Electronic Markets, Search Costs and Firm Boundaries

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Abstract. We study how electronic markets that facilitate broader inter-firm transactions affect the vertical scope of emerging IT-enabled extended enterprises. We do so by modeling firms in a three-tier value chain who are each connected to a common electronic market that facilitates direct business transactions across tiers, and that lowers the search costs associated with finding an appropriate trading partner for each of them. The extent to which search costs are reduced depends on the complexity of B2B search, and the nature of the supporting technologies that the electronic market facilitates. Variation in search costs affect firms across the value chain in three key ways: by a change in the transaction costs of interaction between firms; by a change in the contracting costs associated with outsourcing owing to changes in the costs of moral hazard for delegated search, and by a change in the price dispersion of upstream input commodities. We capture each of these effects in a new model that integrates search theory into the principal-agent framework, and establish that the optimal outsourcing contract has a simple "all or nothing" performance-based structure under fairly general assumptions. We then apply this model to contrast the effect that different information technologies have on the relative B2B search costs of different firms in the value chain, contrasting the predicted changes of proportionate, constant and convergent changes in search costs. When integrated with a detailed analysis of the nature of B2B search, these results predicts that when B2B search is *information-intensive*, electronic markets will facilitate an increase in outsourcing, market-based transactions and a reduction in the vertical scope of extended enterprises. In contrast, when B2B search is primarily *communication-intensive,* electronic markets will lead to tighter integration and an *increase* in the vertical scope of the extended enterprise. Our research suggest that the nature of the information technologies and of the business activities supported by an electronic market are crucial determinants of the organizational and industry changes they induce, and our results have important implications for a variety of industries in which both technological and agency issues will influence the eventual success of global IT-facilitated extended enterprise initiatives.

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1. Introduction

The IT infrastructure created by investments in electronic B2B markets over the last few years facilitates a new array of inter-firm transactions and enterprise forms. As these "extended enterprises" become increasingly viable, they raise new variants of classic organization design and governance questions. Since the shared interorganizational systems (IOS) of B2B markets make outsourced relationships more easily viable, should firms take advantage of these reduced transaction costs to shrink their scope, and focus on their core competencies, while remaining part of a loosely coupled extended enterprise? Or rather, should they exploit the fact that these very same shared IOS and IT platforms of B2B markets facilitate supplier reach and transaction capability across the supply chain, thereby potentially disintermediating those intermediaries whose business models relied on transaction costs asymmetries that these electronic markets have largely eliminated, and making viable an integrated enterprise that extends vertically upstream? At first glance, either scenario seems to be economically justifiable.

In this paper, we explore this trade-off by studying how electronic business-to-business markets affect the vertical scope of the extended enterprises that use them. We do so by modeling the sourcing decision of a downstream firm in a three-tier value chain. Firms in each tier of the value chain are connected to a common electronic market that facilitates direct business transactions across tiers, and lowers the search costs associated with the activities of all the firms in the value chain. In contrast with consumer search, B2B search is considerably more complex and nuanced, and changes in these search costs induces three key effects: a change in the transaction costs for firms across the tiers of the value chain; a change in the contracting costs associated with outsourcing owing to changes in the costs of moral hazard for delegated search, and a change in the price dispersion of upstream input commodities. We capture each of these effects in a new model that integrates search theory into the principal-agent framework, and establish that the optimal outsourcing contract has a simple "all or nothing" performance-based structure under fairly general assumptions. We apply this model to contrast the effect that commonly used information technologies have on the relative B2B search costs of different firms in the value chain, and establish conditions under which the electronic market will increase the scope and integration of an extended enterprise, and conditions under which it will lead to increased outsourcing and a loosely coupled extended enterprise. These results, along with a detailed analysis of B2B search, lead to a contrast between information-intensive and communication-intensive search: the effect of IT of each of these is associated with a different prescribed model for scope and integration.

A simple context that our model describes quite literally is that of procurement outsourcing, a growing phenomenon enabled by electronic markets. A 2003 survey of senior executives by Accenture found that 9% of companies (projected to grow to 22% by 2006) surveyed used procurement service providers (PSPs), rather than in-house procurement divisions, for *direct* materials and services, while 20% of them (projected to grow to 43% by 2006) use PSPs for *indirect* materials and services. Similarly, a more recent survey (conducted in 2004) by A. T. Kearney, finds that between 9% and 20% of companies outsource procurement activities related to maintenance, repair and operating supplies (MRO), and 11% to 17% of them outsource procurement activities related to indirect materials, compared to just 4% to 9% of companies that outsource procurement related to direct materials. These survey results are striking, because they highlight how the extent of outsourcing of the procurement function – often considered of key strategic importance (Wolf, 2005) – varies between indirect/MRO inputs and direct inputs. Our model suggests these differences, based on a contrast between the nature of B2B search associated with MRO/indirect inputs and direct inputs.

In order to place our work in the existing literature we first briefly summarize our model and its results. We model an industry with a three-tier vertical value chain. There is one downstream manufacturer of final goods, an intermediary (tier-1 supplier) to whom the production of complex parts may be outsourced, and upstream (tier-2) suppliers of commodity or near-commodity inputs to this complex part[3]. The outsourcing decision of the manufacturer is influenced by the lowering of search costs through three effects: (1) a reduction in the direct transaction cost of procurement for manufacturers, suggesting less outsourcing and *higher* vertical scope for the extended enterprise, (2) a reduction in the dispersion of commodity input prices, since these prices and the extent of dispersion is influenced by the level of search costs, and by who (manufacturer or intermediary) does the searching, and. (3) reduction in contracting (agency) costs associated with outsourcing, suggesting more procurement-outsourcing and *lower* vertical integration for the extended enterprise[4]. Since the manufacturer is usually unable to observe the intermediary's search effort, it faces costs associated with moral hazard, the extent of which depends on the intermediary's search cost (which may also be lowered by the electronic market), and by the changes in commodity price dispersion.

Our analysis proceeds as follows. First, we derive the optimal cost-plus outsourcing contract for the manufacturer, and show that it has a simple two-part structure, with a fixed performance trigger. This is interesting because we allow the buyer to optimize over contracts of any functional form, and despite this generality, the optimal contract has a simple and easily implementable form. Next, we use this optimal contract to frame the make vs. buy decision, and to examine how this decision is affected by different kinds of changes in relative search costs. First, if B2B search

[3] An illustrative situation is the auto industry. A manufacturer like General Motors buys most of its car seats, a complex intermediate part, from an intermediary parts supplier like Delphi. The sourcing of commoditiy inputs such as plastic and steel, and subsequent production of car seats, could be handled by GM or Delphi, depending on which company has an overall relative advantage. In fact, it has been handled by both of these companies at different times, and recent trade press articles suggest that GM may return to in-house sourcing and production of the parts it currently sources from Delphi (Arndt and Welch, 2005).

[4] We thus move well beyond simple intuition which suggests that if electronic markets lower the search costs of a buyer, in a simple buyer-supplier scenario, buyers will outsource more. This ignores the crucial role intermediaries play in multi-tier industies. When there are many layers of intermediaries as well, electronic markets may lower search costs for buyers as well as intermediaries. If these markets confer a relative advantage to buyers (intermediaries), then the buyers (intermediaries) will perform the transactions, which will leading to relatively less (more) outsourcing, and more (less) vertical scope.

and transactions are information-intensive, involving collecting and processing product information from non-personal or published sources, technologies like online product catalogs, Internet-based supplier portals, and product/price comparison engines induce *constant* decreases in search costs across the tiers of the value chain, for both the manufacturer and the intermediary. In this case, our model shows that the lowering of agency cost dominates the benefits from lower search costs, leading to more outsourcing, a *decrease* in vertical integration and a more loosely coupled extended enterprise. In contrast, if B2B search involves extensive communication (as suggested by the industrial marketing literature, which we discuss at length later in the paper), then marketplace communication platforms like EDI, XML and related collaborative systems reduce the unit cost of each communication iteration/step. B2B search costs then decrease *proportionately* for the manufacturer and intermediary, with the differences reflecting prior expertise and number of iterations before a final price is obtained. In this case, we show that the decrease in the buyer's search cost often dominates the decrease in her contracting costs, which leads to less outsourcing, an *increase* in scope, and a more vertical integrated extended enterprise. Finally, if shared procurement technologies and processes cause search costs for electronic market participants to converge to a common lower value, our model predicts an *increase* in vertical integration, though our emphasis is on the first two scenarios.

Our research adds to a rich and varied literature on information systems and interorganizational transactions. One might first bifurcate this literature into two broad streams: (1) related to the organizational issues associated with contracting for and sourcing of information systems and technologies, and (2) relating to the enabling aspects of information systems in changing interactions across organizations. The former literature has studied some contracting issues related to ours, such as its role in software outsourcing (Richmond, Seidmann and Whinston, 1992; Whang, 1992), contracting and reputation effects in the context of offshore software outsourcing (Banerjee and Duflo, 2000), how software processes affect offshore software development (Gopal, Mukhopadhyay and Krishnan, 2002) and how contractual arrangements help clients derive value from offshore outsourcing (Gopal, Sivaramakrishnan, Krishnan, and Mukhopadhyay, 2003)..

The latter literature, centered around inter-organizational information systems (IOS), can further be divided into three streams: the nature of IOS, the adoption of IOS, and the organizational/industry impact of IOS.

The nature of IOS: This literature has highlighted, among other things, the need for business partner re-engineering (Riggins and Mukhopadhyay, 1994), competing approaches to measuring EDI usage through volume, diversity, breadth and depth of usage (Massetti and Zmud, 1996), the importance of merging technological and process innovations (Clark and Stoddard, 1996), how domain expertise confers strategic advantage to firms using IOS (Christiaanse and Venkatraman, 2002), the use of options to integrate spot and long-term contracts in B2B exchanges (Kleindorfer and Wu, 2003), and why IOS should provide flexibility so that firms can change offerings and partners (Gosain, Malhotra and El Sawy, 2005).

