not be aligned with project revenue: software quality is modeled as $q = e^{\alpha}t^{\beta} + \varepsilon$ whereas project revenue is modeled as $U = u_1\, e^{\alpha}t^{\beta} - u_2 t$; therefore, since, $u_2 \neq 0$, it follows that project revenue and software quality are not perfectly aligned if the client contracts on the latter. To model the former's partially verifiable nature, we assume that project revenue has the following form:

$$v(e) = \theta U(\mathbf{e}) + (1-\theta)S(\mathbf{e})$$

Here, S(e) is verifiable (and so can be contracted on) but U(e) is unverifiable. To exemplify our setting, suppose that the project involves development of some enterprise software. Task 1 involves coding the back end of the software, and task 2 involves coding for the user interface. Task 3 is meant to integrate those two sets of code. In this case, we may view S as the measurable component of the software's quality. That being said, monetization of the software may depend also on other, nonmeasurable aspects of quality (e.g., design of the program architecture) that we denote by U. Our model is similar to the one described by Dey et al., treat the project's quality ($e^{\alpha}t^{\beta}$) as being verifiable and effort t as unverifiable; u_1 and u^2 serve as scaling factors. Just like those scaling factors, the term θ in our model is a relative weighting of the scaling factors. If one assumes that the marginal effect of effort on $U(e)$ and $S(e)$ are not identical, then the metric–revenue misalignment can be interpreted as follows: if $\theta = 0$, then the project revenue $v(\mathbf{e})$ and the verifiable performance metric $S(\mathbf{e})$ are completely aligned; if $\theta = 1$, then the misalignment between revenue and metric is maximized; and if $0 < \theta < 1$, then the project revenue and the VPM are partially aligned. Thus a high (low) value of θ in our model is analogous to a high (low)

[2] Assuming vendor-specific cost functions would entail (trivially) that task specialization by vendor(s) favors the multisourcing strategy, and including the costs and benefits of coordination between tasks would likewise trivially favor single-sourcing. Similar assumptions about the cost function have been made in the literature (Itoh 1994).

u_2/u_1 ratio in Dey et al. Of course, if the marginal effect of efforts *are* identical on $U(\mathbf{e})$ and $S(\mathbf{e})$, then performance metric and project revenue align perfectly regardless of θ's value.

As an example of varying levels of θ, the measurability of project revenue, Dey et al. compare a contract between mPhase Technologies and Magpie Telecom Insiders (where the revenue measurability is "high") and a contract between New Motion and Visionaire (where revenue verifiability is of "medium" level). Another instance of metric–revenue misalignment is reported in Bhattacharya et al. (2014), who describe the misalignment between the project revenue and a verifiable metric in an ITES context. In their example, Travelcountry had already outsourced their call-center services to WNX and now wanted to codevelop their website—Travelcountry's primary customer interface—with WNX. The main problem for customers was having to traverse two links in order to print their itinerary after purchasing a ticket, links that WNX was advising callers to use for that purpose. Travelcountry's aim was to improve its website design, which directly affected the firm's revenues; however, Travelcountry had contracted with WNX on the number of calls answered. It is easy to see that here the VPM (that is, the number of calls handled by the call center) was misaligned with the project revenue: poor website design reduced Travelcountry's revenues while leading to a higher number of calls and hence to greater revenue for WNX.

The unverifiable component of project revenue is denoted by $U(\mathbf{e}) \geq 0$, which we assume is stochastic and given by $U(\mathrm{e}) = \phi\,(e_1 + e_2 + e_3) + \varepsilon_1$. Here ε_1 has a pdf of $g_1(x)$, and $\int xg_1(x)\,dx = 0$; it follows that ε_1 has a mean of 0 and that ϕ is a scalar. We let the verifiable component of revenue be denoted by $S(\mathbf{e}) \geq 0$; we assume that it is also stochastic and is given by $S(\mathbf{e}) = \phi\,(e_1 + \gamma e_2 + \lambda e_3) + \varepsilon_2$. Here ε_2 has a pdf of $g_2(x)$, and $\int xg_2(x)\,dx = 0$; hence ε_2 has a mean of 0. In these expressions, γ (λ) represents the relative marginal effect of task-2 (task-3) effort on the verifiable component of software quality. Without loss of generality, the marginal effect of task 1 has been normalized to 1. As a result,

$$v(\mathbf{e}) = \phi[e_1 + \{\theta + (1-\theta)\gamma\}e_2 + \{\theta + (1-\theta)\lambda\}e_3] + \varepsilon \quad \text{where } \varepsilon = \theta\varepsilon_1 + (1-\theta)\varepsilon_2.$$

When modeling task modularity, we bear in mind Baldwin and Clark's (2000) argument that "increasing modularity through architectural choices represents decreasing interdependence between tasks"—and thus requires less effort devoted to coordination. We model task modularity using a simple condition: if the verifiable performance metric depends on the client's effort, then we consider the project tasks to be integrated. However, if the VPM depends entirely on vendor efforts, then the tasks will be viewed as modular. So if tasks are integrated, then the verifiable metric depends on client effort, $S(\mathrm{e}) = \phi\,(e_1 + \gamma e_2 + \lambda e_3) + \varepsilon_2$; in contrast, if tasks are modular then $S(\mathrm{e}) = \phi\,(e_1 + \gamma e_2) + \varepsilon_2$ (i.e., $\lambda = 0$).

We do not study the case where the VPM is separable in vendor efforts (i.e., the case of complete modularity) because doing so would lead to decoupled principal–agent problems with moral hazard, which would yield a trivial equivalence between multisourcing and single-sourcing (Bapna et al. 2010). In the case-study examples described earlier, GM intended to act as systems integrator (Schaffhauser 2006) in coordinating the efforts of its six vendors. General Motors was therefore required to invest its own effort in coordinating the work of these vendors. In this case, then, the verifiable performance metric reflected the effort not only of the vendors but also of the client.

Without loss of generality, we normalize to 0 the vendor reservation value from the outsourced project. If that reservation value is positive, then the client will pay the vendor(s) the positive reservation value and retain the rest of the surplus generated.

Our model captures the sequence of events illustrated in Figure 1. In the initial stage (at $t = 0$), the client proposes a contract $f(S)$ to the vendor(s), where f is based on the VPM S. 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 revenue of the project is realized (at $t = 2$) and, simultaneously, the verifiable metric is observed by all parties.

We also assume that the cost of effort $c_i(e_i) = e^2_i/2$. This assumption captures decreasing returns to scale, which reflect the increased difficulty of continuously improving software quality (Dey et al. 2010).

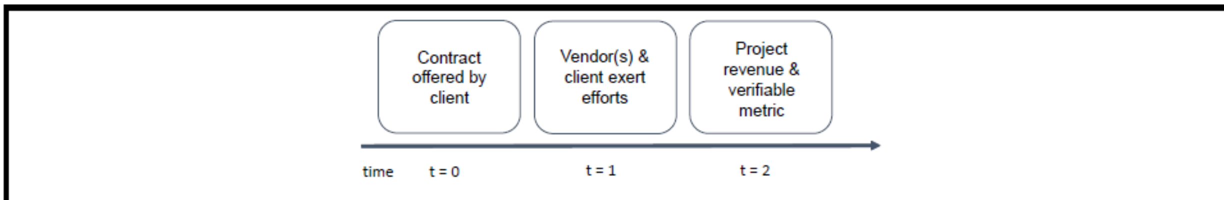

Figure 1. Sequence of Events in the Model)

Model Formulation and Analysis

In this section, we describe the contractual structures capable of yielding optimal results (for the client) under two scenarios: when a single vendor performs tasks 1 and 2 (single-sourcing, SS) and when two vendors are used—that is, when each task is assigned to a dedicated vendor (multisourcing, MS). We then assess the relative efficacy of single-sourcing and multisourcing by comparing the client's optimal profits under these two outsourcing modes.

We begin with the centralized setting in which the client and 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:

$$\mathbf{e}^* = \arg\max_{e_i \geq 0, i \in \{1,2,3\}} E[v(\mathbf{e})] - \sum_{i=1}^{3} c_i(e_i) \quad (1)$$

Equation (1) determines the first-best efforts (e^*i) in the coordinated problem of maximizing the joint profits. Given $v(e) = \phi\ [e_1 + \{\theta + (1 - \theta)\gamma\}e_2 + \{\theta + (1 - \theta)\lambda\}e_3] + \varepsilon$ and $c_i\,(e_i) = e^2_i\ /2$, it is easy to see that $e^*_1 = \phi$, $e^*_2 = \phi\ [\theta + (1 - \theta)\gamma]$, and $e^*_3 = \phi\ [\theta + (1 - \theta)\lambda]$.

We next present results, in the decentralized setting, derived in two cases: whether tasks are modular or integrated—that is, whether or not (respectively) the verifiable performance metric S is independent of client effort.

Modular Tasks

We first examine the case where the VPM is independent of client effort and so depends only on vendor effort. Such modularity presupposes the existence of verifiable performance measures that reflect only vendor efforts on the outsourced tasks (i.e., and not client efforts). Thus, we model a setting in which a service level agreement (SLA) can be designed that is strictly a function of the outsourced activities.

Because we seek to compare single-sourcing with multisourcing, it is necessary to compute the client's optimal expected profit under each sourcing mode. Therefore, we must determine the optimal incentive contract—from the client's perspective—for each case prior to making comparisons. We first consider the single-sourcing case, in which one vendor performs both tasks 1 and 2.

Single-Sourcing

If the client seeks to offer the vendor a contract f based on the performance metric S, then that contract will call for the client to transfer an amount equal to $f(\bar{S})$ (for $\bar{S}$ the realized value of S). Using Π to signify profits and "SS" to indicate single-sourcing, we can state the client's contract design problem as follows:

$$\max_{f(\bullet)} \Pi_{SS} = E\left[v\left(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3\right)\right] - c_3\left(\tilde{e}_3\right) - E\left[f\left(S\right) | \left(\tilde{e}_1, \tilde{e}_2\right)\right] \quad (2)$$

subject to

$$\tilde{e}_3 = \arg\max_{e_3 \geq 0} E\left[v\left(\tilde{e}_1, \tilde{e}_2, e_3\right)\right] - c_3\left(e_3\right) - E\left[f\left(S\right) | \left(\tilde{e}_1, \tilde{e}_2\right)\right] \quad (3)$$

$$\tilde{e}_1, \tilde{e}_2 = \arg\max_{e_1, e_2 \geq 0} E\left[f\left(S\right) | \left(e_1, e_2\right)\right] - c_1\left(e_1\right) - c_2\left(e_2\right) \quad (4)$$

and

$$E\left[f\left(S\right) | \left(\tilde{e}_1, \tilde{e}_2\right)\right] - c_1\left(\tilde{e}_1\right) - c_2\left(\tilde{e}_2\right) \geq 0 \qquad (5)$$

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, and equation (3) represents the analogous problem for the client's effort. Equation (2) formalizes the client's contract design problem.

The decisions made by client and vendor are simultaneous; thus the respective parties can solve (3) and (4) at the same time because each party bases its best response on the other party's reaction function.

Lemma 1. *If both of the development tasks are outsourced to a single vendor, then the client's optimal contract is a linear one* (*of the form* $T + \alpha S$) *that provides for a fixed fee* (T) *and a payment* (αS) *contingent on the verifiable performance metric* (S).

Lemma 1 is useful because it allows us to limit our attention to linear contracts under SS. So, even though we have not shown that the linear contract form is *uniquely* optimal, Lemma 1 establishes that no other contract form can yield a higher expected profit for the client than the optimal linear contract. Note that this result differs from the finding of Bhattacharyya and Lafontaine (1995), who show that linear contracts (on project revenues) are optimal in coordinating investment problems with double-sided moral hazard; we show that linear contracts are optimal for clients faced with the partial alignment of project revenue and a verifiable project metric under moral hazard when that VPM is a function of vendor effort only. It is therefore sufficient for us to use the client's expected profit from an optimal linear contract under single-sourcing as the benchmark for comparison with the outcomes under multisourcing.

Before analyzing the efficacy of multisourcing, we should like to know whether the optimal linear contract in this outsourcing mode also yields the client's *first-best* expected result. That result is defined (in a principal–agent framework) as follows: (1) the principal and the agent (here, client and vendor) make system-optimal efforts, as defined in equation (1); and (2) the principal attains the maximum profits possible—in other words, the vendor's expected profit is equal to its reservation value.

Proposition 1. *If both of the development tasks are outsourced to a single vendor, then the first-best result (from the client's perspective) can be attained if and only if there is perfect alignment between the expected project revenue and the expected verifiable signal. In other words, the first-best result requires that the marginal effects of* e_1 *and* e_2 *on* V(e) *and* S(e) be *identical* (*i.e.,* $\theta = 0$ *or* $\gamma = 1$).

The client earns a profit of $\Pi_{SS} = \phi^2\left[\frac{\theta^2}{2} + \frac{\left[1+\gamma\{\theta+(1-\theta)\gamma\}\right]^2}{2\left(1+\gamma^2\right)}\right]$ if it uses single-sourcing. The linear contract is optimal for the client; however, if project revenue and the verifiable metric are not perfectly aligned, then the SS mode does not attain the first-best solution because it fails to resolve completely the loss (vis-à-vis the vendor) stemming from that merely partial metric–revenue alignment. Proposition 1 states the condition under which such a perfect alignment is achieved; it also shows that eliminating the metric–revenue mismatch allows the client to achieve its first-best profit. We remark that this finding differs from the standard result in Bhattacharyya and Lafontaine, that linear contracts between client and vendor can achieve no more than the second-best profit. Because the verifiable metric is independent of client effort, the only moral hazard encountered by the client concerns the extent of vendor effort. A single vendor performs tasks 1 and 2, and the client approaches a first-best solution to the extent that it mitigates the partial alignment between project revenue and the verifiable metric. If the condition in Proposition 1 is satisfied, then both client and vendor will exert optimal levels of effort and the former will achieve its first-best profit.