The adoption of IOS: this literature has examined, among other things, the incentives for buyers and sellers to invest in IOS (Bakos, 1997), how asset specificity and trust influence IOS adoption (Zaheer & Venkatraman, 1994), the optimal ownership of IOS and the importance of network participants to asset productivity (Bakos and Nault, 1997), how external pressure and organizational readiness affect IOS adoption (Chwelos, Benbasat and Dexter, 2001), how the codifiability of transactions influences their suitability for B2B exchanges (Levi, Kleindorfer and Wu, 2003), and the impact of ownership on adoption and exploitation of IOS (Han, Kauffman and Nault, 2004).

The organizational and industry impact of IOS : This literature has examines the impact of IOS on firm size and scope (Gurbaxani and Whang, 1991), on the number of suppliers and extent of outsourcing (Clemons, Reddi and Row, 1993; Bakos and Brynjolfsson, 1993), on firm size (Brynjolfsson, Malone, Gurbaxani and Kambil, 1994), and on JIT (Just In Time) practices (Srinivasan, Kekre and Mukhopadhyay, 1994). Prior work has also studied how network effects affect IOS adoption and impact (Riggins, Kriebel and Mukhopadhyay, 1994; Wang and Seidmann, 1995; Bhargava and Choudhary, 2004), and the impact of specific technologies like voice mail on inter-organizational effectiveness (Lind and Zmud, 1995). The relative benefits to different players in the value chain has also been investigated: to buyers in the auto industry (Mukhopadhyay, Kekre and Kalathur, 1995), to buyers when IOS drives down search costs (Bakos, 1997), on intermediation (Bailey and Bakos, 1997; Choudhury, Hartzel and Konsynski, 1998), to sellers who can price-discriminate and lock in customers to IOS technologies (Grover and Ramanlal, 1999), on vertical integration (Hitt, 1999), on sharing domain expertise (Argyres, 1999), on the optimality of centralization versus decentralization of decision rights and the resulting performance of a firm facing multiple horizontal markets (Anand and Mendelson, 1997), on policies like vendor managed inventory (VMI) and continuous replenishment (Raghunathan and Yeh, 2001), and on the emergence of biased versus unbiased markets (Granados, Gupta and Kauffman, 2005).

Clearly, this is a diverse and varied literature. Our work places most naturally in the third stream, since we study how an electronic market affects outsourcing and vertical integration. However, our model and results are different from the existing literature in a number of ways. In contrast to most earlier work, which studies the impact of IOS on individual firms or in buyer-supplier contexts, our work is situated at the level of the supply chain, with multiple tiers of buyers, suppliers and intermediaries. This approach is consistent with recent work (Straub, Rai and Klein, 2004) that highlights the need to study the impact of information technologies on the performance of networks of firms. It also highlights the role that different transaction costs, including search and agency costs, play in determining the vertical scope of organizations. It is well-established that electronic markets may decrease search costs (Bakos, 1997). Moreover, Gurbaxani and Whang (1991) point out in their influential early paper that IT lowers agency costs as well as search costs. In a typical value chain with multiple echelons, search costs may predominate in some parts of the supply chain, whereas agency costs may predominate in others. By modeling the interaction of search and agency costs, we make a unique new contribution to this literature.

Moreover, we recognize the fact that B2B search is complex, may depend on the nature of the input, and correspondingly, the impact of IT on search costs is not single-dimensional. For example, search for buyer-specific information involves the use of communication technologies (email, EDI, instant messaging, faxes, phones, letters), whereas search for generic, passive information involves the use of publication technologies (web pages, catalogs). Prior research has shown that price information is relatively easy to convey, whereas conveying product attribute information is more challenging (Bakos, 1997). Parsing the collection of price information, we fine-tune earlier arguments by suggesting that in the context of B2B procurement, getting even the price of so-called commodity goods can be anything but straightforward, if the buyer has to determine terms specific to her case, such as delivery schedules, quantity discounts, commitment to quality levels, and so on. Since buyer-specific terms are less likely to be published, the buyer has to engage in iterative communications with suppliers. In such circumstances, hierarchies (either bilateral long-term contracts or intra-firm governance) rather than markets may be the preferred governance mechanism. This seems consistent with Choudhury, Hartzel and Konsynski, (1998), who describe evidence from the chemical industry, where electronic markets are not widespread despite chemicals being an easily described commodity product. It is also related to early work that suggested that electronic markets will be used for products that are low in asset specificity and complexity of description, and electronic hierarchies for products high on both dimensions (Malone, Yates and Benjamin, 1987), an assertion supported by the empirical results of Choudhury, Hartzel and Konsynski, (1998), and Zaheer and Venkatraman (1994). Recent work in this direction (Granados, Gupta and Kauffman, 2005) finds that when asset specificity and product complexity are low, advanced IT facilitates the move from electronic hierarchies toward unbiased electronic markets. We add to this literature by studying how an electronic markets (featuring search costs) affects the choice between an electronic hierarchy (featuring agency costs) and an IT-mediated transaction-based relationship.

When electronic markets and IOS are widespread, intermediaries may not disappear – their roles can simply change (Choudhury, Hartzel and Konsynski, 1998). This suggests that intermediaries have innate strengths, such as providing aggregation (Bhargava and Choudhary, 2004), trust, lower operating costs, and matching services (Bailey and Bakos, 1997) that enable them to add value despite the presence of electronic markets and other IOS. We condense these innate advantages of intermediaries into the notion that they initially have lower search costs than the manufacturer. This advantage could stem from intermediaries' greater investments in, and opportunities to acquire, domain specific knowledge, which has been shown to confer strategic advantage in technology mediated inter-organizational relationships (Christiaanse and Venkatraman, 2002).

In addition to adding to the IS literature, our model makes a contribution to the related literature from industrial organization economics. Our approach is novel to the literature on firm boundaries in its focus on *pre-contractual* transaction costs (in our context, the costs of searching for appropriate trading partners) and their effects on the scope of firms. In contrast, most recent theories of firm boundaries focus on post-contractual opportunistic behavior (Klein, Crawford and Alchian, 1978), the benefits of ownership (Grossman and Hart, 1986), and the relative viability of relational contracts based on unverifiable outcomes (Baker, Gibbons and Murphy, 2001, 2002).

We model vertical integration as a response to asymmetric information. Salient papers in this literature include Arrow (1975), who models a downstream manufacturer who integrates backwards to gain timely access to upstream input prices, Riordan and Sappington's (1987) study of a retailer who must decide whether to integrate backward with a manufacturer, and Lewis and Sappington (1991), which models the impact of production technology on a firm's decision to make or buy a part from a low-cost supplier whose cost and effort are unobservable. We also add to the literature on the role of middlemen, which in the past has examined competition among middlemen (Stahl, 1988; Fingleton, 1997), their impact on the efficiency of trade (Bloch and Ryder, 1994), and their impact on liquidity (Gehrig, 1993; Yanelle, 1989) and search costs (Rubinstein and Wolinsky, 1987; Yavas, 1992). Spulber (1996) reviews the economics of intermediaries in greater detail.

We do not propose a new model of search, drawing instead from the analytical framework of Stahl (1989, 1996), since his specification most closely resembles the business scenario we analyze (in contrast with other models of search by Stigler, 1961, Diamond, 1971, Salop and Stiglitz, 1977, Shilony, 1977 and Varian, 1980). Finally, our model of a principal delegating costly search to a specialized agent may have applications beyond our paper, and is the first of its kind.

2. Model

There is a single downstream manufacturer (henceforth called the *buyer*), who assembles and sells a finished product (the *product*) at an exogenously specified price π. In order to manufacture the product, the buyer needs a specialized part (henceforth called the *part*). Manufacturing the part requires a commodity input[5] (henceforth called the *commodity*). The commodity is supplied by a set of m competing *tier-2 suppliers*. Each tier-2 supplier chooses a (potentially different) commodity price. Due to potential price dispersion, the buyer is forced to engage in costly search, determining each potential tier-2 supplier's price until she discovers an acceptable price for the commodity. To keep things simple, we think of this as a quality adjusted price, which takes into account different delivery terms, quality differences and so on, and compares the "hedonic" prices associated with some standardized commodity input, to facilitate comparison between suppliers, and define a "lowest" price.

As is customary in the search literature, we assume that a small fraction μ of potential customers for the commodity are traders (or shoppers) who have a zero search cost and so will always

[5] So long as the parts and commodities are independent, the model can generalize to multiple parts, each requiring multiple commodity inputs.

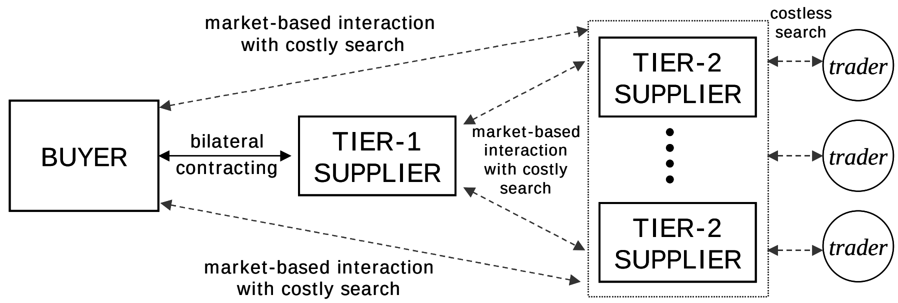


Figure 2.1: Vertical structure of industry in the model

search exhaustively for the lowest price before buying. A fraction $1 - \mu$ of potential customers, which include the buyer, have a have a positive search cost c_P. The presence of these "shoppers" simply ensures a smooth distribution of commodity prices in equilibrium, and they play no further substantive role in the model. Given c_P, the tier-2 suppliers' mixed-strategy Nash equilibrium pricing strategy[6] is denoted $f^*(p)$.

The buyer decides between making the specialized part in-house (insourcing) or buying it from the intermediary tier-1 supplier (outsourcing). If the buyer makes the part in-house, she searches for the best-priced commodity from the tier-2 suppliers, manufactures the part, and assembles it into the finished product. The cost of insourcing therefore comprises (i) search costs of evaluating each potential tier-2 supplier, at the rate of c_P per supplier evaluated, (ii) direct costs of buying the commodity at price p, (iii) the cost of transforming the commodity into the part, and (iv) the manufacturing and assembling cost, to manufacture the product from the part. To focus on search costs associated with the procurement of the commodity, we normalize the costs of manufacturing the specialized part and the product to zero[7].