If there is partial alignment between the project revenue and the verifiable performance metric, then the optimal solution obtained by linear contracts is only second-best. So when there is single-sided moral hazard and partial alignment, no contract can attain the first-best solution. In other words, the inefficiency due to partial alignment between the VPM and project revenue cannot be resolved.

Next we analyze the multisourcing case, in which each task (1 and 2) is assigned to a different vendor. We then compare the two outsourcing strategies.

Multisourcing

If each task is assigned to a different vendor, then the client could, in principle, 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, then the client's contract design problem in the multisourcing (MS) case is

$$\max_{f_i(\cdot)} \Pi_{MS} = E\left[v(\tilde{e}_1,\tilde{e}_2,\tilde{e}_3)\right]-c_3(\tilde{e}_3)-E\left[f_1(S)\,|\,(\tilde{e}_1,\tilde{e}_2)\right] -E\left[f_2(S)\,|\,(\tilde{e}_1,\tilde{e}_2)\right] \quad (6)$$

Subject to the following conditions:

$$\tilde{e}_3 = \arg\max_{e_3\geq 0} E\left[v(\tilde{e}_1,\tilde{e}_2,e_3)\right]-c_3(e_3)-E\left[f_1(S)\,|\,(\tilde{e}_1,\tilde{e}_2)\right] -E\left[f_2(S)\,|\,(\tilde{e}_1,\tilde{e}_2)\right] \quad (7)$$

$$\tilde{e}_1 = \arg\max_{e_1\geq 0} E\left[f_1(S)\,|\,(e_1,\tilde{e}_2)\right]-c_1(e_1) \quad (8)$$

$$\tilde{e}_2 = \arg\max_{e_2\geq 0} E\left[f_2(S)\,|\,(\tilde{e}_1,e_2)\right]-c_2(e_2) \quad (9)$$

$$E\left[f_1(S)\,|\,(\tilde{e}_1,\tilde{e}_2)\right]-c_1(\tilde{e}_1)\geq 0 \quad (10)$$

$$E\left[f_2(S)\,|\,(\tilde{e}_1,\tilde{e}_2)\right]-c_2(\tilde{e}_2)\geq 0 \quad (11)$$

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

Proposition 2. *If development tasks are outsourced to different vendors, then the client obtains the first-best result—irrespective of partial alignment between the verifiable metric and project revenue—by offering the vendors separate linear contracts of the form* $T_1 + \alpha_1 S$ *and* $T_2 + \alpha_2 S$*. These contracts consist* *of a fixed fee and an additional payment based on the VPM.*

A client that uses multisourcing attains the profit $\Pi_{MS} = \phi^2 \left[\frac{1}{2} + \frac{\theta^2}{2} + \frac{\{\theta + (1-\theta)\gamma\}^2}{2} \right]$

The first insight from Proposition 2 is that the effect of partially aligned revenue and metric can be eliminated by using a separate linear contract (with different fixed fees and variable payments) for each vendor. This finding is important because, in the presence of partial alignment, using the same proportion of the VPM as the variable payment for both vendors prevents the client from obtaining their respective best efforts. That is, each vendor has an incentive to free-ride when the client's use of the same contract fails to differentiate between them. Thus a vendor can exert less effort and still receive the same compensation. However, a client that uses separate linear contracts can always sufficiently incentivize each vendor to exert its first-best effort by using different combinations of variable payments and fixed fees. Because such contracts allow the client to distinguish between the two vendors' efforts, neither vendor can free-ride on the other.

Observe that there is no moral hazard on the client's part in this case, since the verifiable metric is independent of client effort. It follows that the client can use separate linear contracts to resolve not only alignment issues but also the moral hazard entailed by contracting with two vendors. As in the SS case, the client uses a fixed fee to ensure that vendors attain their respective reservation values. This strategy ensures the first-best efforts from client and vendors as well as attainment of the first-best solution by the client (the principal).

When taken together, Propositions 1 and 2 allow us to compare the two sourcing strategies. We conclude that when the tasks are modular, multisourcing (weakly) dominates single-sourcing. If there is partial alignment between the project revenue and the VPM, then MS strictly dominates SS. So with reference to our earlier examples, if mPhase Technologies is outsourcing modular tasks, then it could just as well use single-sourcing because the output measurability is high (θ is low) and so the performance of SS will be comparable to that of MS. In the cases of Travelcountry and New Motion, however, if the required tasks are modular, then these firms should use multisourcing. The explanation is that the extent of project revenue–VPM misalignment is high (for Travelcountry) and the output measurability θ itself is medium (for New Motion).

In the next section we analyze the scenario in which the outsourced project tasks are integrated. Here, then, the verifiable performance metric depends on both client and vendor efforts.

Integrated Tasks

When project tasks are integrated, rather than modular, the VPM depends not only on vendor effort but also on client effort. We therefore model a setting in which there is a tight interdependence between the task carried out by the client and the outsourced activities. In our example set, such interdependence is exemplified by General Motors: that client firm adopted the systems integrator role and, as a result, had to invest in such integration; those efforts affected both project revenue and the verifiable performance metric. As before, the client offers a contract that is contingent on the VPM. We first consider the single-sourcing case, in which one vendor performs both tasks 1 and 2.

Single-Sourcing

We continue to assume that the client offers the vendor a contract f based on the VPM S. Then the client's contract design problem can be stated as

$$\begin{aligned}\max_{f(\cdot)} \Pi_{SS} = E\left[v\left(\tilde{e}_1,\tilde{e}_2,\tilde{e}_3\right)\right] - c_3\left(\tilde{e}_3\right) \\ -E\left[f\left(S\right) \mid \left(\tilde{e}_1,\tilde{e}_2,\tilde{e}_3\right)\right]\end{aligned} \qquad (12)$$

Subject to

$$\begin{aligned}\tilde{e}_3 = \arg\max_{e_3 \geq 0} E\left[v\left(\tilde{e}_1,\tilde{e}_2,e_3\right)\right] - c_3\left(e_3\right) \\ -E\left[f\left(S\right) \mid \left(\tilde{e}_1,\tilde{e}_2,e_3\right)\right]\end{aligned} \qquad (13)$$

$$\begin{aligned}\tilde{e}_1,\tilde{e}_2 = \arg\max_{e_1,e_2 \geq 0} E\left[f\left(S\right) \mid \left(e_1,e_2,\tilde{e}_3\right)\right] \\ -c_1\left(e_1\right) - c_2\left(e_2\right)\end{aligned} \qquad (14)$$

And

$$E\left[f\left(S\right) \mid \left(\tilde{e}_1,\tilde{e}_2,\tilde{e}_3\right)\right] - c_1\left(\tilde{e}_1\right) - c_2\left(\tilde{e}_2\right) \geq 0 \qquad (15)$$

In this problem, (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 client's contract design problem.

Lemma 2. *For the single-sourcing of integrated tasks, it is optimal for the client to offer the vendor a linear contract consisting of a fixed fee (T) plus a variable payment (αS) based on the verifiable performance metric. Such an optimal contract attains the second-best profit for the client under single-sourcing.*

The client's profit when single-sourcing is used for integrated tasks is given by

$$\Pi_{SS}^{*} = \phi^2\left[\frac{\{\theta+(1-\theta)\lambda\}^2}{2}+\frac{\left[1+\gamma\{\theta+(1-\theta)\gamma\}\right]^2}{2\left(1+\gamma^2+\lambda^2\right)}\right].$$

The result that linear contracts are optimal also when client and vendor efforts are interdependent is due to the presence of moral hazard with regard to client and vendor efforts, given that Bhattacharyya and Lafontaine show linear contracts to be optimal in cases of double-sided moral hazard. Since the VPM now depends on the efforts of both client and vendor, it follows that 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 less the cost of client and vendor effort in performing the required tasks. Recall from equation (1) that the vendor will exert its first-best effort only if it receives all of 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.

Similarly to Lemma 1, Lemma 2 allows us to limit our attention to linear contracts when computing the client's optimal expected profit under single-sourcing, which is necessary if we are to compare the two sourcing modes. Hence we identify the client's optimal contract under multisourcing and then compare the two modes of outsourcing.

Multisourcing

Suppose now that tasks 1 and 2 are performed by different vendors. Then the client offers the vendors performing task 1 and task 2 the respective contracts f1 and f2, both of which are based (as before) on the verifiable metric S. In this case, the client's contract design problem is

$$\max_{fi(\bullet)} \Pi_{MS} = E\left[v\left(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3\right)\right] - c_3\left(\tilde{e}_3\right)$$
$$-E\left[f_1(S) \mid \left(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3\right)\right] - E\left[f_2(S) \mid \left(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3\right)\right] \quad (16)$$

subject to the following conditions:

$$\tilde{e}_3 = \arg\max_{e_3 \geq 0} E\left[v\left(\tilde{e}_1, \tilde{e}_2, e_3\right)\right] - c_3\left(e_3\right)$$
$$-E\left[f_1(S) \mid \left(\tilde{e}_1, \tilde{e}_2, e_3\right)\right] - E\left[f_2(S) \mid \left(\tilde{e}_1, \tilde{e}_2, e_3\right)\right] \quad (17)$$

$$\tilde{e}_1 = \arg\max_{e_1 \geq 0} E\left[f_1(S) \mid \left(e_1, \tilde{e}_2, \tilde{e}_3\right)\right] - c_1\left(e_1\right) \quad (18)$$

$$\tilde{e}_2 = \arg\max_{e_2 \geq 0} E\left[f_2(S) \mid \left(\tilde{e}_1, e_2, \tilde{e}_3\right)\right] - c_2\left(e_2\right) \quad (19)$$

$$E\left[f_1(S) \mid \left(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3\right)\right] - c_1\left(\tilde{e}_1\right) \geq 0 \quad (20)$$

$$E\left[f_2(S) \mid \left(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3\right)\right] - c_2\left(\tilde{e}_2\right) \geq 0 \quad (21)$$

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

Lemma 3. *For the multisourcing of integrated tasks, it is optimal for the client to offer each vendor a separate linear contract consisting of different variable payments (based on the VPM) and fixed fees. Such optimal contracts obtain the second-best profit for the client under multisourcing.*

Lemma 3 states that, in the presence of partial alignment and moral hazard involving the principal (client) and two agents (vendors), separate linear contracts mitigate the effect of partial alignment. This insight is related to Proposition 2, although here the partial metric–revenue alignment is eliminated by offering separate linear contracts to each vendor. However, there is still the moral hazard problem between client and vendors.

Next we compare the client rewards from the single-sourcing and multisourcing strategies (ΠSS and ΠMS) when tasks are integrated. The possibility of free-riding prevents the client from attaining its first-best result under either outsourcing mode (Holmstrom 1982). In SS, sources of inefficiency include partial metric–revenue alignment and the moral hazard between client and vendor; in MS, however, the moral hazard between the client and *two* vendors is the sole source of inefficiency. Proposition 3 shows that, when the tasks to be outsourced are integrated, no sourcing mode (even weakly) dominates the other. This result contrasts with the modular tasks case, where MS does weakly dominate SS.

Proposition 3. *If the verifiable performance metric is a function of the efforts devoted to all three tasks, then either* $\Pi_{SS} \geq \Pi_{MS}$ *or* $\Pi_{SS} \leq \Pi_{MS}$ *is possible. In other words, there is no universally (weakly) dominant sourcing mode.*

If the effect of partial alignment between (vendor efforts to increase) project revenue and the verifiable metric is eliminated under single-sourcing—that is, if project revenue and the VPM are aligned with respect to vendor effort (either $\gamma = 1$ or $\theta = 0$ are sufficient conditions to ensure this alignment)—then the only distinction (from the client's perspective) between single- and multisourcing is the extent of moral hazard. Because MS requires the client to face moral hazard with two vendors, we can expect SS (which involves moral hazard with only one vendor) to dominate.

For the case of *integrated* tasks, the difference in client profits under single-sourcing and multisourcing (ΠSS – ΠMS) is illustrated in Figure 2. This figure confirms that—when project revenue and the verifiable metric are both aligned with vendor effort—the moral hazard associated with two vendors makes the client's expected profit lower than does moral hazard with one vendor.

When tasks are integrated and there is partial revenue–metric alignment, the client should choose its outsourcing mode based on trade-offs between the effects of moral hazard and partial alignment with the vendor's effort. In this integrated tasks case, the presence of moral hazard (with either one or two vendors) favors single-sourcing. Yet MS can mitigate the effect on vendor effort of partial alignment between project revenue and the VPM; this follows because vendors can be incentivized by linear contracts that are differentiated. In contrast, the client that uses SS cannot eliminate this effect of partial alignment because both outsourced tasks are performed by the same vendor (and so are governed by a single linear contract).

We now analyze how θ, the extent of verifiability, affects the optimal sourcing mode. When θ is high, the verifiable performance metric contributes a small share of the project revenue while the unverifiable part of project revenue contributes a large share. A high value of θ plays a similar role to that of a high degree of misalignment (γ) between project revenue and the VPM, since MS is more efficient than SS at mitigating the misalignment effect because each vendor can be offered a different linear contract. Thus a higher value of θ implies a greater misalignment between the verifiable metric and project revenue, a situation that favors multisourcing.