The buyer may also outsource the part from a specialist intermediary (henceforth called the

[6] Since the tier-2 sellers are identical, we focus on symmetric mixed-strategy Nash equilibrium pricing strategies, consistent with Stahl, 1989.

[7] This is equivalent to assuming that all parties have access to the same manufacturing technology for the part. The main results of the paper are not directionally affected by assuming positive (and different) part manufacturing costs, so long as electronic markets don't affect these costs. Since the buyer always incurs the product manufacturing cost, there is no loss of generality in normalizing this to zero.

tier-1 supplier) who, by virtue of specialization, has a lower search cost c_A. The buyer can observe the commodity price p obtained by the tier-1 supplier, but cannot observe the number of candidate tier-2 suppliers that the tier-1 supplier samples before buying the commodity. Since the part is specialized, and the tier-1 supplier bears idiosyncratic risk in supplying the part, we assume that the tier-1 supplier is risk-averse, with preferences represented by the utility function $u(x)$, where x is the intermediary's payoff. $u(x)$ is twice-differentiable, strictly increasing and strictly concave. The outside opportunity of the intermediary is denoted $\underline{u} \geq 0$. All parties (that is, the buyer, the tier-1 suppliers, and the tier-2 suppliers) know $u(x)$, $\underline{u}$, c_P, and c_A.

In order to induce the tier-1 supplier to search optimally, the buyer offers the tier-1 supplier a contract $[p + w(p)]$, which reimburses the tier-1 supplier for the price p of the commodity, and additionally specifies a performance-based wage $w(p)$, where $w(p)$ can be any function. The buyer's optimal contract must be designed to ensure participation from the tier-1 supplier (individual rationality), and to induce the tier-1 supplier to search optimally (incentive-compatibility). Therefore, the buyer benefits from the tier-1 supplier's lower search cost, but incurs hidden-action moral hazard costs when hiring the tier-1 supplier.

The payoffs under each option are as follows. If the tier-1 supplier (the agent) searches and obtains a commodity price p she receives a payment of $[p+w^*(p)]$, of which she pays p to the tier-2 supplier for the commodity, and derives utility of $u(w^*(p)) - (n-1)c_A$, where n is the number of searches undertaken. Consistent with the literature on search, we assume the first search to be costless. The corresponding payoff to the buyer (the principal), who is risk-neutral, is $\pi - [p+w^*(p)]$. If, on the other hand, the buyer chooses to manufacture the part in-house, her payoff from obtaining a commodity price p is $\pi - [p + (n-1)c_P]$, where n is now the number of searches undertaken by the buyer.

The sequence of events is summarized in Figure 2.2. To decide whether to insource or outsource,

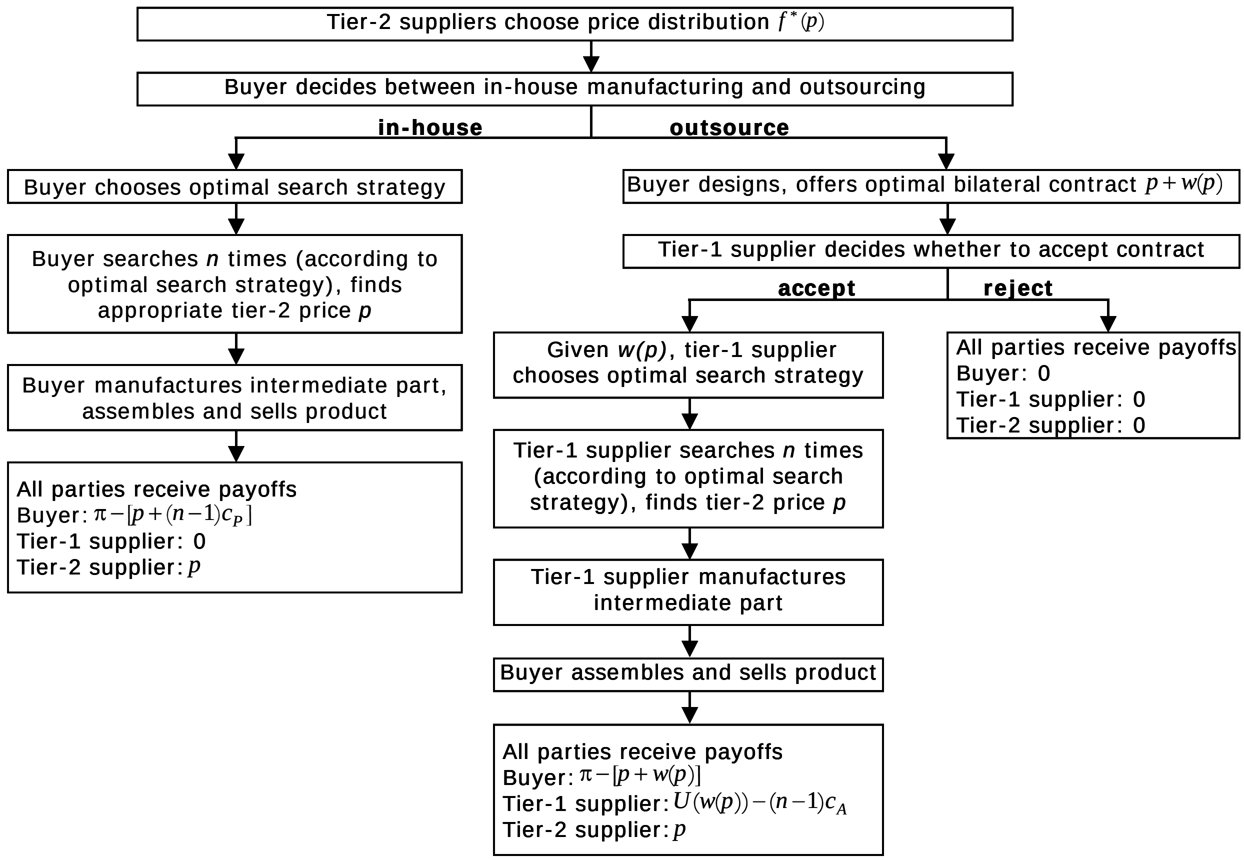


Figure 2.2: Sequence of events in the model

the buyer compares the ex ante payoffs of each alternative, and chooses the better option. For simplicity, we have chosen $m = 2$ for the subsequent analysis. The results generalize directionally to the case of m tier-2 suppliers, though the analysis is substantially more complex.

3. Search costs, contracting, and make versus buy

The first part of this section derives the tier-2 suppliers' equilibrium pricing strategies, and the buyer's payoff from insourcing. The next part derives the optimal outsourcing contract, demonstrating that it has a simple two-part form, and characterizes the buyer's payoff from outsourcing. The third part establishes that for any given buyer search cost, the buyer's make-buy choice is monotonic in the tier-1 supplier's search cost. The final part examines how organizational scope changes when search costs vary, by comparing the relative changes in the buyer's payoffs from insourcing and outsourcing, for different kinds of changes in search costs.

3.1. Insourcing

We first consider the buyer's payoff from insourcing, where the buyer procures the commodity directly from a tier-2 supplier, makes the intermediate part, and then makes the final product. Suppose each tier-2 supplier chooses a symmetric mixed-strategy pricing strategy $f(p)$ with support $p \in [r_0, \overline{p}]$, and corresponding distribution function $F(p)$. The following lemma, based on Stahl (1989), establishes that the optimal search strategy for the buyer is to search until a price below a cutoff price r_P is found, or all tier-2 suppliers have been exhaustively sampled.

Lemma 1. *The buyer's optimal search strategy for the tier-2 commodity is to search until a price less than or equal to a cutoff price r_P has been obtained, or all tier-2 suppliers have been sampled, where r_P is implicitly defined by:*

$$c_P = \int_{r_0}^{r_P} F^*(p)dp \tag{3.1}$$

Given Lemma 1, the equilibrium pricing strategy of the tier-2 suppliers should place zero probability on any value of $p > r_P$, since no buyer (or trader) will purchase from a supplier whose price is higher than r_P, and placing a probability $\int_{r_P}^{\overline{p}} f(p)dp$ on the price r_P is a profitable deviation from any strategy for which $f(p) > 0$ for $p > r_P$. In other words, in the tier-2 suppliers' equilibrium strategy, $\overline{p} = r_P$.

The next lemma characterizes the symmetric mixed-strategy Nash equilibrium pricing strategy of the tier-2 suppliers.

Lemma 2. *The unique symmetric mixed-strategy Nash equilibrium pricing strategy $f^*(p)$ for all* *tier-2 is specified by the following equations:*

$$f^*(p) = \left(\frac{1-\mu}{2\mu}\right)\frac{r_P}{p^2} \text{ for } p \in [r_0, r_P] \tag{3.2}$$

$$r_0 = \left[\frac{1-\mu}{1+\mu}\right] r_P \tag{3.3}$$

$$c_P = r_P\left[1 - \left(\frac{1-\mu}{2\mu}\right)\log\left(\frac{1+\mu}{1-\mu}\right)\right] \tag{3.4}$$

where $F^*(p)$ is the distribution function corresponding to the density $f^*(p)$

Given this pricing strategy, the ex-ante expected payoff to the buyer from insourcing is simply

$$\Pi^I = \pi - \int_{r_0}^{r_P} p f^*(p) dp, \tag{3.5}$$

since the first tier-2 supplier sampled by the buyer is bound to have a price below the cutoff price r_P, and the first search is costless for the buyer. Integrating (3.5) by parts and using (3.1) yields

$$\Pi^I = \pi - (r_P - c_P). \tag{3.6}$$

3.2. Outsourcing

We next consider the buyer's payoff from outsourcing. The buyer's problem is to design the profit-maximizing contract $p + w(p)$, while inducing incentive-compatible search on the part of the tier-1 supplier, and ensuring the tier-1 supplier's participation. We continue to maintain that c_P, the search cost of the buyer, determines the equilibrium tier-2 commodity prices, and hence the pricing strategy for these suppliers continues to be as specified by Lemma 2.

Once the contract $p + w(p)$ is specified, the tier-1 supplier will sample tier-2 suppliers until the expected gains from an additional search is less than the expected increase in expected utility. Therefore, given any contract in which $w(p)$ is non-increasing in p, there will be a cutoff price at which the tier-1 supplier stops searching. We formulate the buyer's problem for *each* such arbitrary cutoff price r_A that the buyer may wish to *induce* the tier-1 supplier to stop searching at (we will subsequently choose the optimal r_A). Denote this contract for an arbitrary r_A as $p + w(p, r_A)$. Given any such r_A, the buyer must design $w(p, r_A)$ so that r_A is indeed the cutoff price at which the tier-1 supplier stops searching, which leads to the following incentive-compatibility constraint:

$$[IC]: \int_{r_0}^{r_A} [u(w(p, r_A)) - u(w(r_A, r_A))] f^*(p) dp \geq c_A. \tag{3.7}$$

The contract must also ensure the tier-1 supplier's participation. The formulation of this participation constraint, and of the buyer's objective function are constructed by assigning the appropriate probability to each possible outcome for a cutoff price of r_A – the details of this are available in Appendix B. Summing up, the buyer's contract design problem reduces to:

$$\max_{w(.,r_A)} \ \pi - \left([2 - F(r_A)] \int_{r_0}^{r_A} f^*(p)[p + w(p, r_A)]dp + \int_{r_A}^{r_P} 2f^*(p)[1 - F^*(p)][p + w(p, r_A)]dp \right)$$

subject to :

$$[IC] \ : \ \int_{r_0}^{r_A} [u(w(p, r_A)) - u(w(r_A, r_A))] f^*(p) dp \geq c_A \tag{3.8}$$

$$[IR] \ : \ [2 - F(r_A)] \int_{r_0}^{r_A} f^*(p) u(w(p, r_A)) dp + \int_{r_A}^{r_P} 2f^*(p)[1 - F^*(p)] u(w(p, r_A)) dp - c_A[1 - F^*(r_A)] \geq \underline{u} \tag{3.9}$$

Solving the buyer's problem leads to the following proposition:

Proposition 1. *The optimal bilateral contract $p + w^*(p, r_A)$ that induces a cutoff price of r_A has*

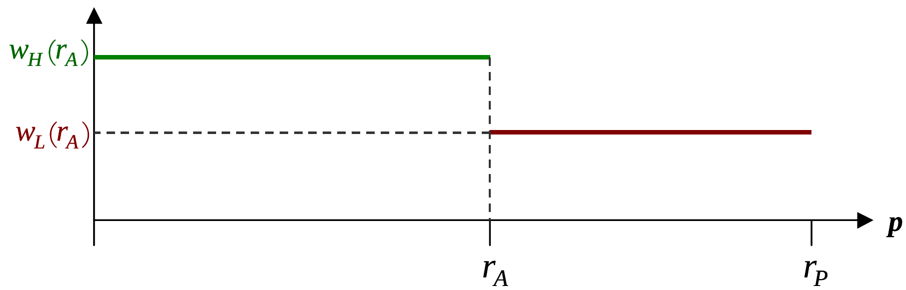


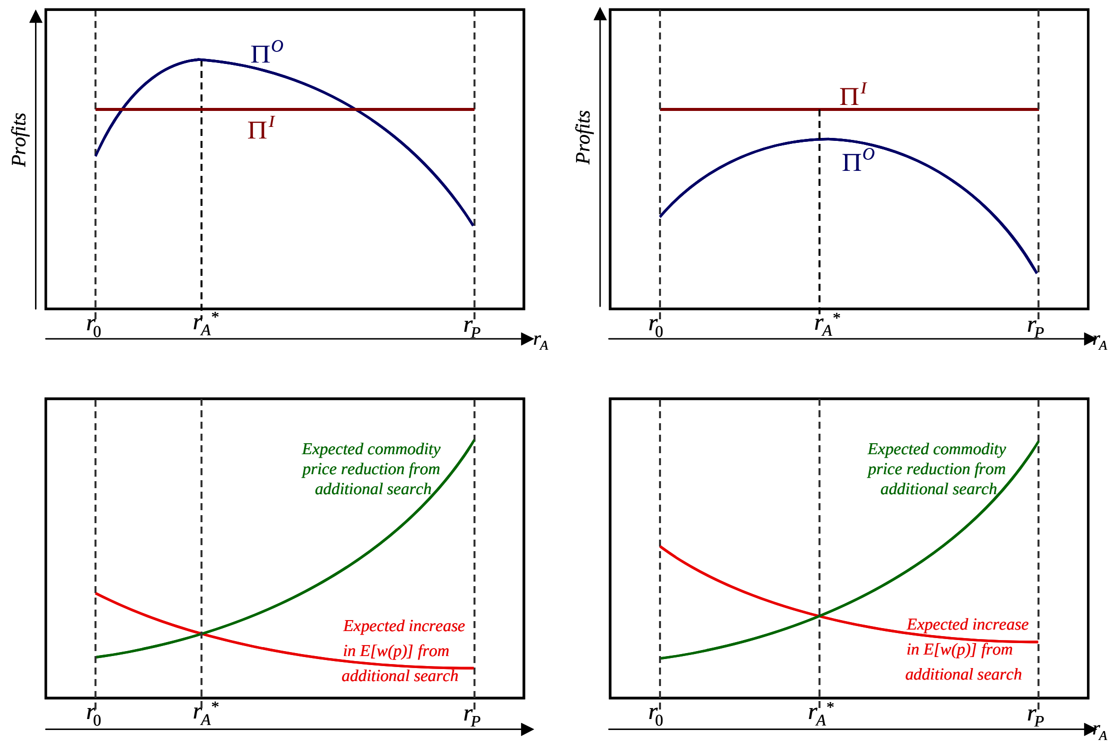
Figure 3.1: Performance-based portion of bilateral contract between buyer and tier-1 supplier.

the following simple structure:

$$\begin{aligned} w^*(p, r_A) &= u^{-1}(\underline{u} + c_A \frac{1 - F^*(r_A)}{F^*(r_A)}) \text{ for } p \leq r_A \qquad (3.10) \\ w^*(p, r_A) &= u^{-1}(\underline{u} - c_A) \text{ for } p > r_A \end{aligned}$$

Therefore, the buyer pays the tier-1 supplier the commodity price and (a) a constant higher wage $w^H(r_A) = u^{-1}(\underline{u} + c_A \frac{1-F^*(r_A)}{F^*(r_A)})$ *if the tier-1 supplier obtains a commodity price* $p \leq r_A$ *and (b) a constant lower wage* $w^L(r_A) = u^{-1}(\underline{u} - c_A)$ *if the tier-1 supplier obtains a commodity price* $p > r_A$.

The structure of the contract derived in Proposition 1 is illustrated in Figure 3.1. Despite the fact that the outcome set (price of the commodity obtained) is continuous, the nature of the agent's task (search) naturally lends itself to a partition of this space into favorable and unfavorable outcomes. This is because even when the payoffs are continuous and directly to the party searching (as is the case in the first-best), the decision rule for whether to search again is based on a deterministic cutoff price. Proposition 1 shows that this induces the principal (the buyer) to structure a contract that explicitly makes the payoff from the task of the agent (the tier-1 supplier) discrete. Additionally, the tier-1 supplier can take one of two (or in general, one of m) discrete actions (search once, twice), rather than having a continuous action space (as is the case in moral hazard models in which the agent chooses effort). This provides some intuition for why the optimal contract is discontinuous and flat, rather than varying smoothly with observed outcome p.



(a) When outsourcing is preferable **(b) When insourcing is preferable**

Figure 3.2: Illustrates the profits from outsourcing and insourcing respectively, and how they vary with the buyer's choice of r_A (the cutoff price which the tier-1 supplier is induced to stop searching at by the bilateral contract), for two candidate sets of parameter values. The figure below the profit curve illustrates that at the optimal value $r_A = r_A^*$, the expected value of an additional search by the agent exactly balances the expected cost to the buyer (principal) of inducing this search. However, since r_A^* is strictly higher than the agent's first-best search strategy, the contract results in an effective increase in the magnitude of agent's search cost. In (a), which illustrates a lower value of c_A, outsourcing is more profitable. In (b), which illustrates a higher value of c_A, even the best choice of r_A yields lower profits than those from insourcing, and so the buyer chooses to manufacture the intermediate part in-house.

The buyer choosing the value of r_A that maximizes profits, given that their optimal contract for a fixed r_A is as specified by Proposition 1. Rearranging the buyer's objective function, this optimal cutoff price r_A^* solves:

$$r_A^* = \arg\min_{r_A \in [r_0, r_P]} [2 - F^*(r_A)]F^*(r_A)w^H(r_A) + [1 - F^*(r_A)]^2 w^L(r_A) \quad (3.11)$$

$$+[2 - F^*(r_A)] \int_{r_0}^{r_A} pf^*(p)dp + 2 \int_{r_A}^{r_P} pf^*(p)[1 - F^*(p)]dp$$

and the buyer's payoff from outsourcing is therefore

$$\Pi^O = \pi - [[2 - F^*(r_A^*)]F^*(r_A^*)w^H(r_A^*) + [1 - F^*(r_A^*)]^2 w^L(r_A^*) + [2 - F^*(r_A^*)]\int_{r_0}^{r_A^*} pf^*(p)dp + 2\int_{r_A^*}^{r_P} pf^*(p)[1 - F^*(p)]dp]. \tag{3.12}$$

3.3. Relative search costs and organizational scope

We now characterize the buyer's decision between outsourcing and insourcing. Clearly, the buyer chooses to outsource (insource) if $\Pi^O > \Pi^I$ ($\Pi^O < \Pi^I$). Comparing (3.5) and (3.12) and rearranging, *outsourcing* is optimal if the following condition is satisfied:

$$[2-F^*(r_A^*)]F^*(r_A^*)w^H(r_A^*)+[1-F^*(r_A^*)]^2w^L(r_A^*) \leq \int_{r_A^*}^{r_P} pf^*(p)[2F^*(p)-1]dp-[1-F^*(r_A^*)]\int_{r_0}^{r_A^*} pf^*(p)dp. \tag{3.13}$$

The intuition behind this expression is straightforward. Given the optimal bilateral contract, the LHS of (3.13) is the expected payment to the tier-1 supplier; $[2 - F^*(r_A^*)]F^*(r_A^*)$ is the ex-ante probability of the favorable outcome, and $[1-F^*(r_A^*)]^2$ is the ex-ante probability of the unfavorable outcome. The RHS of (3.13) is the expected reduction in commodity prices as a consequence of the tier-1 supplier's superior search. Clearly, when the latter is greater than the former, the buyer prefers to outsource. Correspondingly, when the LHS of (3.13) is greater than the RHS of (3.13), the buyer prefers to insource.