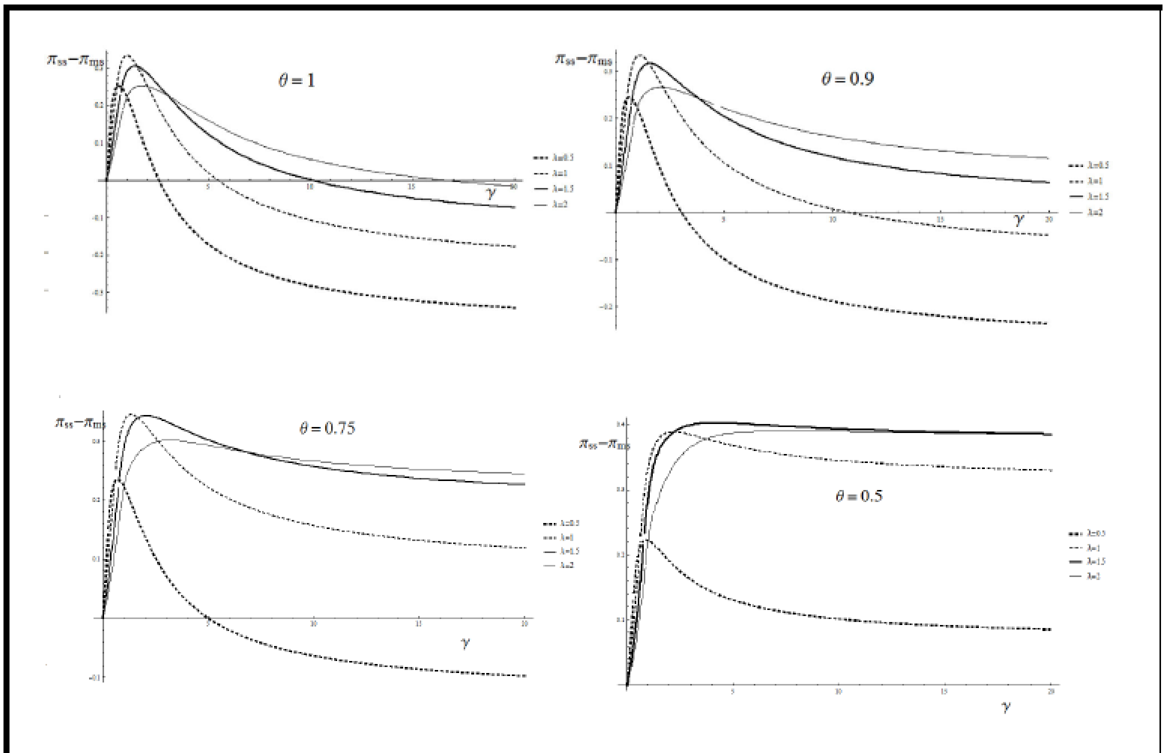

Figure 2. Difference in Client Profits from Single-Sourcing and Multisourcing of Integrated Tasks

Finally, the greater the effect of VPM–project revenue misalignment on client effort (λ), the higher the value of S for a given effort vector. Hence a vendor receives more of a payout provided its contract's variable component is positive (which is always the case), and so a high value of λ encourages free-riding. Multisourcing is more affected more by this problem than is single sourcing because MS entails moral hazard involving two agents and SS only one. Hence the effect of misalignment—between project revenue and the verifiable metric—on the client's effort is to make single-sourcing more attractive than multisourcing. Conversely, the client finds MS more attractive than SS for low values of λ.

In our example set, General Motors clearly faced tasks that had to be integrated. If the revenue–metric misalignment is low in client effort and high in vendor effort and if the measurability of project revenue is low, then GM should favor the MS mode; it should favor the SS mode if the revenue–metric misalignment is low in vendor effort and high in client effort and if the measurability of project revenue is low. We conjecture that a firm (such as GM) with a large base of operations will find it difficult to verify performance and will therefore have a hard time designing SLAs for its vendors that are aligned with project revenue. For that reason, multisourcing is likely to be preferred.

Studies in the information systems literature have sought to identify the most appropriate domains for single-sourcing versus multisourcing (Bapna et al. 2010; Herz et al. 2011). Our paper is among the first to provide a basis for modeling the benefits of the two modes for the purpose of comparing their efficiency. This model is both parsimonious and able to capture the trade-offs—when choosing between these two outsourcing modes—among task modularity, project revenue verifiability, and metric–revenue misalignment. We show that the effect of moral hazard with multiple vendors favors SS; however, the effects of partial alignment and relatively unverifiable project revenue favor MS. Hence, a more nuanced approach to the choice of outsourcing mode must be adopted.

Comparative Statics: Risk Aversion and Cost Interdependence

In this section, we analyze how the choice between single-versus multisourcing is affected by two factors: the risk aversion of vendors and the cost of task interdependence. The case with integrated tasks does not yield a tractable analysis, so our discussion here is limited to the case with modular tasks. (For the integrated tasks case, we shall later summarize the insights gleaned from numerical experiments.)

Risk Aversion

We model only vendor risk aversion in this section, as clients are typically larger and have diversified portfolios of IT projects and, hence, they are likely to be risk-neutral. Adding client aversion to the model would make the model hard to analyze without numerical simulations, which can take away from the main focus of this paper.[3] Ceteris paribus, we assume vendors to be risk averse and then assess how vendor risk aversion alters the efficacy (from the client's perspective) of single-sourcing and multisourcing. For simplicity, we assume also that vendor risk aversion is captured by a constant absolute risk aversion (CARA) model whose coefficient of risk aversion we denote by r. The distribution of uncertainty about the VPM S, which we denote by ε_2, is assumed to be normally distributed with a mean

[3] The main reason for not including client risk aversion is that in our model, we do not capture vendor specific risks, which may be the key drivers of risk mitigation strategies such as multisourcing. Instead, we focus on task modularity and the misalignment between the project metric and the revenues.

of 0 and a standard deviation of σ. We compute the certainty equivalent of the profits for risk-averse vendor(s), after which we estimate the effect of that risk aversion on client profits.

Proposition 4. *If vendors are risk averse, then there exists an* $\overline{r\sigma^2} > 0$ *such that* ΠMS – ΠSS ≥□0 *for all* $r\sigma^2 \leq \overline{r\sigma^2}$ *and* ΠMS – ΠSS < 0 *for all* $r\sigma^2 \leq \overline{r\sigma^2}$ *. So if the effect of risk aversion is high (i.e., if either uncertainty or the coefficient of risk aversion is high), then single-sourcing is preferred by the client; otherwise, multisourcing is preferred.*

This proposition reveals the effect of vendor risk aversion on the efficacy of each outsourcing mode. Vendor risk aversion affects client profits because each vendor must be more highly compensated in order to mitigate the effect of risk aversion (thus vendors are paid a risk premium to participate, with the client, in a joint development effort). Under multisourcing, the effect of risk aversion is evident in two different ways: the client must compensate two vendors for risk and so must pay two risk premiums, or multisourcing can attain the first-best solution for modular efforts, and Proposition 3 indicates that MS performs better than SS when the vendor effort is highly distorted by misalignment. However, one inescapable effect of risk aversion is that the client cannot attain the first-best solution, even for modular tasks under multisourcing, because vendors must be paid a risk premium. Along these same lines, our numerical experiments for the integrated case suggest that the area of the region in which the client prefers MS is diminished (because, once again, two vendors must each be paid a risk premium).

Smaller firms are more likely to be risk averse; in our example set, vendors such as WNX (client: Travelcountry) and Visionaire (client: New Motion) should be more averse to risk, which would indicate working for clients employing a SS strategy. The smaller SMEs in China are similarly more risk averse, so SS is likely preferable to MS in that context. However, larger firms—such as EDS, HP, and Wipro (client: General Motors)—should be less risk averse because they have undertaken a diversified portfolio of projects; hence, their typical client is likely to favor MS.

Effect of Task Interdependence Costs on Single- and Multisourcing

Ceteris paribus, we assume in this section that there is a cost of task coordination; we must, therefore, assess that cost's effect on the optimal sourcing mode. In Itoh (1994), the cost of task interdependence between vendor efforts is modeled for the single-sourcing case as ae_1e_2, where e_1 and e_2 are the efforts exerted by the single vendor on tasks 1 and 2. In the IT context, this formulation is akin to an increasing cost of coordinating the coding on two activities; thus an increased number of features included in one task (which entails greater effort) leads to a higher cost of task coordination. When the cost of coordinating two activities is high, those tasks can be regarded as substitutes. If the cost term a is close to 0, then the tasks can be executed independently of each other and so can be regarded as complements.

Itoh (1994) assigned a cost of task coordination in the single-sourcing case only. For the purpose of making comparisons, we suppose that the cost of task coordination is the same for both SS and MS; hence, the coordinated efforts in both types of outsourcing are comparable. We also include the cost for task coordination of vendor effort (in the modular tasks case) and for coordination of both vendor effort and vendor and client efforts (in the integrated tasks case). Observations of real-world software development reveal that clients tend to identify a primary vendor as the coordinating agent; in our model, we assign the cost of task coordination to the vendor (in the SS case) or, without loss of generality, to vendor 2 (in the MS case). Following Itoh (1994), we take the cost of coordination between vendor efforts to be ae1e2. Proposition 5 summarizes our findings related to the effect of task interdependence costs on the optimal sourcing strategy.

Proposition 5. *If there is a cost to coordinating task 1 and task 2, then multisourcing is preferable to single-sourcing.*

The intuition underlying this claim is as follows: If it is costly to coordinate two modular tasks, then client profits under single-sourcing are reduced still further because the single vendor may attempt to reduce its coordination costs by investing less effort in one of the two tasks. Under multisourcing, however, each vendor reduces its effort yet they still achieve the first-best effort (corresponding to the coordinated case with costly task coordination). Note that our result is stronger than that of Itoh (1994), as we show that MS dominates even when an equivalent coordination cost is introduced for the coordinating vendor in MS (Itoh does not impute a coordination cost in the MS context).

For the integrated tasks case, we express the cost of task interdependence as $ae_1e_2 + be_2e_3$. Here the additional cost of coordinating two tasks reduces the MS mode’s efficacy, as all three firms reduce their respective efforts to compensate for the additional cost of coordination. Single-sourcing suffers more from costly coordination because the single vendor reduces its efforts on both tasks to compensate for the additional cost of coordination (see Figure 3 and compare to Figure 2). Multisourcing is then more attractive than single-sourcing compared to the situation where no cost of coordination is incurred.

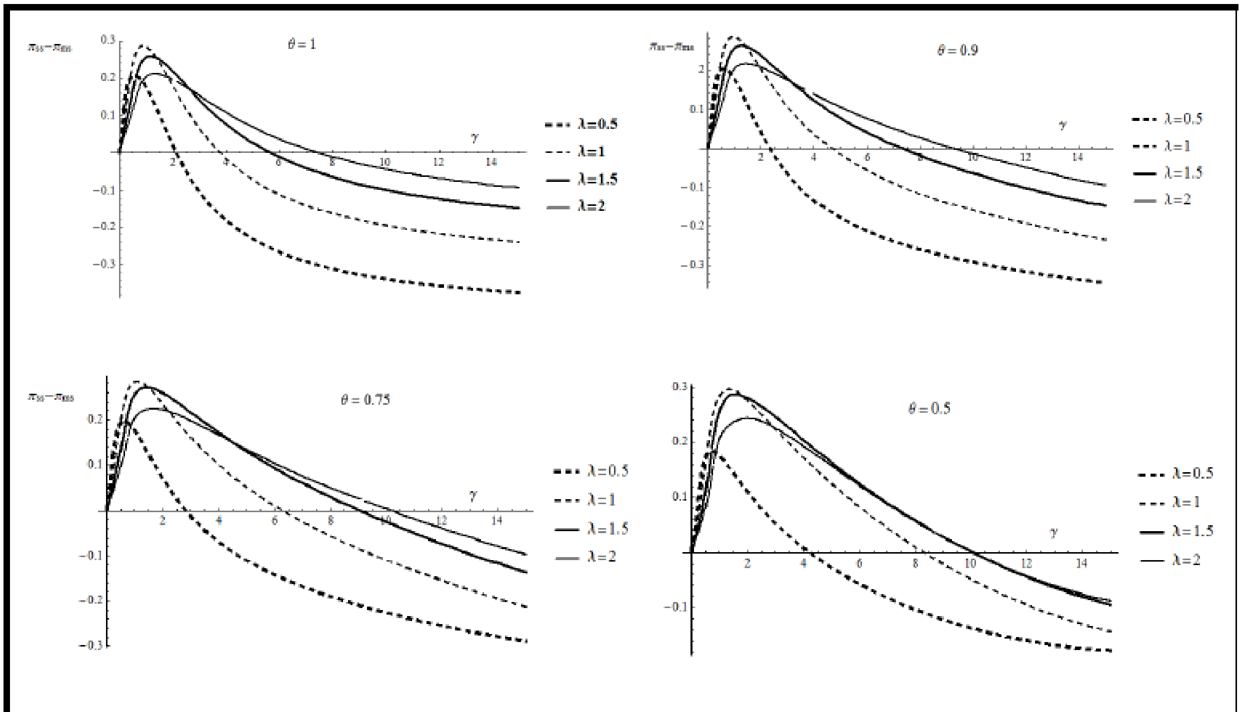

Figure 3. Effect of Task Coordination Cost on Single- and Multisourcing (Integrated Tasks)

Conclusions and Future Research

The main findings of this paper are as follow: If tasks are modular, then multisourcing performs better than single-sourcing if project revenue and the verifiable metric are partially aligned (if they are exactly aligned, then the two outsourcing modes perform equally well). If the tasks are integrated, then SS outperforms MS provided that (1) alignment of project revenue and the verifiable performance metric is high in vendor effort; (2) revenue–metric alignment is low in client effort; and (3) project revenue has a high degree of verifiability; otherwise MS outperforms SS. Single-sourcing is favored when vendors are strongly averse to risk, whereas multisourcing is favored when task interdependence results in coordination costs. These findings are summarized in Figure 4.

In all cases, we find that linear contracts (which are easy to implement) based on the VPM are optimal from the client's perspective. These results can be extended to a more general setting that can accommodate various kinds of IT and IT-enabled outsourcing projects. Thus we can demonstrate that this model's applicability is not limited by the functional forms assumed in this paper.

Our results have two overarching implications. First, if tasks are modular, then multisourcing performs no worse (and sometimes better) than single-sourcing. This observation contrasts with Itoh (1994), where the author reports that SS dominates MS in the absence of misalignment between project revenue and the verifiable metric. If tasks are modular and if revenue is aligned with the VPM (upper left quadrant in Figure 4), then single-sourcing performs as well as multisourcing. However, the optimal sourcing mode for the other three cases we study has not been addressed in the literature. A key contribution of our paper is thus to build a parsimonious model that captures important factors— acknowledged but not previously studied in the literature—in the client firm's strategic sourcing decision. In particular, we contribute to the extant literature (Itoh 1991, 1994) by presenting a model that captures metric–revenue misalignment. Our model also incorporates such factors as integrated versus modular tasks and the extent to which revenue is verifiable, which previous research has not tested for their effect on the firm's outsourcing mode. Whereas the extant literature has studied the trade-off between MS and SS in terms of agency issues such as risk aversion, limited liability, and relational contracts (Che and Yoo 2001; Holmstrom and Milgrom 1991), in this paper we identify domains in which multisourcing dominates because misalignment of project revenue and the verifiable performance metric is low (high) in client (vendor) effort and/or project revenue is not easily verified.

	Perfect alignment	Partial alignment $0 < \theta \leq 1, \gamma \neq 1$
Modular tasks	SS=MS	SS$<$MS
Integrated tasks	SS$>$MS	SS$>$MS (Low θ, γ, α; High λ, r) SS$<$MS (High θ, γ, α; Low λ, r)

Figure 4. Summary of Model Findings

These results concur with other observations in practice and with the case-study examples presented earlier. The greatest use of multisourcing has been observed in the banking and manufacturing sectors (Cohen and Young 2006; Levina and Su 2008), although IT-specific tasks are not core client activities in these sectors. Whereas the project's revenue may depend on the joint efforts of client and vendor(s), an IT project's verifiable metric may reflect vendor more than client effort—recall, for example, our earlier discussion on mPhase Technologies.

The second major implication of our research is that single-sourcing performs well on integrated tasks when the VPM–revenue alignment is high (low) in vendor (client) effort and when project revenue is easily verified. If client–vendor relations involve any moral hazard, then free-rider problems arise—and even more so when there are multiple vendors. It follows that SS should be used when a larger number of vendors exacerbates outsourcing's inherent moral hazard problem. However, if a single vendor requires more incentives than multiple vendors (as when project revenue is not easily verified and metric–revenue misalignment is high in vendor effort but low in client effort), then MS should be used by the client.

As mentioned in the "Literature Review," this paper adds to the growing body of work on multisourcing by developing a theoretical model that provides answers to important yet previously unanswered questions about comparisons between single- and multisourcing in the presence of revenue–metric misalignment, task modularity, risk aversion, and task interdependence costs. Here we have studied only the pure modes of single-sourcing and multisourcing; future research should consider hybrid systems that incorporate both SS and MS. The exploration of many other unanswered questions including a detailed model of client risk aversion will also increase our understanding of the various outsourcing modes.

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Single-Sourcing Versus Multisourcing: The Roles of Output Verifiability and Task Modularity

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Appendix

In this appendix we provide mathematical proofs of all lemmas and propositions presented in the paper. It will be useful in what follows to have set, as we do now, $\bar{\boldsymbol{S}} = \boldsymbol{E}[\boldsymbol{S}]$ and $\bar{\boldsymbol{U}} = \boldsymbol{E}[\boldsymbol{U}]$.

Proof of Lemma 1. Let us assume that a contract $f_0(\cdot)$ is optimal (i.e., it maximizes the client's expected profit) and that it induces the optimal efforts $\tilde{e}_1$ and $\tilde{e}_2$ by the vendor. Then the vendor's problem can be represented as

$$\max_{e_1, e_2 \geq 0} E[f_0(S) \mid (e_1, e_2)] - c_1(e_1) - c_2(e_2)$$

The first-order conditions (FOCs) for this problem are

$$c_1'(\tilde{e}_1) = \tilde{e}_1 = \frac{\partial E\big[f_0(S) \mid (e_1,\ e_2)\big]}{\partial \bar{S}} \frac{\partial \bar{S}}{\partial e_1}\bigg|_{\{\tilde{e}_1, \tilde{e}_2\}} \tag{L1.1}$$

$$c_2'(\tilde{e}_2) = \tilde{e}_2 = \frac{\partial E\big[f_0(S) \mid (e_1,\ e_2)\big]}{\partial \bar{S}} \frac{\partial \bar{S}}{\partial e_2}\bigg|_{\{\tilde{e}_1, \tilde{e}_2\}} \tag{L1.2}$$

The FOCs for the vendor's problem under a linear contract $\{\alpha, T\}$ are

$$\alpha \frac{\partial E[S]}{\partial e_1} = e_1$$

$$\alpha \frac{\partial E[S]}{\partial e_2} = e_2$$

Therefore, equations (L1.1) and (L1.2) can be implemented via a linear contract $\{\alpha, T\}$ by setting

$$\alpha = \frac{\partial E[f_0(S) \mid (e_1, e_2)]}{\partial \bar{S}} |_{(\tilde{e}_1, \tilde{e}_2)}$$

Note that the fixed payment T does not affect vendor effort and so can be chosen to make the vendor's participation constraint tight. Checking for second-order conditions (SOCs) under a linear contract yields $\alpha \frac{\partial^2 \bar{S}}{\partial e_i^2} - 1 = -1 < 0$. We have thus established the optimality of the linear contractual form $\{\alpha, T\}$.

Proof of Proposition 1. In the modular tasks case, $S = \phi(e_1 + \gamma e_2) + \varepsilon_2$ because project outcomes do not depend on the client's effort ($\lambda = 0$). Having established in Lemma 1 that the linear contract is optimal, in this proof we need attend only to linear contracts (of the form $T + \alpha S$).

Effort choice. The FOCs for the first-best effort level, as defined in equation (4), are

$$\begin{aligned}\tilde{e}_1 &= \arg\max_{e_1} E[f(S) \mid e_1, e_2] - c_1(e_1) - c_2(e_2)\\ &= \arg \quad \max_{e_1} T + \alpha\phi[e_1 + \gamma e_2] - \tfrac{e_1^2}{2} - \tfrac{e_2^2}{2} = \alpha\phi \end{aligned} \tag{P1.1}$$

and, similarly,

$$\tilde{e}_2 = \alpha\gamma\phi \tag{P1.2}$$

As shown in the proof of Lemma 1, the SOCs for linear contracts are satisfied. Then, by equation (5), $E[f(S) \mid \tilde{e}_1, \tilde{e}_2] - c_1(\tilde{e}_1) - c_2(\tilde{e}_2) \geq 0$. Hence the client will set T such that $E[f(S) \mid \tilde{e}_1, \tilde{e}_2] - c_1(\tilde{e}_1) - c_2(\tilde{e}_2) = 0$, thereby making the vendor's participation constraint tight and extracting all the surplus. Therefore,

$$T + \alpha E[S \mid \tilde{e}_1, \tilde{e}_2] - c_1(\tilde{e}_1) - c_2(\tilde{e}_2) = 0 \tag{P1.3}$$

From equation (3) it follows that

$$\tilde{e}_3 = \arg\max_{e_3 \geq 0} E[v(\tilde{e}_1, \tilde{e}_2, e_3)] - c_3(e_3) - E[f(S) \mid \tilde{e}_1, \tilde{e}_2]$$

As a result,

$$\tilde{e}_3 = \arg\max_{e_3 \geq 0} \phi[\tilde{e}_1 + \{\theta + (1-\theta)\gamma\}\tilde{e}_2 + \theta e_3] - \tfrac{e_3^2}{2} - \tfrac{\tilde{e}_1^2}{2} - \tfrac{\tilde{e}_2^2}{2} = \theta\phi \tag{P1.4}$$

Contract design. According to equation (2), the client's contract design problem can be stated as

$$\max_{f(\cdot)} \Pi_{\mathrm{SS}} = E[v(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3)] - c_3(\tilde{e}_3) - E[f(S) \mid (\tilde{e}_1, \tilde{e}_2)]$$

And

$$\max_{\alpha} \Pi_{\mathrm{SS}} = \phi[\tilde{e}_1 + \{\theta + (1-\theta)\gamma\}\tilde{e}_2 + \theta\tilde{e}_3] - \frac{\tilde{e}_3^2}{2} - \frac{\tilde{e}_1^2}{2} - \frac{\tilde{e}_2^2}{2}$$

since $E[f(S) \mid (\tilde{e}_1, \tilde{e}_2)] = \frac{\tilde{e}_1^2}{2} + \frac{\tilde{e}_2^2}{2}$. Substituting the values of $\tilde{e}_1$, $\tilde{e}_2$, and $\tilde{e}_3$ from equations (P1.1), (P1.2), and (P1.4) into the contract design problem yields

$$\max_{\alpha} \Pi_{\mathrm{SS}} = \phi^2\left[\alpha + \gamma\alpha\{\theta + (1-\theta)\gamma\} + \theta^2 - \tfrac{\theta^2}{2} - \tfrac{\alpha^2}{2} - \tfrac{\alpha^2\gamma^2}{2}\right]$$

which is a concave function in α. The FOC for the contract design problem gives us $\alpha = \frac{1+\gamma\{\theta+(1-\theta)\gamma\}}{1+\gamma^2}$, and the SOC yields $\frac{\partial^2 \Pi_{\mathrm{SS}}}{\partial \alpha^2} = -\phi^2[1+\gamma^2] < 0$. Substituting into the values of $\tilde{e}_1$, $\tilde{e}_2$, and $\tilde{e}_3$, we obtain $\tilde{e}_1 = \phi[\frac{1+\gamma\{\theta+(1-\theta)\gamma\}}{1+\gamma^2}]$, $\tilde{e}_2 = \phi[\frac{\gamma[1+\gamma\{\theta+(1-\theta)\gamma\}]}{1+\gamma^2}]$, and $\tilde{e}_3 = \phi\theta$. Finally, substituting these efforts into the profit function yields the profits given in Proposition 1.

First-best outcome. From equation (1) in the "Model Description and Assumptions" section, we know that the coordinated solution is $e_1^* = \phi$, $e_2^* = \phi[\theta + (1-\theta)\gamma]$, and $e_3^* = \phi\theta$. We can see that client effort in the SS modular case is $\tilde{e}_3 = \phi\theta$, which is the coordinated solution. For the vendor effort to be first-best, we need $\frac{1+\gamma\{\theta+(1-\theta)\gamma\}}{1+\gamma^2} = 1$ and $\frac{\gamma[1+\gamma\{\theta+(1-\theta)\gamma\}]}{1+\gamma^2} = \theta + (1-\theta)\gamma$. Solving these two equations simultaneously gives us that either $\theta = 0$ or $\gamma = 1$ is both a necessary and sufficient condition for the client to attain the first-best solution in the single-sourcing case.

Proof of Proposition 2. 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 fixed. The vendors' optimal efforts are given by

$$\tilde{e}_1 = \arg\max_{e_1 \geq 0} \alpha_1 E[S(e_1, \tilde{e}_2)] - c_1(e_1) + T_1 = \alpha_1 \phi$$

$$\tilde{e}_2 = \arg\max_{e_2 \geq 0} \alpha_2 E[S(\tilde{e}_1, e_2)] - c_2(e_2) + T_2 = \gamma \alpha_2 \phi$$

From Equations (10) and (11), which are the individual rationality constraints, we can see that T_1 and T_2 do not affect vendors' effort decisions. Therefore, we can freely adjust these terms to ensure that the vendor participation constraint is tight. Hence we can write

$$T_1 = -\alpha_1 E[S(\tilde{e}_1, \tilde{e}_2)] + \frac{\tilde{e}_1^2}{2}$$

and

$$T_2 = -\alpha_2 E[S(\tilde{e}_1, \tilde{e}_2)] + \frac{\tilde{e}_2^2}{2}$$

We can now complete the proof by showing that there exist $\{\alpha_1, \alpha_2\}$ such that $\tilde{e}_i = e_i^*$ is the unique Nash equilibrium for the vendor's effort decision. Set $\alpha_1 = 1$ and $\alpha_2 = \frac{\{\theta + \gamma(1-\theta)\}}{\gamma}$ It is easy to check that $\{e_1^*, e_2^*\}$ is a Nash equilibrium outcome and also the first-best solution. The reason is that vendor i's FOC is satisfied at e_i^* when vendor j chooses e_j^*. Since in this case the vendors' effort game is decoupled from client effort, we must show that $\{e_1^*, e_2^*\}$ is a unique Nash equilibrium. For that purpose, the Hessian is computed. We can check that

$$|\mathbf{H}| = \begin{vmatrix} \frac{\alpha_1 \partial^2 ES(e_1, e_2)}{\partial e_1^2} - \frac{\partial^2 c_1(e_1)}{\partial e_1^2} & \frac{\alpha_1 \partial^2 ES(e_1, e_2)}{\partial e_1 \partial e_2} \\ \frac{\alpha_2 \partial^2 ES(e_1, e_2)}{\partial e_1 \partial e_2} & \frac{\alpha_2 \partial^2 ES(e_1, e_2)}{\partial e_2^2} - \frac{\partial^2 c_2(e_2)}{\partial e_2^2} \end{vmatrix}$$
$$= \begin{vmatrix} -1 & 0 \\ 0 & -1 \end{vmatrix} = 1 > 0$$

because $\frac{\partial^2 ES(e_1, e_2)}{\partial e_1^2} = \frac{\alpha_2 \partial^2 ES(e_1, e_2)}{\partial e_2^2} = \frac{\alpha_1 \partial^2 ES(e_1, e_2)}{\partial e_1 \partial e_2} = 0$ and $\frac{\partial^2 c_1(e_1)}{\partial e_1^2} = \frac{\partial^2 c_2(e_2)}{\partial e_2^2} = -1$.Therefore, $\{e_1^*, e_2^*\}$ is a unique Nash equilibrium. Given that T_1 and T_2 are set such that no vendor earns a surplus over its reservation value, we conclude that the client can attain the first-best outcome for itself.