The next proposition shows that this decision is monotonic in the tier-1 supplier's search cost c_A in the following sense – there is generally a continuous lower range of value of c_A over which the buyer outsources, and a continuous higher range of values of c_A over which the buyer insources.

Proposition 2. *For any buyer search cost $c_P > 0$:*

(a) If $c_A = c_P$, then the firm always prefers insourcing to outsourcing

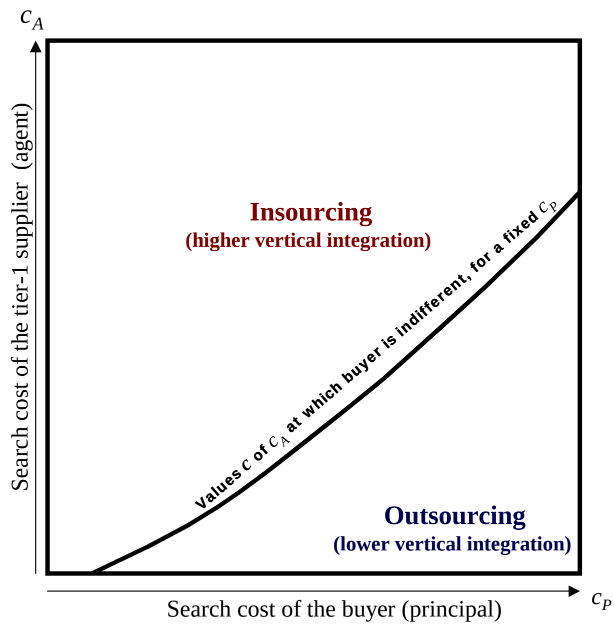


Figure 3.3: Illustrates the result of of Proposition 2, by depicting the regions in which the buyer chooses to outsource, and those regions in which the buyer chooses to insource.

(b) The buyer's profits from outsourcing decrease monotonically with c_A.

Therefore, if there exists a threshold value $c \in (0, c_P)$ at which the buyer is indifferent between outsourcing and insourcing, the buyer outsources when $c_A < c$, and the buyer insources when $c_A > c$.

Figure 3.3 illustrates the result from Proposition 2. At each high enough value of c_P, there is a corresponding value c of c_A at which the buyer is indifferent between outsourcing and insourcing. At each fixed value of c_P, the buyer outsources for $c_A < c$, and insources for $c_A > c$. The graph of c as a function of c_P is increasing and convex, and its slope is bounded above by 1. It also lies entirely below the 45^o line, as demonstrated by part (a) of the proposition.

Given c_P, the existence of the threshold value c depends on whether the buyer ever chooses to outsource. If outsourcing is preferable when the tier-1 supplier has zero search costs (that is, for $c_A = 0$), then an immediate corollary of (a) and (b) in Proposition 2 is that there is a positive threshold value $c \in (0, c_P)$. On the other hand, if the tier-1 supplier's reservation utility is high enough, or the buyer's search cost low enough, to make insourcing optimal even when $c_A = 0$, the buyer will choose to manufacture the intermediate part in-house for all $c_A > 0$.

4. How electronic market technologies affect the extended enterprise

As we have discussed, an electronic market may change search costs for different firms across different tiers of the value chain to varying degrees. In this section, we first characterize how the organizational scope of an extended enterprise built around such an electronic market varies as there are differential changes in search costs across the manufacturer (buyer) and the tier-1 intermediary. We then describe the nature of B2B search in some detail, link its characteristics to technologies that affect information intensive and communication-intensive search, and, integrating the nature of search with our analytical results, contrast the changes in the scope of the enterprise that the electronic market is thereby likely to induce.

4.1. Changes in organizational scope as search costs vary

In order to characterize directional changes in organizational scope in a general way, and only in contexts of interest, we do the following. We assume that under the status-quo (prior to the adoption of the electronic market), the buyer is indifferent between outsourcing and insourcing. This is equivalent to assuming that c_A is at the threshold level c corresponding to c_P, as described in Proposition 2. We then vary the search costs c_A and c_P in a systematic way, and establish whether the changes in search costs cause the buyer to insource or outsource. If the buyer *insources* as a consequence of the changes described, we conclude that search costs changes of that kind are likely to *increase* the organizational scope of an enterprise built around the electronic market. Correspondingly, if the buyer *outsources* as a consequence of the changes in the search costs, we conclude that search costs changes of that kind are likely to *decrease* organizational scope, and lead

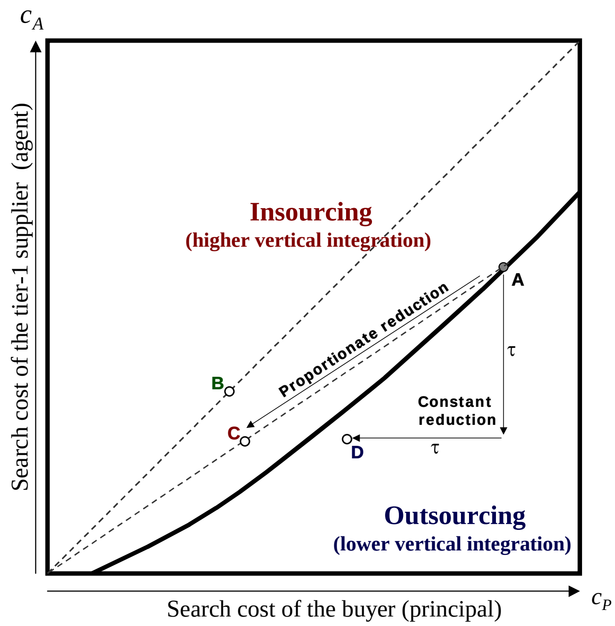


Figure 4.1: Illustrates the results of Propositions 3, 4 and 5. Starting at any indifferent point A, when the electronic market causes search costs to converge to a common value B, the buyer prefers to insource. Any proportionate reduction in costs (along the dotted line joining A to the origin) results in an indifferent buyer choosing to insource, confirming Proposition 4. In contrast, a constant bilateral reduction in search costs, to point D results in an indifferent buyer opting to outsource, as shown by Proposition 5.

to a more loosely coupled enterprise.

The first result, which follows directly from Proposition 2(a), establishes that if the electronic market causes search costs converge to a common value, this leads to a decrease in organizational scope.

Proposition 3. *An electronic market that causes the search costs of both the buyer and the tier-1 supplier to converge to a common value results in* ***higher*** *organizational scope.*

Sometimes, a precursor (or parallel activity) to the adoption of an electronic market may be the implementation of a common technology platform that spans many business processes, the associated re-engineering of these processes (Sanders, 2001), and the adoption of best practice shared processes for functions like procurement across firms in the marketplace. If a tier-1 supplier's search cost advantage is embedded in a superior procurement process, this kind of re-engineering could potentially result in the convergence of the buyer and tier-1 supplier's search costs, and lead to an increase in the scope of the buyer firm.

Next, we examine the effects of a *proportionate* reduction in both c_P and c_A:

Proposition 4. *An electronic market that causes the search costs of both the buyer and tier-1 supplier to reduce by the same constant proportion $k < 1$ – that is, from their original values c_P, c_A to new values kc_P, kc_A – results in **higher** organizational scope.*

Intuitively, the result in Proposition 4 is driven by the invariance of the tier-1 supplier's outside alternatives, and the corresponding increased importance of the tier-1 supplier's outside opportunity when search costs decrease across the industry. This is the result underlying our subsequent discussion of communication-intensive search.

Finally, we establish the effects of a *constant* reduction in both c_P and c_A:

Proposition 5. *An electronic market that causes the search costs of both the buyer and tier-1 supplier to reduce by the same constant amount τ – that is, from their original values c_P, c_A to new values $(c_P - \tau), (c_A - \tau)$ – results in **lower** organizational scope*

Some intuition for this proposition can be obtained by considering an extreme case, when $\tau = c_A$. This represents a reduction in search costs that takes the tier-1 supplier's search costs to zero. Since $c_P > c_A$, the buyer still has a positive search cost after the reduction, and consequently, finds it profitable to outsource. This is the result underlying our subsequent discussion of communication-intensive search.

The results of Propositions 3 through 5 are illustrated in Figure 4.1. Consider a buyer at the indifferent point A prior to the adoption of the electronic market. When the search costs of both the buyer and tier-1 supplier converge, to any point B on the 45^o line, the buyer then chooses to insource. When they reduce proportionately (along the line joining A to the origin) to point C, the

Nature of product	Raw materials, **processed materials**, **generic parts**, specialized parts, capital equipment, MRO (maintenance, repair and operations), business services.
Procurement situation	**New task**, **modified rebuy**, straight rebuy.
Steps in the process	Recognition of need, specification determination and description, **search for qualified suppliers**, **RFP**, **proposal analysis and evaluation**, **supplier selection**, order routine specification, performance feedback and evaluation

Figure 4.2: Classifies B2B procurement based on the nature of the product and buying situation; also summarizes the steps in the B2B buying process.

buyer chooses to insource. In contrast, when they each reduce by a constant factor τ to the point D, the buyer chooses to outsource.

4.2. The nature of B2B search

The prior subsection has characterized directional changes in the scope of the enterprise for different kinds of changes in search costs. While search costs tend to be reduced by electronic markets, it seems important to explore the connection between the nature of search in business-to-business transactions, and the corresponding extent of change in search costs, since, unlike consumer search, B2B search is quite involved, and requires substantial organizational resources.

Figure 4.2 summarizes a classification of the nature of B2B buying, based on Kotler (2002) and Robinson, Faris and Wind (1967). The types of products/situations that are generally considered search-intensive are highlighted, as are the steps in the process that are most likely to contribute to search costs. During this search process, buyers often must evaluate multiple vendor and product characteristics. This process often requires *information acquisition* from multiple sources. Dempsey (1978) identifies and classifies these attributes into five factors: basic economic criteria (price, quality, delivery), attendant services (repair, packaging), geographic affinity (location), assurance mechanisms (production facilities, delivery capability, control systems), and vendor stability (labor relations, management and organization).In addition, buyers must often engage in

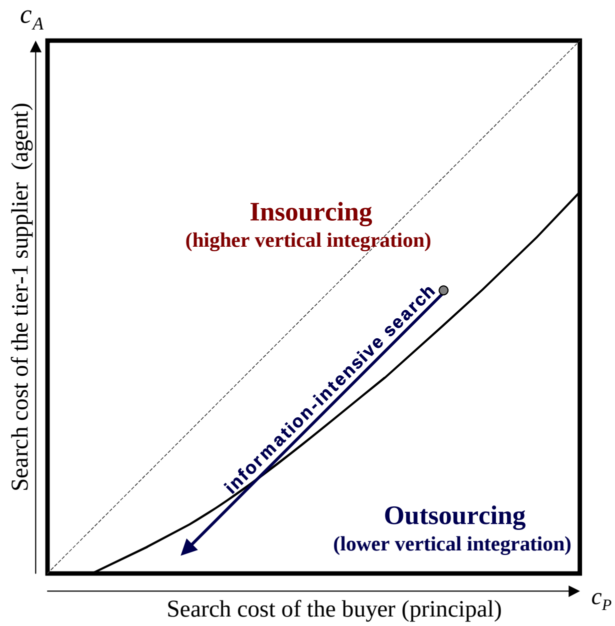


Figure 4.3: Illustrates how electronic marketplaces change organizational scope when search is information-intensive.

active and iterative *communication* with their suppliers, and within their organization, to facilitate effective collaborative decision making by a number of different participants in the buying organization[8].

Highlighting these two dimensions of search is important, as our next two sections illustrate.

4.3. Information-intensive search

In general, information sources are classified as either personal or non-personal, and as commercial or non-commercial. Personal information sources are capable of providing specialized information directly addressing a specific buyer's concerns, whereas impersonal information sources provide general information that all potential buyers are likely to find useful. Commercial information

[8] For example, Webster and Wind (1972) classify participants in the industrial procurement process into the roles of users, buyers, deciders, gatekeepers and influencers. Users affect the buying decision positively by specifying product requirements, or negatively by refusing to work with certain materials. Buyers have the formal authority to arrange for the procurement, and tend to be purchasing managers. Deciders tend to be senior managers who approve the buying decision. Gatekeepers control the flow of information to other participants in the buying decision. Influencers could be distinct from any of the above, and exert direct or indirect influence on the buying decision.

sources are those that the seller provides – examples of personal commercial sources are salespeople and trade shows; of personal non-commercial sources are internal departments, outside consultants and colleagues; of impersonal commercial sources are trade-publication ads, sales literature and catalogs, and of impersonal non-commercial sources are trade press articles and rating services[9].

We term the search *information-intensive* if it involves the acquisition and processing of a substantial amount of non-personal information. Many marketplace technologies substantially lower the cost of acquiring and evaluating this kind of information. Examples include online product catalogs, Internet-based supplier portals, and product/price comparison engines.

When marketplace participants gain access to these information systems, their search costs are therefore likely to reduce by a constant amount. This kind of constant reduction in search costs is especially likely in straight-rebuy situations, since it requires the evaluation of relatively few vendor and product attributes, using impersonal sources of information, and involves fewer decision makers. However, it is highly unlikely that search costs will reduce to zero, since there are still costly evaluation steps involved for each candidate supplier This kind of change in search costs is illustrated in Figure 4.3, and as demonstrated by Proposition 5, our model predicts that it tends to lead to a *reduction* in organizational scope.

4.4. Communication-intensive search

Often, one thinks of search as being a simple process of information acquisition. However, our analysis of the industrial procurement process above has revealed that inter-entity (person, department, firm) *communication* is always a critical part of the process, and often an important cost driver. Acquiring information often involves communication – with personal commercial sources like salespeople and trade shows personnel, and with personal non-commercial sources like outside

[9] This is based on Moriarty and Spekman (1984). In their listing of perceived importance of fourteen information sources, six of the top seven are personal sources.

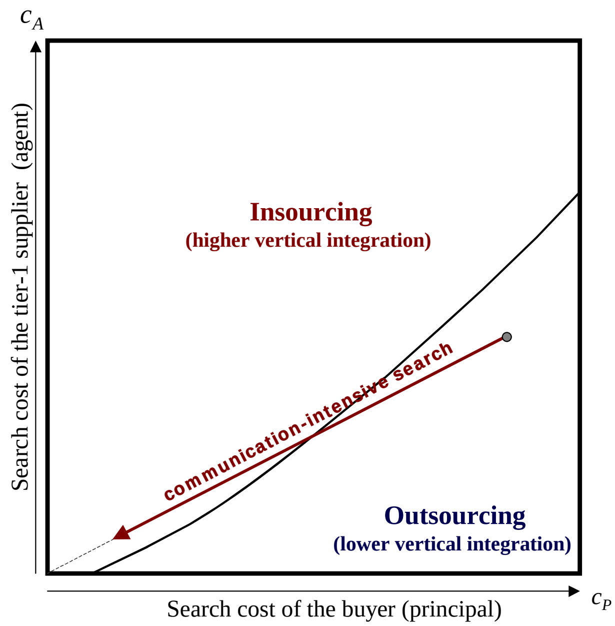


Figure 4.4: Illustrates how electronic marketplaces change organizational scope when search is *communication-intensive.*

consultants and colleagues. Additionally, several departments[10] within the buyer firm are involved in the evaluation of each supplier proposal, with significant iterative communication during the process. Participants in the buying firm don't necessarily consult the same non-personal information sources, and are therefore likely to have different opinions that are reconciled by iterative communication before making the buying decision. This is especially true in new task and modified re-buy situations, which require the evaluation of multiple vendor and product attributes.

The interorganizational systems in electronic markets reduce this cost of iterative communication significantly. For example, Covisint's Connect platform moves beyond EDI to provide it's marketplace participants with sophisticated any-to-any translation capability that can handle both EDI and XML technologies in one environment; their Communicate platform also serves as the framework for OEM-to-supplier and supplier-to-supplier communications. These information systems make each iteration of communication less expensive, faster, less error-prone, and richer. This

[10] For instance, Jackson, Keith and Burdick (1984) show that personnel from purchasing, manufacturing, engineering, top management and other departments influence the process to varying degrees.

may decreases the number of iterations required, probably by some fixed fraction, and also decreases the cost of each iteration, and therefore results in a *proportionate* decrease in search costs across firms. Recall that we had characterized differences in search costs between manufacturers and intermediaries as stemming from the number of communication iterations before the final terms are established, and prior expertise that makes this determination effective. This kind of change in search costs is illustrated in Figure 4.4, and as demonstrated by Proposition 4, our model predicts that it will tend to lead to an *increase* in organizational scope.

5. Discussion and conclusions

Given that the IT infrastructure of Internet-based B2B electronic markets facilitates the interaction of a firm with a broader array of trading partners, and lowers the cost of transacting with them, it is therefore natural to conclude that these electronic markets will reduce the size of organizations. Before coming to this conclusion, however, it is important to notice that the industries in which such markets are situated have complex and multi-tier supply chains, and a number of intermediaries owe their existence to their transaction cost and expertise advantages. Thus, the same changes that facilitate ease of transaction between firms across the supply chain may also cause these intermediaries to lose the advantages that lead to their activities being located outside the scope of the traditional downstream enterprise. In other words, they could well be disintermediated, and firms scope may increase, an outcome that is further favored by the lowering of moral hazard and incomplete contracting costs that accompany the move to a more vertically integrated enterprise.

Our paper has studied this trade-off, by integrating search theory, which models how changes in search costs caused by the marketplace systems affect input price distributions, with the hidden action principal-agent model, which forms the basis for analyzing the costs of bilateral contracting between an intermediary and a downstream manufacturer. Our results show that the resulting changes in enterprise scope and integration depend critically on the nature of search and the corresponding capabilities of the technologies associated with the electronic market.

Often, electronic marketplaces combine technologies that reduce the cost of acquiring published information with those that facilitate faster and less costly communication. In light of our results contrasting information intensive and communication intensive search, these have opposing effects on the desirability of vertical integration, and the resulting changes in organizational scope will thus depend on the relative information-intensity and communication-intensity of search. Returning to our introductory example, for MRO and indirect materials with well-specified characteristics, and a lower dependence on the firms' product design and other supplier relationships, search tends to be more information-intensive, whereas for direct materials, search tends to be more communication-intensive, and the relative pace at which PSP's have been adopted for each of these categories is therefore consistent with our model's predictions.

Our model predicts certain simple conditions under which industry-wide electronic business-to-business markets are likely to increase or decrease the vertical scope of the extended enterprise over time. A natural direction for future research would be towards confirming this direction of change empirically. This would involve a structured analysis and collection of data relating to the effects of marketplace technologies on search costs, and while our model provides the necessary theoretical basis and testable predictions for a first study, such data is likely to have immense value in studying other questions of importance to IS research as well.

There are several other contexts featuring both costly search, contracting under asymmetric information, and the delegation of costly search to an intermediary. Our model provides a first explanation for why these contracts are often "all or nothing." Our context is therefore part of a larger class of problems that investigate how differing search costs, and correspondingly, different search behavior across agents can affect the decision-making process of each of these agents (Reinganum, 1982). It would be interesting to extend the model developed in our paper to inform this question further. In some industries, downstream buyers may not be aware of their intermediate tier-1 supplier's search cost. A procurement contract between the buyer and tier-1 supplier would then be characterized by adverse selection as well as moral hazard (a somewhat related problem is addressed by Dai and Lewis, 2003). Another direction involves examining how the technological infrastructure associated with a B2B market changes the feasibility of implementing market-like relationships within the firm, since recent research (Baker, Gibbons and Murphy, 2001) has indicated that many market-like transactions cannot be replicated within a firm – this is especially relevant when dealing with procurement.

To summarize, we have studied how electronic business-to-business markets affect the vertical scope and integration of the extended enterprise, and the desirability of outsourcing. We characterize B2B search as being more complex than consumer search, and model three key effects that declining search costs induce: a change in the transaction costs of all firms; a change in the contracting costs associated with outsourcing, and a change in the price dispersion of input commodities. Integrating the nature of B2B search with the details of the IT in an electronic market, our model predicts that when search is information-intensive, electronic markets will facilitate an increase in outsourcing and a reduction in organizational scope, whereas when it is primarily communication-intensive, electronic markets will lead to an increase in organizational scope. There are a variety of industries in which both technological and agency issues will influence the eventual success of global IT-facilitated extended enterprise initiatives, and we hope that our work will provide useful guidelines for companies who face increasingly challenging organizational design and governance decisions in these industries.