Proof of Lemma 2. Suppose that a contract $f_0(\cdot)$ is optimal and that it induces the optimal efforts $\tilde{e}_1$ and $\tilde{e}_2$ by the vendor and $\tilde{e}_3$ by the client. Then the FOCs for this vendor's problem are

$$c_1'(\tilde{e}_1) = \tilde{e}_1 = \frac{\partial E\left[f_0(S) \mid (e_1, e_2, e_3)\right]}{\partial \bar{S}} \frac{\partial \bar{S}}{\partial e_1}\bigg|_{\{\tilde{e}_1, \tilde{e}_2, \tilde{e}_3\}} \tag{L2.1}$$

$$c_2'(\tilde{e}_2) = \tilde{e}_2 = \frac{\partial E[f_0(S) \mid (e_1, e_2, e_3)]}{\partial \bar{S}} \frac{\partial \bar{S}}{\partial e_2}\bigg|_{\{\tilde{e}_1, \tilde{e}_2, \tilde{e}_3\}} \tag{L2.2}$$

It follows that either $\tilde{e}_1, \tilde{e}_2 \in (0, \infty)$ or $\tilde{e}_1 = \tilde{e}_2 = 0$. The latter case can easily be implemented by setting $\alpha = 0$; we therefore focus on the case $\tilde{e}_1, \tilde{e}_2 \in (0, \infty)$, which renders equations (L2.1) and (L2.2) necessary. The FOCs for the vendor's problem under a linear contract $\{\alpha, T\}$ are

$$\alpha \frac{\partial E[S]}{\partial e_1} = c_1'(e_1)$$

$$\alpha \frac{\partial E[S]}{\partial e_2} = c_2'(e_2)$$

Therefore, equations (L2.1) and (L2.2) can be implemented via a linear contract $\{\alpha, T\}$ by setting

$$\alpha = \frac{\partial E[f_0(S) \mid (e_1, e_2, e_3)]}{\partial \bar{S}}\bigg|_{\{\tilde{e}_1, \tilde{e}_2, \tilde{e}_3\}} \quad \text{(L2.3)}$$

We now examine the client's effort decision. If $\tilde{e}_3 > 0$ then, under $f_0(\cdot)$, the FOC for the client's effort choice problem is

$$\frac{\partial v(\tilde{e}_1, \tilde{e}_2, e_3)}{\partial e_3}\bigg|_{e_3 = \tilde{e}_3} - \frac{\partial E\big[f_0(S) \mid (e_1, e_2, e_3)\big]}{\partial \bar{S}}\bigg|_{\{\tilde{e}_1, \tilde{e}_2, \tilde{e}_3\}} = c_3'(\tilde{e}_3) = \tilde{e}_3$$

Under the linear contract $\{\alpha, T\}$, the FOC for the client's effort choice problem becomes

$$\frac{\partial v(e_1, e_2, e_3)}{\partial e_3} - \alpha \frac{\partial E[S]}{\partial e_3} = c_3'(e_3)$$

A comparison of the two preceding FOCs shows that the value of α, as given in equation (L2.3), ensures that the client's FOC under linear contracts is satisfied at $\tilde{e}_3$. As in the proof of Lemma 1, $\alpha > 0$; also, $\alpha < 1$ because $\tilde{e}_3 \in (0, \infty)$. All SOCs are (trivially) met. If $\tilde{e}_3 = 0$ then, under $f_0(\cdot)$,

$$\frac{\partial v(\tilde{e}_1, \tilde{e}_2, e_3)}{\partial e_3}\bigg|_{e_3 = \tilde{e}_3} - \frac{\partial E\big[f_0(S) \mid (e_1, e_2, e_3)\big]}{\partial \bar{S}} \frac{\partial \bar{S}}{\partial e_3}\bigg|_{\{\tilde{e}_1, \tilde{e}_2, \tilde{e}_3\}} \le 0$$

Under the linear contract $\{\alpha, T\}$, the derivative of the client's expected profit is

$$\frac{\partial v(e_1, e_2, e_3)}{\partial e_3} - \alpha \frac{\partial E[S]}{\partial e_3} - c_3'(e_3)$$

Substituting the value of α as determined by equation (L2.3) ensures that the client's effort choice is $\tilde{e}_3 = 0$. Furthermore, since $\tilde{e}_3 = 0$ it follows that $\alpha = 1$—thus ensuring satisfaction of the sufficient conditions for the linear contract to implement $\tilde{e}_1$, $\tilde{e}_2$, and $\tilde{e}_3$. Because the fixed payment T does not affect vendor effort, it can (again) be chosen such that the vendor's participation constraint is tight. Hence a linear contract can replicate the performance of any optimal contract and so is itself optimal. We must now establish that the optimal linear contract's performance cannot yield the client's first-best result.

Recall that, when tasks are integrated, the VPM $S = \phi(e_1 + \gamma e_2 + \lambda e_3) + \varepsilon_2$.

Effort choice. The FOCs for the effort devoted to outsourced tasks, as defined in equation (14), are

$$\tilde{e}_1 = \arg\max_{e_1} E[f(S) \mid e_1, e_2, \tilde{e}_3] - c_1(e_1) - c_2(e_2) = \arg\max_{e_1} T + \alpha\phi[e_1 + \gamma e_2 + \lambda e_3] - \frac{e_1^2}{2} - \frac{e_2^2}{2} = \alpha\phi \quad \text{(L2.4)}$$

and, similarly,

$$\tilde{e}_2 = \alpha\gamma\phi \quad \text{(L2.5)}$$

Equation (5) implies that $E[f(S) \mid \tilde{e}_1, \tilde{e}_2, \tilde{e}_3] - c_1(\tilde{e}_1) - c_2(\tilde{e}_2) \ge 0$. Here the client will set T such that $E[f(S) \mid \tilde{e}_1, \tilde{e}_2, \tilde{e}_3] - c_1(\tilde{e}_1) - c_2(\tilde{e}_2) = 0$, thereby making the vendor's participation constraint tight and extracting all the surplus. Hence

$$T + \alpha E[S] - c_1(\tilde{e}_1) - c_2(\tilde{e}_2) = 0 \quad \text{(L2.6)}$$

The equality $\tilde{e}_3 = \arg\max_{e_3 \ge 0} E[v(\tilde{e}_1, \tilde{e}_2, e_3)] - c_3(e_3) - E[f(S) \mid (\tilde{e}_1, \tilde{e}_2, e_3)]$ now follows from equation (13). Therefore,

$$\begin{aligned}\tilde{e}_3 = {} & \arg\max_{e_3 \ge 0} \phi[\tilde{e}_1 + \{\theta + (1-\theta)\gamma\}\tilde{e}_2 + \{\theta + (1-\theta)\lambda - \alpha\lambda\}e_3] \\ & - \frac{e_3^2}{2} - \frac{\tilde{e}_1^2}{2} - \frac{\tilde{e}_2^2}{2} + \alpha\phi\lambda\tilde{e}_3 = \phi[\theta + (1-\theta)\lambda - \lambda\alpha]\end{aligned} \quad \text{(L2.7)}$$

<u>Contract design</u>. Equation (12) gives the contract design problem as

$$\max_{f(\cdot)} \Pi_{SS} = E[v(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3)] - c_3(\tilde{e}_3) - E[f(S) \mid (\tilde{e}_1, \tilde{e}_2, \tilde{e}_3)]$$

and we have

$$\max_\alpha \Pi_{SS} = \phi[\tilde{e}_1 + \{\theta + (1-\theta)\gamma\}\tilde{e}_2 + \{\theta + (1-\theta)\lambda\gamma\}\tilde{e}_3] - \frac{\tilde{e}_3^2}{2} - \frac{\tilde{e}_1^2}{2} - \frac{\tilde{e}_2^2}{2}$$

because $E[f(S) \mid (\tilde{e}_1, \tilde{e}_2, \tilde{e}_3)] = \frac{\tilde{e}_1^2}{2} + \frac{\tilde{e}_2^2}{2}$. Substituting the values of $\tilde{e}_1$, $\tilde{e}_2$, and $\tilde{e}_3$ from equations (L2.4), (L2.5), and (L2.7) into the contract design problem yields

$$\begin{aligned}\max_\alpha \Pi_{SS} &= \phi^2[\alpha + \gamma\alpha\{\theta + (1-\theta)\gamma\} + \{\theta + (1-\theta)\lambda\}\{\theta + (1-\theta)\lambda - \lambda\alpha\} \\ &\quad - \frac{\{\theta+(1-\theta)\lambda-\lambda\alpha\}^2}{2} - \frac{\alpha^2}{2} - \frac{\alpha^2\gamma^2}{2}] \\ &= \phi^2\left[\alpha + \gamma\alpha\{\theta + (1-\theta)\gamma\} + \frac{\{\theta + (1-\theta)\lambda\}^2}{2} - \frac{\alpha^2\lambda^2}{2} - \frac{\alpha^2}{2} - \frac{\alpha^2\gamma^2}{2}\right]\end{aligned}$$

which is a concave function in α. The FOC for the client's contract design problem now gives us

$$\alpha = \frac{1+\gamma\{\theta+(1-\theta)\gamma\}}{1+\gamma^2+\lambda^2}$$

Substituting into the values of $\tilde{e}_1$, $\tilde{e}_2$, and $\tilde{e}_3$, we obtain

$$\tilde{e}_1 = \phi[\frac{1+\gamma\{\theta+(1-\theta)\gamma\}}{1+\gamma^2+\lambda^2}], \quad \tilde{e}_2 = \phi[\frac{\gamma[1+\gamma\{\theta+(1-\theta)\gamma\}]}{1+\gamma^2+\lambda^2}], \text{ and } \quad \tilde{e}_3 = \phi[\theta + (1-\theta)\lambda - \frac{\lambda[1+\gamma\{\theta+(1-\theta)\gamma\}]}{1+\gamma^2+\lambda^2}]$$

First-best outcome. We know that the coordinated solution is $e_1^* = \phi$, $e_2^* = \phi[\theta + (1-\theta)\gamma]$, and $e_3^* = \phi[\theta + (1-\theta)\lambda]$. It is clear that the first-best efforts can never be achieved, since client effort in the single-sourcing case with integrated tasks is strictly less than the coordinated solution. Substituting the value of α in the SS integrated tasks case gives us

$$\Pi_{SS}^* = \phi^2[\frac{\{\theta + (1-\theta)\lambda\}^2}{2} + \frac{[1 + \gamma\{\theta + (1-\theta)\gamma\}]^2}{2(1+\gamma^2+\lambda^2)}]$$

Proof of Lemma 3. We shall start by proving the optimality of linear contracts. Assume that contracts $f_i(\cdot)$ for vendor i are optimal and that they induce optimal efforts $\tilde{e}_1$ and $\tilde{e}_2$ by the vendor and $\tilde{e}_3$ by the client. Note that if $\tilde{e}_i = 0$ for $i \in 1,2$ then $\alpha_i = 0$ trivially implements that effort level; as a consequence, we can restrict our focus to $\tilde{e}_1, \tilde{e}_2 \in (0, \infty)$. The vendors' FOCs are

$$c_1'(\tilde{e}_1) = \tilde{e}_1 = \frac{\partial E[f_1(S) \mid (e_1,e_2,e_3)]}{\partial \bar{S}} \frac{\partial E[S]}{\partial e_1}\Big|_{\{\tilde{e}_1,\tilde{e}_2,\tilde{e}_3\}} \quad \text{(L3.1)}$$

$$c_2'(\tilde{e}_2) = \tilde{e}_2 = \frac{\partial E[f_2(S) \mid (e_1,e_2,e_3)]}{\partial \bar{S}} \frac{\partial E[S]}{\partial e_2}\Big|_{\{\tilde{e}_1,\tilde{e}_2,\tilde{e}_3\}} \quad \text{(L3.2)}$$

and the FOCs for vendors under linear contracts $\{\alpha_i, T_i\}$ are

$$\alpha_1 \frac{\partial E[S]}{\partial e_1} = c_1'(e_1)$$

$$\alpha_2 \frac{\partial E[S]}{\partial e_2} = c_2'(e_2)$$

Therefore, equations (L3.1) and (L3.2) can be implemented via linear contracts $\{\alpha_i, T_i\}$ by setting

$$\alpha_i = \frac{\partial E[f_i(S) \mid (e_1,e_2,e_3)]}{\partial \bar{S}}\Big|_{\{\tilde{e}_1,\tilde{e}_2,\tilde{e}_3\}} \quad \text{(L3.3)}$$

We now check the client's effort decision. If $\tilde{e}_3 > 0$ then, under $f_i(\cdot)$, the FOC for the client's effort choice problem is

$$\frac{\partial E[v(\tilde{e}_1,\tilde{e}_2,e_3)]}{\partial e_3}\Big|_{e_3=\tilde{e}_3} - \sum_{i=1}^{2} \frac{\partial E\left[f_i(S) \mid (e_1,e_2,e_3)\right]}{\partial \bar{S}} \frac{\partial \bar{S}}{\partial e_i}\Big|_{\{\tilde{e}_1,\tilde{e}_2,\tilde{e}_3\}} = c_3'(\tilde{e}_3) = \tilde{e}_3$$

Under the linear contracts $\{\alpha_i, T_i\}$, the FOC for the client's effort choice problem becomes

$$\frac{\partial E[v(e_1,e_2,e_3)]}{\partial e_3} - (\alpha_1+\alpha_2)\frac{\partial \bar{S}}{\partial e_3} = c_3'(e_3)$$

Comparing these two FOCs reveals that the value of α_i, as determined in equation (L3.3), ensures that the client's FOC under linear contracts is satisfied at $\tilde{e}_3$. Just as in the proof of Lemma 1, we have $\alpha_i > 0$. Also, since $\tilde{e}_3 \in (0,\infty)$ it follows that $\alpha_1+\alpha_2 < 1$. As before, all SOCs are trivially met. If $\tilde{e}_3 = 0$, then under $f_i(\cdot)$ we have

$$\frac{\partial E[v(\tilde{e}_1,\tilde{e}_2,e_3)]}{\partial e_3}\Big|_{e_3=\tilde{e}_3} - \sum_{i=1}^{2}\frac{\partial E[f_i(S) \mid (e_1,e_2,e_3)]}{\partial \bar{S}}\frac{\partial \bar{S}}{\partial e_i}\Big|_{\{\tilde{e}_1,\tilde{e}_2,\tilde{e}_3\}} \le 0$$

Under the linear contracts $\{\alpha_i, T_i\}$, the derivative of the client's expected profit is

$$\frac{\partial E[v(e_1,e_2,e_3)]}{\partial e_3} - (\alpha_1+\alpha_2)\frac{\partial \bar{S}}{\partial e_3} - c_3'(e_3)$$

Substituting the value of α_i as determined in equation (L3.3) ensures that the client's effort choice is $\tilde{e}_3 = 0$. Similarly to the proof of Lemma 1, we have $\alpha_i > 0$. Also, since $\tilde{e}_3 = 0$ it follows that $\alpha_1+\alpha_2 \ge 1$, thus ensuring that the sufficient conditions for the linear contract to implement $\tilde{e}_3$, $\tilde{e}_3$, and $\tilde{e}_3$ are satisfied. Finally, the fixed payments T_i do not affect vendor effort and can therefore be chosen such that the vendor participation constraints are tight. So again linear contracts can replicate the result of any optimal contract, which means that linear contracts are optimal.

Our next task is to show that the optimal linear contract's performance cannot be the client's first-best result.

Effort choice. The FOCs for effort spent on the outsourced tasks, as defined in equations (18) and (19), are

$$\tilde{e}_1 = \arg\max_{e_1} E[f_1(S) \mid e_1,\tilde{e}_2,\tilde{e}_3] - c_1(e_1)$$

$$\tilde{e}_2 = \arg\max_{e_2} E[f_2(S) \mid \tilde{e}_1,e_2,\tilde{e}_3] - c_2(e_2)$$

$$\tilde{e}_1 = \arg\max_{e_1} T + \alpha_1[\phi(e_1+\gamma e_2+\lambda e_3)] - \frac{e_1^2}{2} = \alpha_1\phi \quad \text{(L3.4)}$$

$$\tilde{e}_2 = \arg\max_{e_2} T + \alpha_2[\phi(e_1+\gamma e_2+\lambda e_3)] - \frac{e_2^2}{2} = \gamma\alpha_2\phi \quad \text{(L3.5)}$$

From equations (20) and (21) it follows that $E[f_1(S) \mid \tilde{e}_1,\tilde{e}_2,\tilde{e}_3] - c_1(\tilde{e}_1) \ge 0$ and $E[f_2(S) \mid \tilde{e}_1,\tilde{e}_2,\tilde{e}_3] - c_2(\tilde{e}_2) \ge 0$. Hence the client will set T_1 and T_2 such that $E[f_1(S) \mid \tilde{e}_1,\tilde{e}_2,\tilde{e}_3] - c_1(\tilde{e}_1) = 0$ and $E[f_2(S) \mid \tilde{e}_1,\tilde{e}_2,\tilde{e}_3] - c_2(\tilde{e}_2) = 0$, thereby making the vendor's participation constraint tight and extracting all the surplus. Then

$$T_1 + \alpha_1 E[S] - c_1(\tilde{e}_1) = 0 \quad \text{and} \quad T_2 + \alpha_2 E[S] - c_2(\tilde{e}_2) = 0$$

We can now conclude from equation (17) that

$$\tilde{e}_3 = \arg\max_{e_3\ge 0} E[v(\tilde{e}_1,\tilde{e}_2,e_3)] - c_3(e_3) - E[f_1(S) \mid (\tilde{e}_1,\tilde{e}_2,\tilde{e}_3)] - E[f_2(S) \mid (\tilde{e}_1,\tilde{e}_2,\tilde{e}_3)]$$

Therefore,

$$\begin{aligned}\tilde{e}_3 = \arg\max_{e_3\ge 0} &\ \phi[\tilde{e}_1 + \{\theta+(1-\theta)\gamma\}\tilde{e}_2 + \{\theta+(1-\theta)\lambda - \lambda(\alpha_1+\alpha_2)\}e_3] \\ &-\frac{e_3^2}{2} - \frac{\tilde{e}_1^2}{2} - \frac{\tilde{e}_2^2}{2} + \lambda\phi(\alpha_1+\alpha_2)\tilde{e}_3 = \phi[\theta+(1-\theta)\lambda - \lambda(\alpha_1+\alpha_2)]\end{aligned} \quad \text{(L3.6)}$$

Contract design. According to equation (16), the client's contract design problem can be stated as

$$\max_{f(\cdot)} \Pi_{MS} = E[v(\tilde{e}_1,\tilde{e}_2,\tilde{e}_3)] - c_3(\tilde{e}_3) - E[f_1(S) \mid (\tilde{e}_1,\tilde{e}_2,\tilde{e}_3)] - E[f_2(S) \mid (\tilde{e}_1,\tilde{e}_2,\tilde{e}_3)]$$

$$\max_{\alpha_1,\alpha_2} \Pi_{MS} = \phi[\tilde{e}_1 + \{\theta+(1-\theta)\gamma\}\tilde{e}_2 + \{\theta+(1-\theta)\lambda\}\tilde{e}_3] - \frac{\tilde{e}_3^2}{2} - \frac{\tilde{e}_1^2}{2} - \frac{\tilde{e}_2^2}{2}$$

since $E[f_1(S) \mid (\tilde{e}_1, \tilde{e}_2, \tilde{e}_3)] = \frac{\tilde{e}_1^2}{2}$ and $E[f_2(S) \mid (\tilde{e}_1, \tilde{e}_2, \tilde{e}_3)] = \frac{\tilde{e}_2^2}{2}$. Substituting the values of $\tilde{e}_1$, $\tilde{e}_2$, and $\tilde{e}_3$ from equations (L3.4)–(L3.6) into the contract design problem now gives

$$\max_{\alpha_1,\alpha_2\geq 0} \Pi_{\text{MS}} = \phi^2[\alpha_1 + \gamma\alpha_2\{\theta + (1-\theta)\gamma\} + \{\theta + (1-\theta)\lambda\}\{\theta + (1-\theta)\lambda - \lambda(\alpha_1 + \alpha_2)\} - \frac{\{\theta + (1-\theta)\lambda - \lambda(\alpha_1 + \alpha_2)\}^2}{2} - \frac{{\alpha_1}^2}{2} - \frac{{\alpha_2}^2\gamma^2}{2}]$$

which is a concave function in α_1 and α_2. The FOC for the client's contract design problem yields the following three cases.

Case (i) If $0 \leq \gamma\{\theta + (1-\theta)\gamma\} < \frac{\lambda^2}{1+\lambda^2}$, then $\alpha_2 = 0$, $\alpha_1 = \frac{1}{1+\lambda^2}$, and $\Pi_{\text{MS}} = \phi^2\left[\frac{\{\theta+(1-\theta)\lambda\}^2}{2} + \frac{1}{2(1+\lambda^2)}\right]$.

In this case it is easy to see that $\tilde{e}_2 = 0$, from which it follows that the client does not attain its first-best outcome.

Case (ii) If $\frac{\lambda^2}{1+\lambda^2} \leq \gamma\{\theta + (1-\theta)\gamma\} < 1 + \frac{\gamma^2}{\lambda^2}$, then $\alpha_1 = \frac{\gamma^2+\lambda^2-\lambda^2\gamma\{\theta+(1-\theta)\gamma\}}{\gamma^2+\lambda^2+\gamma^2\lambda^2}$, $\alpha_2 = \frac{(1+\lambda^2)\gamma\{\theta+(1-\theta)\gamma\}-\lambda^2}{\gamma^2+\lambda^2+\gamma^2\lambda^2}$, and

$$\Pi_{\text{MS}} = \phi^2[\alpha_1 + \gamma\alpha_2\{\theta + (1-\theta)\gamma\} + \{\theta + (1-\theta)\lambda\}\{\theta + (1-\theta)\lambda - \lambda(\alpha_1 + \alpha_2)\} - \frac{\{\theta + (1-\theta)\lambda - \lambda(\alpha_1 + \alpha_2)\}^2}{2} - \frac{\alpha_1^2}{2} - \frac{\alpha_2^2\gamma^2}{2}]$$

$$= \phi^2\left[\frac{\{\theta+(1-\theta)\lambda\}^2}{2} + \frac{\gamma^2+\lambda^2-2\lambda^2\gamma\{\theta+(1-\theta)\gamma\}+(1+\lambda^2)[\gamma\{\theta+(1-\theta)\gamma\}]^2}{2(\gamma^2+\lambda^2+\gamma^2\lambda^2)}\right].$$

Substituting the expressions of α_1 and α_2 into the values of $\tilde{e}_1$, $\tilde{e}_2$, and $\tilde{e}_3$, we obtain

$$\tilde{e}_1 = \phi\left[\frac{\gamma^2+\lambda^2-\lambda^2\gamma\{\theta+(1-\theta)\gamma\}}{\gamma^2+\lambda^2+\gamma^2\lambda^2}\right], \quad \tilde{e}_2 = \phi\left[\frac{\gamma[(1+\lambda^2)\gamma\{\theta+(1-\theta)\gamma\}-\lambda^2]}{\gamma^2+\lambda^2+\gamma^2\lambda^2}\right]$$

$$\text{and} \quad \tilde{e}_3 = \phi\left[\theta + (1-\theta)\lambda - \lambda\left\{\frac{\gamma^2+\lambda^2-\lambda^2\gamma\{\theta+(1-\theta)\gamma\}}{\gamma^2+\lambda^2+\gamma^2\lambda^2} + \frac{(1+\lambda^2)\gamma\{\theta+(1-\theta)\gamma\}-\lambda^2}{\gamma^2+\lambda^2+\gamma^2\lambda^2}\right\}\right]$$

We know that the coordinated solution is $e_1^* = \phi$, $e_2^* = \phi[\theta + (1-\theta)\gamma]$, and $e_3^* = \phi[\theta + (1-\theta)\lambda]$. It is now trivial to deduce that the client's first-best effort in the multisourcing case with integrated tasks is less than in the coordinated solution.

Case (iii) If $\gamma\{\theta + (1-\theta)\gamma\} > 1 + \frac{\gamma^2}{\lambda^2}$, then $\alpha_1 = 0$, $\alpha_2 = \frac{\gamma\{\theta+(1-\theta)\gamma\}}{\gamma^2+\lambda^2}$, and $\Pi_{\text{MS}} = \phi^2\left[\frac{\{\theta+(1-\theta)\lambda\}^2}{2} + \frac{[\gamma\{\theta+(1-\theta)\gamma\}]^2}{2(\gamma^2+\lambda^2)}\right]$.

In this case it trivially follows that $\tilde{e}_1 = 0$, so again the client does not attain its first-best outcome.

Proof of Proposition 3. We shall compare the profits resulting the single-sourcing and multisourcing strategies when tasks are interdependent.

Single-sourcing. From the proof of Lemma 2 we know that the client's profit under the SS strategy is

$$\Pi_{\text{SS}}^* = \phi^2[\frac{\{\theta + (1-\theta)\lambda\}^2}{2} + \frac{[1 + \gamma\{\theta + (1-\theta)\gamma\}]^2}{2(1 + \gamma^2 + \lambda^2)}]$$

By the proof of Lemma 3, the client's profit under the MS strategy is

$$\Pi_{\text{MS}} = \phi^2[\alpha_1 + \gamma\alpha_2\{\theta + (1-\theta)\gamma\} + \{\theta + (1-\theta)\lambda\}\{\theta + (1-\theta)\lambda - \lambda(\alpha_1 + \alpha_2)\} - \frac{\{\theta + (1-\theta)\lambda - \lambda(\alpha_1 + \alpha_2)\}^2}{2} - \frac{\alpha_1^2}{2} - \frac{\alpha_2^2\gamma^2}{2}]$$

Note that if $\gamma\{\theta + (1-\theta)\gamma\} < \frac{\lambda^2}{1+\lambda^2}$ then $\alpha_2 = 0$ and if $\gamma\{\theta + (1-\theta)\gamma\} > 1 + \frac{\gamma^2}{\lambda^2}$ then $\alpha_1 = 0$. Therefore, under multisourcing we obtain the following results:

Case (i) If $0 \leq \gamma\{\theta + (1-\theta)\gamma\} < \frac{\lambda^2}{1+\lambda^2}$, then $\alpha_2 = 0$, $\alpha_1 = \frac{1}{1+\lambda^2}$, and $\Pi_{\text{MS}} = \phi^2\left[\frac{\{\theta+(1-\theta)\lambda\}^2}{2} + \frac{1}{2(1+\lambda^2)}\right]$.

Case (ii) If $\frac{\lambda^2}{1+\lambda^2} \leq \gamma\{\theta + (1-\theta)\gamma\} < 1 + \frac{\gamma^2}{\lambda^2}$, then $\alpha_1 = \frac{\gamma^2+\lambda^2-\lambda^2\gamma\{\theta+(1-\theta)\gamma\}}{\gamma^2+\lambda^2+\gamma^2\lambda^2}$ and $\alpha_2 = \frac{(1+\lambda^2)\gamma\{\theta+(1-\theta)\gamma\}-\lambda^2}{\gamma^2+\lambda^2+\gamma^2\lambda^2}$. Hence

$$\begin{aligned}\Pi_{\text{MS}} &= \phi^2[\alpha_1 + \gamma\alpha_2\{\theta + (1-\theta)\gamma\} + \{\theta + (1-\theta)\lambda\}\{\theta + (1-\theta)\lambda - \lambda(\alpha_1+\alpha_2)\} - \frac{\{\theta+(1-\theta)\lambda-\lambda(\alpha_1+\alpha_2)\}^2}{2} - \frac{\alpha_1^2}{2} - \frac{\alpha_2^2\gamma^2}{2}] \\ &= \phi^2\left[\frac{\{\theta+(1-\theta)\lambda\}^2}{2} + \frac{\gamma^2+\lambda^2-2\lambda^2\gamma\{\theta+(1-\theta)\gamma\}+(1+\lambda^2)[\gamma\{\theta+(1-\theta)\gamma\}]^2}{2(\gamma^2+\lambda^2+\gamma^2\lambda^2)}\right].\end{aligned}$$

Case (iii) If $\gamma\{\theta + (1-\theta)\gamma\} > 1 + \frac{\gamma^2}{\lambda^2}$, then $\alpha_1 = 0$, $\alpha_2 = \frac{\gamma\{\theta+(1-\theta)\gamma\}}{\gamma^2+\lambda^2}$, and $\Pi_{\text{MS}} = \phi^2\left[\frac{\{\theta+(1-\theta)\lambda\}^2}{2} + \frac{[\gamma\{\theta+(1-\theta)\gamma\}]^2}{2(\gamma^2+\lambda^2)}\right]$.