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7. Appendix A: Proofs

Proof. of Lemma 1: (Based on Stahl, 1989) Suppose each tier-2 supplier plays the same mixed strategy $f(p)$. Given an observed price z, a buyer with search cost c_P will search again only if the benefit from additional search $\Delta(z)$ is greater than c_P, where the benefit from additional search given z is:

$$\Delta(z) = z - \left[\int_{r_0}^{z} p f(p) dp + \int_{z}^{\overline{p}} z f(p) dp \right], \tag{7.1}$$

which can be rewritten as

$$\Delta(z) = z - \left[\int_{r_0}^{z} p \frac{dF(p)}{dp} dp + z(1 - F(z)) \right] = \int_{r_0}^{z} F(p) dp. \tag{7.2}$$

The buyer optimal cutoff price r_P equates the benefit from additional search to the search cost c_P, and therefore solves

$$\Delta(r_P) = c_P. \tag{7.3}$$

Since$F(p) > 0$ for $p > r_0$, $\Delta(z)$ is strictly increasing in z, and therefore (7.3) has a unique solution, and the result follows. ■

Proof. of Lemma 2: (Based on Stahl, 1989) Consider a candidate tier-2 supplier who faces the mixed strategy $f(p)$ from its opponent. The profits from a choice of price p to this supplier can be reduced to

$$\pi(p) = \left(\mu \left[1 - F(p) \right] + \frac{1-\mu}{2} \right) p. \tag{7.4}$$

Substituting $p = r_P$ into (7.4) yields

$$\pi(r_P) = \frac{1-\mu}{2} r_P. \tag{7.5}$$

The tier-2 supplier must make the same expected profit from each price in the support of their mixed strategy $p \in [r_0, r_P]$. Substituting (7.5) into (7.4) yields

$$\left(\mu \left[1 - F^*(p) \right] + \frac{1-\mu}{2} \right) p = \frac{1-\mu}{2} r_P, \tag{7.6}$$

which yields

$$F^*(p) = 1 - \left(\frac{1-\mu}{2\mu} \right) \left(\frac{r_P}{p} - 1 \right), \tag{7.7}$$

and therefore,

$$f^*(p) = \frac{dF^*(p)}{dp} = \left(\frac{1-\mu}{2\mu} \right) \frac{r_P}{p^2}. \tag{7.8}$$

Using the fact that $F(r_0) = 0$ in (7.7) yields

$$r_0 = \left[\frac{1-\mu}{1+\mu} \right] r_P \tag{7.9}$$

From equation 3.1 we have $c_P = \int_{r_0}^{r_P} F^*(p) dp$. Substituting $F^*(p) = 1 - \left(\frac{1-\mu}{2\mu} \right) \left(\frac{r_P}{p} - 1 \right)$ from equation 7.7, we have

$$c_P = r_P \left[1 - \left(\frac{1-\mu}{2\mu} \right) \log \left(\frac{1+\mu}{1-\mu} \right) \right] \tag{7.10}$$

, which completes the proof. ■

Proof. of Proposition 1: Given a fixed r_A, since π is fixed, the buyer's problem is equivalent to:

$$\min_{w(.,r_A)} \left([2-F(r_A)] \int_{r_0}^{r_A} f^*(p)[p+w(p,r_A)]dp + \int_{r_A}^{r_P} 2f^*(p)[1-F^*(p)][p+w(p,r_A)]dp \right) \tag{7.11}$$

subject to :

$$[IR] : \quad [2-F(r_A)] \int_{r_0}^{r_A} f^*(p)u(w(p,r_A))dp + \int_{r_A}^{r_P} 2f^*(p))[1-F^*(p)]u(w(p,r_A))dp - c_A[1-F^*(r_A)] \geq \underline{u} \tag{7.12}$$

$$[IC] : \quad \int_{r_0}^{r_A} [u(w(p)) - u(w(p,r_A))].f^*(p)dp \geq c_A \tag{7.13}$$

The Lagrangian for this problem is:

$$\begin{aligned} L(\lambda_1, \lambda_2, w(., r_A)) &= \left([2-F(r_A)] \int_{r_0}^{r_A} f^*(p)[p+w(p,r_A)]dp + \int_{r_A}^{r_P} 2f^*(p)[1-F^*(p)][p+w(p,r_A)]dp \right) \\ &+\lambda_1 \left(\begin{array}{c} [2-F(r_A)] \int_{r_0}^{r_A} f^*(p)u(w(p,r_A))dp \\ + \int_{r_A}^{r_P} 2f^*(p))[1-F^*(p)]u(w(p,r_A))dp - c_A[1-F^*(r_A)] - \underline{u} \end{array} \right) \\ &+\lambda_2 \left(\int_{r_0}^{r_A} [u(w(p)) - u(w(p,r_A))].f^*(p)dp - c_A \right) \end{aligned} \tag{7.14}$$

Optimizing pointwise for $w(.,r_A)$ in the intervals $[r_0, r_A]$ and $[r_A, r_P]$ respectively yields first-order conditions that simplify to:

$$\frac{\partial L}{\partial w} = 0 : \frac{1}{u_1(w(p))} = \lambda_1 + \frac{\lambda_2}{2-F(r_A)} \text{ for } p \in [r_0, r_A] \tag{7.15}$$

and

$$\frac{\partial L}{\partial w} = 0 : \frac{1}{u_1(w(p))} = \lambda_1 \text{for } p \in [r_A, r_P] \tag{7.16}$$

Therefore, $w(p)$ is a constant value $w^H(r_A)$ in $[r_0, r_A]$, and a different constant value $w^L(r_A)$ in $[r_A, r_P]$. Since $u_{11}(x) < 0$, it follows that $w^H(r_A) > w^L(r_A)$. Using the first-order conditions $\frac{\partial L}{\partial \lambda_1} = 0$ and $\frac{\partial L}{\partial \lambda_2} = 0$ (that is, using the fact that the conditions IC and IR will bind), and simplifying yields the functional forms for $w^H(r_A)$ and $w^L(r_A)$. ■

Proof. of Proposition 2: (a) Assume the converse – that is, when $c_A = c_P$, the cost of outsourcing is less than the cost of insourcing. Suppose now that the buyer insources and uses exactly the same search strategy as prescribed to the tier-1 supplier by the optimal bilateral contract (a cutoff of r_A^*). This would lead to exactly the same ex-ante expected search costs (since

$c_A = c_P$), and the same ex-ante expected commodity price (since the search strategy is identical). This would also lead to costs that were weakly higher than the buyer's optimal insourcing search strategy. The fact that the cost of outsourcing is less than the costs of this optimal insourcing strategy imply that ex-ante expected wages are negative, which contradicts the fact that $\underline{u} > 0$.

(b) The buyer chooses the stopping rule r_A that maximizes the objective function:

$$\begin{aligned}\Pi(r_A) &= \pi - \{[2 - F^*(r_A)]F^*(r_A)w^H(r_A) + [1 - F^*(r_A)]^2 w^L(r_A) \qquad (7.17)\\ &\qquad + [2 - F^*(r_A)] \int_{r_0}^{r_A} pf^*(p)dp + 2\int_{r_A}^{r_P} pf^*(p)[1 - F^*(p)]dp\}.\end{aligned}$$

Simplifying $\frac{d\Pi(r_A)}{dr_A} = 0$ yields the following first-order necessary condition for this problem:

$$2f^*(r_A^*)[1 - F^*(r_A^*)][w^H(r_A^*) - w^L(r_A^*)] + f^*(r_A^*)\left(r_A^* F(r_A^*) - \int_{r_0}^{r_A^*} pf^*(p)dp\right) \qquad (7.18)$$

$$= -F^*(r_A^*)[2 - F^*(r_A^*)]w_1^H(r_A^*). \qquad (7.19)$$

Now, from Proposition 1, we know that:

$$u(w^H(r_A^*)) = \underline{u} + c_A \frac{1 - F^*(r_A^*)}{F^*(r_A^*)}. \qquad (7.20)$$

Differentiating both sides of (7.20) with respect to r_A and rearranging yields:

$$w_1^H(r_A^*) = -\frac{c_A f^*(r_A^*)}{[u_1(w^H(r_A^*))][F^*(r_A^*)]^2}. \qquad (7.21)$$

Also, integration by parts yields the identity:

$$r_A^* F(r_A^*) - \int_{r_0}^{r_A^*} pf^*(p)dp = \int_{r_0}^{r_A^*} F^*(p)dp. \qquad (7.22)$$

Furthermore, the optimal choice cutoff r_A^* should be such that having found a price r_A^*, the expected reduction in commodity price from a second search by the agent must exactly balance the increase in wages that this search entails, or

$$\int_{r_0}^{r_A^*} F^*(p)dp = \left(\int_{r_0}^{r_A^*} w^H(r_A^*)f^*(p)dp + \int_{r_A^*}^{r_P} w^L(r_A^*)f^*(p)dp\right) - w^L(r_A^*), \qquad (7.23)$$

which implies that:

$$[w^H(r_A^*) - w^L(r_A^*)] = \frac{1}{[F(r_A^*)]} \int_{r_0}^{r_A^*} F^*(p)dp. \qquad (7.24)$$

Substituting the expressions for $w_1^H(r_A^*)$ from (7.20), $r_A^* F(r_A^*) - \int_{r_0}^{r_A^*} pf^*(p)dp$ from (7.22) and

$[w^H(r_A^*) - w^L(r_A^*)]$ from (7.24) into (7.18) and rearranging terms yields the simplified first-order condition:

$$\frac{[2 - F^*(r_A^*)]}{[F(r_A^*)]} \int_{r_0}^{r_A^*} F^*(p)dp = \frac{[2 - F^*(r_A^*)]}{[F(r_A^*)]} \frac{c_A}{u_1(w^H(r_A^*))}, \tag{7.25}$$

which in turn implies that

$$c_A = u_1(w^H(r_A^*)) \int_{r_0}^{r_A^*} F^*(p)dp. \tag{7.26}$$

Differentiating both sides of (7.26) with respect to c_A and rearranging yields:

$$\frac{dr_A^*}{dc_A} = \frac{1}{u_{11}(w^H(r_A^*))w_1^H((r_A^*) \int_{r_0}^{r_A^*} F^*(p)dp + u_1(w^H(r_A^*))F^*(r_A)}. \tag{7.27}$$

Since $u_1(x) > 0$, $u_{11}(x) < 0$, and $w_1^H(r_A) < 0$ from (7.21), the RHS of (7.27) is strictly positive, and therefore, $\frac{dr_A^*}{dc_A} > 0$.