A numerical comparison of the SS- and MS-based profits under different values of θ, γ, and λ now yields the results in the proposition. (These comparisons are plotted in Figure 2 of the main text.)

Proof of Proposition 4. Here we consider only the case when tasks are modular. Also, for this proof we normalize ϕ to 1; doing so does not affect the analysis because it merely acts as a scaling factor in our model.

Single-sourcing. We can state the client's contract problem under SS as follows, where "CE" denotes "certainty equivalent":

$$\max_{f(\cdot)} \Pi_{\text{SS}} = E[v(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3)] - c_3(\tilde{e}_3) - E[f(S) \mid (\tilde{e}_1, \tilde{e}_2)] \tag{P4.1}$$

subject to

$$\tilde{e}_3 = \arg\max_{e_3 \geq 0} E[v(\tilde{e}_1, \tilde{e}_2, e_3)] - c_3(e_3) - E[f(S) \mid (\tilde{e}_1, \tilde{e}_2)], \tag{P4.2}$$

$$\tilde{e}_1, \tilde{e}_2 = \arg\max_{e_1, e_2 \geq 0} \text{CE}[f(S) \mid (e_1, e_2)] - c_1(e_1) - c_2(e_2), \tag{P4.3}$$

$$\text{and} \quad \text{CE}[f(S) \mid (\tilde{e}_1, \tilde{e}_2)] - c_1(\tilde{e}_1) - c_2(\tilde{e}_2) \geq 0. \tag{P4.4}$$

The client is risk neutral and so takes only the *expected value* of the contract into account; in contrast, the vendor is risk averse and therefore, when making its decisions, accounts instead for the *certainty equivalent* of the contract. We first use a CARA model to derive the form of the certainty equivalent for a risk utility function, in which case the uncertainty ε_2 is normally distributed. For the CARA model, $U(x) = 1 - e^{-rx}$, where r is the absolute coefficient of risk aversion. Because the verifiable signal is of the form $S = e_1 + \gamma e_2 + \lambda e_3 + \varepsilon_2$, we seek the certainty equivalent of a general signal of the type $S = A + \varepsilon_2$. Let CE(S) denote the certainty equivalent of signal S. Then

$$\begin{aligned}1 - e^{-r\,\text{CE}(S)} &= \int_{-\infty}^{\infty}\{1 - e^{-r(A+\varepsilon_2)}\}\frac{1}{\sqrt{2\pi}\sigma}e^{-\varepsilon_2^2/2\sigma^2}\,d\varepsilon_2 \\ &= 1 - e^{-rA}\int_{-\infty}^{\infty}\{e^{-r\varepsilon_2}\}\frac{1}{\sqrt{2\pi}\sigma}e^{-\varepsilon_2^2/2\sigma^2}\,d\varepsilon_2 5 \\ &= 1 - e^{-rA}\int_{-\infty}^{\infty}\frac{1}{\sqrt{2\pi}\sigma}e^{-\varepsilon_2^2/2\sigma^2 - r\varepsilon_2 - \frac{r^2\sigma^4}{2\sigma^2} + \frac{r^2\sigma^4}{2\sigma^2}}\,d\varepsilon_2 \\ &= 1 - e^{-rA + \frac{r^2\sigma^4}{2\sigma^2}}\int_{-\infty}^{\infty}\frac{1}{\sqrt{2\pi}\sigma}e^{-(\varepsilon_2+r\sigma^2)^2/2\sigma^2}\,d\varepsilon_2\end{aligned}$$

Yet because $\int_{-\infty}^{\infty}\frac{1}{\sqrt{2\pi}\sigma}e^{-(\varepsilon_2+r\sigma^2)^2/2\sigma^2}\,d\varepsilon_2 = 1$, it follows that

$$r\,\text{CE}(S) = rA - \frac{r^2\sigma^2}{2} \implies \text{CE}(S) = A - \frac{r\sigma^2}{2}$$

.

If tasks are modular, then $S = (e_1 + \gamma e_2) + \varepsilon_2$ because project outcomes do not depend on client effort ($\lambda = 0$). We shall focus on linear contracts of the form $T + \alpha S$.

Effort choice. The FOCs for devoting first-best efforts to the outsourced tasks are

$$\tilde{e}_1 = \arg\max_{e_1} \mathrm{CE}[f(S) \mid e_1, e_2] - c(e_1) - c(e_2)$$
$$= \arg\max_{e_1} T + \alpha[e_1 + \gamma e_2] - \frac{r\sigma^2\alpha^2}{2} - \frac{e_1^2}{2} - \frac{e_2^2}{2} = \alpha$$

and, similarly,

$$\tilde{e}_2 = \alpha\gamma$$

.
Here the participation constraint is expressed as $\mathrm{CE}[f(S) \mid \tilde{e}_1, \tilde{e}_2] - c(\tilde{e}_1) - c(\tilde{e}_2) \geq 0$ and so the client will set T such that $\mathrm{CE}[f(S) \mid \tilde{e}_1, \tilde{e}_2] - c(\tilde{e}_1) - c(\tilde{e}_2) = 0$, which makes the vendor's participation constraint tight and also extracts all the surplus. Therefore,

$$T + \alpha E[S] - \frac{r\sigma^2\alpha^2}{2} - c(\tilde{e}_1) - c(\tilde{e}_2) = 0 \quad \text{and}$$
$$\tilde{e}_3 = \arg\max_{e_3 \geq 0} E[v(\tilde{e}_1, \tilde{e}_2, e_3)] - c_3(e_3) - E[f(S) \mid (\tilde{e}_1, \tilde{e}_2)]$$

It follows that

$$\tilde{e}_3 = \arg\max_{e_3 \geq 0} \tilde{e}_1 + \{\theta + (1-\theta)\gamma\}\tilde{e}_2 + \{\theta + (1-\theta)\lambda\}e_3 - \frac{e_3^2}{2} - \frac{\tilde{e}_1^2}{2} - \frac{\tilde{e}_2^2}{2} - \frac{r\sigma^2\alpha^2}{2}$$
$$= \theta + (1-\theta)\lambda$$

Contract design. According to equation (P4.1), the contract design problem can be stated as

$$\max_{f(\cdot)} \Pi_{\mathrm{SS}} = E[v(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3)] - c_3(\tilde{e}_3) - E[f(S) \mid (\tilde{e}_1, \tilde{e}_2)]$$

$$\mathrm{Max}_{\alpha}\, \Pi_{\mathrm{SS}} = \tilde{e}_1 + \{\theta + (1-\theta)\gamma\}\tilde{e}_2 + \{\theta + (1-\theta)\lambda\}\tilde{e}_3 - \frac{\tilde{e}_3^2}{2} - \frac{\tilde{e}_1^2}{2} - \frac{\tilde{e}_2^2}{2} - \frac{r\sigma^2\alpha^2}{2}$$

since $E[f(S) \mid (\tilde{e}_1, \tilde{e}_2, \tilde{e}_3)] = \frac{\tilde{e}_1^2}{2} + \frac{\tilde{e}_2^2}{2}$. Substituting the values of $\tilde{e}_1$, $\tilde{e}_2$, and $\tilde{e}_3$ into the contract design problem then yields

$$\max_{\alpha} \Pi_{\mathrm{SS}} = \alpha + \gamma\alpha\{\theta + (1-\theta)\gamma\} + \{\theta + (1-\theta)\lambda\}^2$$
$$- \frac{\{\theta + (1-\theta)\lambda\}^2}{2} - \frac{\alpha^2}{2} - \frac{\alpha^2\gamma^2}{2} - \frac{r\sigma^2\alpha^2}{2}$$

which is a concave function in α. The FOC for the contract design problem now gives us

$$\alpha = \frac{1 + \gamma\{\theta + (1-\theta)\gamma\}}{1 + \gamma^2 + r\sigma^2}$$

and the firm's profits under SS are given by

$$\Pi_{\mathrm{SS}} = \frac{[\theta + (1-\theta)\lambda]^2}{2} + \frac{[1 + \gamma\{\theta + (1-\theta)\gamma\}]^2}{2[1 + \gamma^2 + r\sigma^2]}$$

Multisourcing. The client's contract problem in the MS case can be stated as

$$\max_{f_i(\cdot)} \Pi_{\mathrm{MS}} = E[v(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3)] - c_3(\tilde{e}_3) - E[f_1(S) \mid (\tilde{e}_1, \tilde{e}_2)] - E[f_2(S) \mid (\tilde{e}_1, \tilde{e}_2)] \tag{P4.5}$$

subject to the following conditions:

$$\tilde{e}_3 = \arg\max_{e_3 \geq 0} E[v(\tilde{e}_1, \tilde{e}_2, e_3)] - c_3(e_3) - E[f_1(S) \mid (\tilde{e}_1, \tilde{e}_2)] - E[f_2(S) \mid (\tilde{e}_1, \tilde{e}_2)] \tag{P4.6}$$

$$\tilde{e}_1 = \arg\max_{e_1 \geq 0} \mathrm{CE}[f_1(S) \mid (e_1, \tilde{e}_2)] - c_1(e_1) \tag{P4.7}$$

$$\tilde{e}_2 = \arg\max_{e_2 \geq 0} \mathrm{CE}[f_2(S) \mid (\tilde{e}_1, e_2)] - c_2(e_2) \tag{P4.8}$$

$$\mathrm{CE}[f_1(S) \mid (\tilde{e}_1, \tilde{e}_2)] - c_1(\tilde{e}_1) \geq 0 \tag{P4.9}$$

$$\mathrm{CE}[f_2(S) \mid (\tilde{e}_1, \tilde{e}_2)] - c_2(\tilde{e}_2) \geq 0 \tag{P4.10}$$

Effort choice. The FOCs for the first-best efforts on the outsourced tasks are

$$\tilde{e}_1 = \arg\max_{e_1} \mathrm{CE}[f_1(S) \mid e_1, \tilde{e}_2] - c_1(e_1)$$

$$\tilde{e}_2 = \arg\max_{e_2} \mathrm{CE}[f_2(S) \mid \tilde{e}_1, e_2] - c_2(e_2)$$

therefore,

$$\tilde{e}_1 = \arg\max_{e_1} T + \alpha_1(e_1 + \gamma e_2) - \frac{r\sigma^2{\alpha_1}^2}{2} - \frac{e_1^2}{2} = \alpha_1$$

$$\tilde{e}_2 = \arg\max_{e_2} T + \alpha_2(e_1 + \gamma e_2) - \frac{r\sigma^2{\alpha_2}^2}{2} - \frac{e_2^2}{2} = \gamma\alpha_2$$

Here the participation constraints are $\mathrm{CE}[f_1(S) \mid \tilde{e}_1, \tilde{e}_2] - c_1(\tilde{e}_1) \geq 0$ and $\mathrm{CE}[f_2(S) \mid \tilde{e}_1, \tilde{e}_2] - c_2(\tilde{e}_2) \geq 0$. The client will set T_1 and T_2 such that $\mathrm{CE}[f_1(S) \mid \tilde{e}_1, \tilde{e}_2] - c_1(\tilde{e}_1) = 0$ and $\mathrm{CE}[f_2(S) \mid \tilde{e}_1, \tilde{e}_2] - c_2(\tilde{e}_2) = 0$, thus making the vendor's participation constraint tight and extracting all the surplus. Hence

$$T_1 + \alpha_1 E[S] - \frac{r\sigma^2{\alpha_1}^2}{2} - c_1(\tilde{e}_1) = 0 \quad \text{and} \quad T_2 + \alpha_2 E[S] - \frac{r\sigma^2{\alpha_2}^2}{2} - c_2(\tilde{e}_2) = 0$$

from which we conclude that

$$\begin{aligned}\tilde{e}_3 = \arg\max_{e_3 \geq 0} & E[v(\tilde{e}_1, \tilde{e}_2, e_3)] - c_3(e_3) - E[f_1(S) \mid (\tilde{e}_1, \tilde{e}_2)] - E[f_2(S) \mid (\tilde{e}_1, \tilde{e}_2)] \\ &= \arg\max_{e_3 \geq 0} \tilde{e}_1 + \{\theta + (1-\theta)\gamma\}\tilde{e}_2 + \{\theta + (1-\theta)\lambda\}e_3 \\ &- \frac{e_3^2}{2} - \frac{\tilde{e}_1^2}{2} - \frac{\tilde{e}_2^2}{2} - \frac{r\sigma^2{\alpha_1}^2}{2} - \frac{r\sigma^2{\alpha_2}^2}{2} = \theta + (1-\theta)\lambda\end{aligned}$$

Contract design. The client's contract design problem is

$$\max_{f(\cdot)} \Pi_{\mathrm{MS}} = E[v(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3)] - c_3(\tilde{e}_3) - E[f_1(S) \mid (\tilde{e}_1, \tilde{e}_2)] - E[f_2(S) \mid (\tilde{e}_1, \tilde{e}_2)]$$
$$\max_{\alpha_1, \alpha_2} \Pi_{\mathrm{MS}} = \tilde{e}_1 + \{\theta + (1-\theta)\gamma\}\tilde{e}_2 + \{\theta + (1-\theta)\lambda\}\tilde{e}_3 - \frac{\tilde{e}_3^2}{2} - \frac{\tilde{e}_1^2}{2} - \frac{\tilde{e}_2^2}{2} - \frac{r\sigma^2\alpha_1^2}{2} - \frac{r\sigma^2\alpha_2^2}{2}$$

the reason is that $E[f_1(S) \mid (\tilde{e}_1, \tilde{e}_2)] = \frac{\tilde{e}_1^2}{2} + \frac{r\sigma^2\alpha_1^2}{2}$ and $E[f_2(S) \mid (\tilde{e}_1, \tilde{e}_2)] = \frac{\tilde{e}_2^2}{2} + \frac{r\sigma^2\alpha_2^2}{2}$. Substituting the values of $\tilde{e}_1$, $\tilde{e}_2$, and $\tilde{e}_3$ into the contract design problem now yields

$$\begin{aligned}\max_{\alpha_1, \alpha_2 \geq 0} \Pi_{\mathrm{MS}} &= \alpha_1 + \gamma\alpha_2\{\theta + (1-\theta)\gamma\} + \{\theta + (1-\theta)\lambda\}^2 \\ &- \frac{\{\theta + (1-\theta)\lambda\}^2}{2} - \frac{{\alpha_1}^2}{2} - \frac{{\alpha_2}^2\gamma^2}{2} - \frac{r\sigma^2{\alpha_1}^2}{2} - \frac{r\sigma^2{\alpha_2}^2}{2}\end{aligned}$$

which is a concave function in α_1 and α_2. By the FOC for the contract design problem, $\alpha_1 = \frac{1}{1+r\sigma^2}$ and $\alpha_2 = \frac{\{\theta+(1-\theta)\gamma\}\gamma}{\gamma^2+r\sigma^2}$. We can see that the first-best outcomes are not attained under the multisourcing of modular tasks if vendors are risk averse:

$$\Pi_{\mathrm{MS}} = \frac{[\theta + (1-\theta)\lambda]^2}{2} + \frac{1}{2(1+r\sigma^2)} + \frac{\gamma^2\{\theta + (1-\theta)\gamma\}^2}{2(\gamma^2 + r\sigma^2)}$$

Comparing profits from the SS and MS of modular tasks under risk aversion. We are now in a position to compare the profits from single-sourcing and multisourcing. Thus,

$$\Pi_{SS} = \frac{[\theta+(1-\theta)\lambda]^2}{2} + \frac{[1+\gamma\{\theta+(1-\theta)\gamma\}]^2}{2[1+\gamma^2+r\sigma^2]} \quad \text{and} \quad \Pi_{MS} = \frac{[\theta+(1-\theta)\lambda]^2}{2} + \frac{1}{2(1+r\sigma^2)} + \frac{\gamma^2\{\theta+(1-\theta)\gamma\}^2}{2(\gamma^2+r\sigma^2)}$$

These equations confirm our expectations that SS and MS strategies both have lower profits when vendors are risk averse.

We next compare the relative efficacy of these two sourcing strategies as follows:

$$\Pi_{MS} - \Pi_{SS} = \frac{1}{2}\left[\frac{1}{(1+r\sigma^2)} + \frac{\gamma^2\{\theta+(1-\theta)\gamma\}^2}{(\gamma^2+r\sigma^2)} - \frac{[1+\gamma\{\theta+(1-\theta)\gamma\}]^2}{[1+\gamma^2+r\sigma^2]}\right]$$

Put $\zeta = \gamma\{\theta+(1-\theta)\gamma\}$. Then the preceding equation can be rewritten as

$$\Pi_{MS} - \Pi_{SS} = \frac{1}{2}\left[\frac{1}{(1+r\sigma^2)} + \frac{\gamma^2\zeta^2}{(\gamma^2+r\sigma^2)} - \frac{[1+\gamma\zeta]^2}{[1+\gamma^2+r\sigma^2]}\right]$$

and further simplification yields

$$\Pi_{MS} - \Pi_{SS} = \frac{1}{2[1+\gamma^2+r\sigma^2]}\left[\frac{\gamma^2}{(1+r\sigma^2)} + \frac{\gamma^2\zeta^2}{(\gamma^2+r\sigma^2)} - 2\gamma\zeta\right]$$

From the term in brackets, it trivially follows that there exist $\overline{r\sigma^2} > 0$ such that $\Pi_{MS} - \Pi_{SS} \geq 0$ for all $r\sigma^2 \leq \overline{r\sigma^2}$ and $\Pi_{MS} - \Pi_{SS} < 0$ for all $r\sigma^2 > \overline{r\sigma^2}$. Here $\overline{r\sigma^2}$ is the positive root of the quadratic equation (with $r\sigma^2$ as the variable) $\left[\frac{\gamma^2}{1+r\sigma^2} + \frac{\gamma^2\zeta^2}{\gamma^2+r\sigma^2} - 2\gamma\zeta\right] = 0$.

Proof of Proposition 5. Proving this proposition will require that we compute the optimal efforts of the vendor(s) as a simultaneous effort decision, since their costs of coordination depend on the efforts exerted on both tasks. We first compute the first-best efforts with inter-dependent costs and modular tasks. We normalize $\phi = 1$ to simplify the calculations; this has no effect on the insights that we derive.

Modular tasks. The coordinated firm solves the problem

$$\max_{e_1,e_2,e_3} e_1 + \{\theta+(1-\theta)\gamma\}e_2 + \{\theta+(1-\theta)\lambda\}e_3 - \frac{e_1^2}{2} - \frac{e_2^2}{2} - \frac{e_3^2}{2} - ae_1e_2$$

This function is concave with respect to effort, as can be verified from the Hessian. The FOCs for the first-best efforts are

$$1 = e_1^* + ae_2^*, \qquad \{\theta+(1-\theta)\gamma\} = e_2^* + ae_1^*, \qquad e_3^* = \{\theta+(1-\theta)\lambda\}$$

Solving the first two equations simultaneously gives the following coordinated solution:

$$e_1^* = \frac{1-a\{\theta+(1-\theta)\gamma\}}{1-a^2}, \qquad e_2^* = \frac{\{\theta+(1-\theta)\gamma\}-a}{1-a^2}, \qquad e_3^* = \{\theta+(1-\theta)\lambda\}$$

Depending on the relative values of γ and a, the coordinated firm may decide to invest in only one of tasks 1 and 2.

Case (i) If $0 < \{\theta+(1-\theta)\gamma\} < a$, then $e_1^* = 1$, $e_2^* = 0$, and $e_3^* = \{\theta+(1-\theta)\lambda\}$.

Case (ii) If $a < \{\theta+(1-\theta)\gamma\} < \frac{1}{a}$, then $e_1^* = \frac{1-a\{\theta+(1-\theta)\gamma\}}{1-a^2}$, $e_2^* = \frac{\{\theta+(1-\theta)\gamma\}-a}{1-a^2}$, and $e_3^* = \{\theta+(1-\theta)\lambda\}$. In this case, the firm invests effort on all three tasks.

Case (iii) If $\{\theta+(1-\theta)\gamma\} > \frac{1}{a}$, then $e_1^* = 0$, $e_2^* = \{\theta+(1-\theta)\gamma\}$, and $e_3^* = \{\theta+(1-\theta)\lambda\}$.

We now compare the efficacy of single- and multisourcing strategies when interdependent tasks are costly. We first compute vendor effort in the SS case.

Single-sourcing. The client's contract design problem can be stated as

$$\max_{f(\cdot)} \Pi_{\text{SS}} = E[v(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3)] - c_3(\tilde{e}_3) - E[f(S) \mid (\tilde{e}_1, \tilde{e}_2)]$$

subject to

$$\tilde{e}_3 = \arg\max_{e_3 \geq 0} E[v(\tilde{e}_1, \tilde{e}_2, e_3)] - c_3(e_3) - E[f(S) \mid (\tilde{e}_1, \tilde{e}_2)]$$

$$\tilde{e}_1, \tilde{e}_2 = \arg\max_{e_1, e_2 \geq 0} E[f(S) \mid (e_1, e_2)] - c_1(e_1) - c_2(e_2) - ae_1e_2,$$
$$\text{and} \quad E[f(S) \mid (\tilde{e}_1, \tilde{e}_2)] - c_1(\tilde{e}_1) - c_2(\tilde{e}_2) - ae_1e_2 \geq 0$$

For the modular tasks case, we have $S = (e_1 + \gamma e_2) + \varepsilon_2$ and focus on linear contracts.

Effort choice. The FOCs for the first-best efforts on the outsourced tasks are

$$\begin{aligned} \tilde{e}_1 &= \arg\max_{e_1} E[f(S) \mid e_1, e_2] - c(e_1) - c(e_2) - ae_1e_2 \\ &= \arg\max_{e_1} T + \alpha[(e_1 + \gamma e_2)] - \tfrac{e_1^2}{2} - \tfrac{e_2^2}{2} - ae_1e_2 \end{aligned}$$

and, similarly,

$$\tilde{e}_2 = \arg\max_{e_2} T + \alpha[(e_1 + \gamma e_2)] - \tfrac{e_1^2}{2} - \tfrac{e_2^2}{2} - ae_1e_2$$

and $\tilde{e}_3 = \theta$. The participation constraint is written as $E[f(S) \mid \tilde{e}_1, \tilde{e}_2] - c(\tilde{e}_1) - c(\tilde{e}_2) - a\tilde{e}_1\tilde{e}_2 \geq 0$. The client will set T such that $E[f(S) \mid \tilde{e}_1, \tilde{e}_2] - c(\tilde{e}_1) - c(\tilde{e}_2) - a\tilde{e}_1\tilde{e}_2 = 0$, making the vendor's participation constraint tight and extracting all the surplus. Therefore, $T + \alpha E[S] - a\tilde{e}_1\tilde{e}_2 - c(\tilde{e}_1) - c(\tilde{e}_2) = 0$.

So in order to see whether single-sourcing will attain the *client's* first-best *outcome*, we need only check for the existence of an α that can yield the *vendor's* first-best *efforts*. Given that the first-best efforts maximize the function $e_1 + \{\theta + (1 - \theta)\gamma\}e_2 + \theta e_3 - \frac{e_1^2}{2} - \frac{e_2^2}{2} - \frac{e_3^2}{2} - ae_1e_2$, it is easy to see that SS will yield the first-best outcome for the client if and only if $\theta = 0$ or $\gamma = 1$.

Multisourcing. Because we assume that the cost of task interdependence is borne by the primary vendor (and thus we assume, without loss of generality, that the primary vendor performs the second task), the client's contract design problem can be stated as

$$\text{Max}_{f_i(\cdot)} \Pi_{\text{MS}} = E[v(\tilde{e}_1, \tilde{e}_2, \tilde{e}_3)] - c_3(\tilde{e}_3) - E[f_1(S) \mid (\tilde{e}_1, \tilde{e}_2)] - E[f_2(S) \mid (\tilde{e}_1, \tilde{e}_2)]$$

subject to the following conditions:

$$\tilde{e}_3 = \arg\max_{e_3 \geq 0} E[v(\tilde{e}_1, \tilde{e}_2, e_3)] - c_3(e_3) - E[f_1(S) \mid (\tilde{e}_1, \tilde{e}_2)] - E[f_2(S) \mid (\tilde{e}_1, \tilde{e}_2)]$$

$$\tilde{e}_1 = \arg\max_{e_1 \geq 0} E[f_1(S) \mid (e_1, \tilde{e}_2)] - c_1(e_1)$$

$$\tilde{e}_2 = \arg\max_{e_2 \geq 0} E[f_2(S) \mid (\tilde{e}_1, e_2)] - c_2(e_2) - ae_1e_2$$

$$E[f_1(S) \mid (\tilde{e}_1, \tilde{e}_2)] - c_1(\tilde{e}_1) \geq 0$$

$$E[f_2(S) \mid (\tilde{e}_1, \tilde{e}_2)] - c_2(\tilde{e}_2) - a\tilde{e}_1\tilde{e}_2 \geq 0$$

Effort choice. The FOCs for the first-best efforts on the outsourced tasks are

$$\tilde{e}_1 = \arg\max_{e_1} E[f_1(S) \mid e_1, e_2] - c(e_1) = \alpha_1, \text{ and } \tilde{e}_3 = \theta,$$

and, similarly, $\tilde{e}_2 = \max\{\alpha_2\gamma - a\tilde{e}_1, 0\} = (\alpha_2\gamma - a\alpha_1)^+$. Here the participation constraints are $E[f_1(S) \mid \tilde{e}_1, \tilde{e}_2] - c(\tilde{e}_1) \geq 0$ and $E[f_2(S) \mid \tilde{e}_1, \tilde{e}_2] - c(\tilde{e}_2) - a\tilde{e}_1\tilde{e}_2 \geq 0$. The client will set T_i such that the vendor's participation constraint is tight, thereby extracting all the surplus; hence $T_1 + \alpha_1 E[S] - c_1(\tilde{e}_1) = 0$ and $T_2 + \alpha_2\{S\} - a\tilde{e}_1\tilde{e}_2 - c_2(\tilde{e}_2) = 0$. Therefore, the client can attain its first-best outcome if it can set feasible values for α_1 and α_2 that also yield first-best efforts by vendors. We now demonstrate that the client can indeed set such values.

Case (i) If $0 < \{\theta + (1-\theta)\gamma\} < a$, then $e_1^* = 1$, $e_2^* = 0$, and $e_3^* = \theta$. In this case, the client can set $\alpha_2 = 0$ and $\alpha_1 = 1$ to attain the first-best outcome.

Case (ii) If $a < \{\theta + (1-\theta)\gamma\} < \frac{1}{a}$, then $e_1^* = \frac{1-a\{\theta+(1-\theta)\gamma\}}{1-a^2}$, $e_2^* = \frac{\{\theta+(1-\theta)\gamma\}-a}{1-a^2}$, and $e_3^* = \theta$. Now, setting the contract parameter values such that $\alpha_1 = \frac{1-a\{\theta+(1-\theta)\gamma\}}{1-a^2}$ and $\alpha_2 = \frac{\{\theta+(1-\theta)\gamma\}}{\gamma}$ results in the client attaining its first-best outcome.

Case (iii) If $\{\theta + (1-\theta)\gamma\} > \frac{1}{a}$, then $e_1^* = 0$, $e_2^* = \{\theta + (1-\theta)\gamma\}$, and $e_3^* = \theta$. Here the client can set $\alpha_2 = \frac{\{\theta+(1-\theta)\gamma\}}{\gamma}$ and $\alpha_1 = 0$ to attain the first-best outcome.

We therefore conclude that the multisourcing strategy attains the first-best outcome for the client.