Now, using (7.24) and (3.1), and regrouping terms in the integrals, (7.17) reduces to:

$$K(r_A^*) = r_P - \int_{r_A^*}^{r_P} \left(2F^*(p) - [F(p)]^2\right) dp + w^L(r_A^*), \tag{7.28}$$

and it is straightforward to verify that $K(r_A)$ is strictly increasing in r_A^*. Since $\frac{dr_A^*}{dc_A} > 0$, the result follows. ■

Proof. of Proposition 3: This follows directly from Proposition 2(a).

■

The proof of Proposition 4 uses the following lemma, which is proved in the extended appendix.

Lemma 3. *Denote the set of values (c_P, c_A) for which the buyer is indifferent between outsourcing and insourcing. If one expresses this locus a a function c_A of c_P, then this function is strictly convex, or* $\frac{d^2c_A}{dc_P^2} > 0$

Proof. of Proposition 4: Lemma 3 implies that a straight line from the origin to (c_A, c_P)on the locus intersects the locus at exactly one point, this one, and since the locus is convex, the result follows. ■

Proof. of Proposition 5: Assume the converse. Therefore, there exists $\tau > 0$ such that (c_P^*, c_A^*) lies on the locus, while $(c_P^* - \tau, c_A^* - \tau)$ lies above the locus. This implies that $\frac{dc_A}{dc_P} > 1$ at (c_P^*, c_A^*), and from Lemma 3, this implies that $\frac{dc_A}{dc_P} > 1$ for each $c_P > c_P^*$, which in turn means that at some point, $c_P = c_A$ on the locus, contradicting Proposition 2(a). The result follows. ■

8. Appendix B: Extended Appendix

Formulating the buyer's contracting problem

Let the first price observed by the tier-1 supplier be p_1. If she decides to search again the second price observed is p_2. The final price chosen is $\min[p_1, p_2]$. When the tier-1 supplier searches once, she could encounter either of the two tier-2 suppliers with equal likelihood. In either case, the tier-2 supplier could have a price $p_1 < r_A$ with probability $F(r_A)$, in which case the tier-1 supplier stops searching. Or the tier-2 supplier could have a price $p_1 > r_A$ with a probability $[1 - F(r_A)]$, in which case the tier-1 supplier must sample the second tier-2 supplier, and incur a search cost c_A. Now the second tier-2 supplier could offer a price $p_2 < r_A$, in which case the tier-1 supplier chooses her offer. Or the second tier-2 supplier could offer a price $p_2 > r_A$, in which case the tier-1 supplier selects $\min[p_1, p_2]$. These possible outcomes are summarized in Figure B.1.

Under outcome (A) the ex-ante expected payment from the tier-1 supplier to the tier-2 supplier is $\int_{r_0}^{r_A} pf^*(p)dp$. Therefore the expected payment from the buyer to the tier-1 supplier is $\frac{1}{2}\int_{r_0}^{r_A} f^*(p)[p+w(p)]dp$. Similarly, the buyer's expected payment to the tier-1 supplier under outcome (B) is $\frac{1}{2}[1-F^*(r_A; c_P)]\int_{r_0}^{r_A} f^*(p)[p+w(p)]dp$ and under outcome (C) or (D) is $\frac{1}{2}\int_{r_A}^{r_P} f^*(p)[1-F^*(r_A)][p+w(p)]dp$. The expected costs of outcomes (C) and (D) are identical. There are corresponding outcomes (E) through (H) on the other side of the tree (indicated by dotted lines). Summing over each of these eight outcomes yields the expected cost

$$[2 - F^*(r_A)]\int_{r_0}^{r_A} f^*(p)[p + w(p)]dp + 2\int_{r_A}^{r_P} f^*(p)[1 - F^*(p)][p + w(p)]dp,$$

which when subtracted from the price π yields the buyer's objective function. Correspondingly, under each outcome of figure B.1, the tier-1 supplier receives a wage $w(p)$ which yields utility $u(w(p))$. Calculating expected value over each outcome, and taking into account that a search cost of zero is incurred in outcome (A) because the first search is costless, and a search cost c_A in outcomes (B), (C) and (D), yields the tier-1 supplier's expected payoff:

$$[2 - F(r_A)]\int_{r_0}^{r_A} f^*(p)u(w(p))dp + \int_{r_A}^{r_P} 2f^*(p))[1 - F^*(p)]u(w(p))dp - c_A[1 - F^*(r_A)],$$

which must be greater than or equal to the tier-1 supplier's reservation utility $\underline{u}$.

Proof. of Lemma 3: From (7.28), the locus of all values (c_P, c_A) such that the buyer is

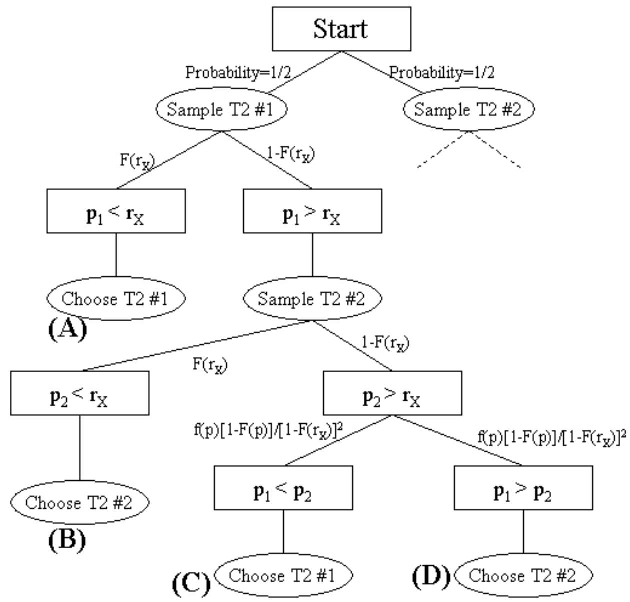

Figure 8.1: Partial tree of outcomes when the tier-1 supplier searches.

indifferent between making the part in-house and outsourcing it, is given by the equation:

$$r_P - c_P = r_P - \int_{r_A^*}^{r_P} \left(2F^*(p) - [F(p)]^2\right) dp + w^L(r_A^*) \tag{8.1}$$

or by

$$c_P = \int_{r_A^*}^{r_P} \left(2F^*(p) - [F(p)]^2\right) dp - w^L(r_A^*) \tag{8.2}$$

The slope of the locus is simply

$$\frac{dc_A}{dc_P} = -\frac{\partial G/\partial c_P}{\partial G/\partial c_A} \tag{8.3}$$

where

$$G \equiv c_P - \int_{r_A^*}^{r_P} \left(2F^*(p) - [F(p)]^2\right) dp + w^L(r_A^*) \tag{8.4}$$

In what follows, we denote $\frac{\partial G}{\partial c_P} = G_{c_P}, \frac{\partial G}{\partial c_A} = G_{c_A}, \frac{\partial^2 G}{\partial c_P^2} = G_{c_p,c_p}, \frac{\partial^2 G}{\partial c_A^2} = G_{c_A,c_A}, \frac{\partial^2 G}{\partial c_A \partial c_P} = G_{c_A,c_P}$.First, we show that $-_{c_P} > 0G$. Differentiating both sides of (8.4) with respect to c_P and using (3.10) and (3.4) to simplify yields:,

$$-G_{c_P} = -1 + \frac{1}{\mu} - \frac{(1-\mu)^2}{2\mu^3}\left(\frac{r_P}{r_A} - 1 - \log\frac{r_P}{r_A}\right) \tag{8.5}$$

It can be verified that the expression $(\frac{r_P}{r_A} - 1 - \log\frac{r_P}{r_A})$ is increasing in $\frac{r_P}{r_A} - 1$. Since $\left(\frac{r_P}{r_A} - 1\right)_{MAX}$

$= \left(\frac{r_P}{r_A} - 1\right)_{r_A = r_0} = \frac{r_P}{r_0} - 1 = \frac{1+\mu}{1-\mu} - 1 = \frac{2\mu}{1-\mu}$, we have $(\frac{r_P}{r_A} - 1 - \log\frac{r_P}{r_A})_{MAX} = \frac{2\mu}{1-\mu} - \log(\frac{1+\mu}{1-\mu}) = \frac{2\mu}{1-\mu} - (2\mu + \frac{2}{3}\mu^3 + \frac{2}{5}\mu^5 + ...) \simeq \frac{2\mu^2}{1-\mu} - (\frac{2}{3}\mu^3 + \frac{2}{5}\mu^5 + ...)$, and so $-\frac{\partial G}{\partial c_P} = -1 + \frac{1}{\mu} - \frac{(1-\mu)^2}{2\mu^3}(\frac{2\mu^2}{1-\mu} - (\frac{2}{3}\mu^3 + \frac{2}{5}\mu^5 + ...)) = -1 + \frac{1}{\mu} - \frac{1-\mu}{\mu} + \frac{2}{3}\mu^3 + \frac{2}{5}\mu^5 + ... = \frac{2}{3}\mu^3 + \frac{2}{5}\mu^5 + ... > 0$.

Next, we show that $G_{c_A} > 0$, as follows:

$$\begin{aligned}\frac{\partial G}{\partial c_A} &= -\frac{\partial(\int_{r_A^*}^{r_P}\left(2F^*(p) - [F(p)]^2\right)dp)}{\partial c_A} - \frac{\partial(u^{-1}(\underline{u} - c_A))}{\partial c_A} \\ &= \frac{\partial r_A^*}{\partial c_A}(2F(r_A^*) - (F(r_A^*))^2) + \frac{1}{u_1^L},\end{aligned}$$

where $u^L = u(w^L(r_A^*))$, i.e. wages paid when outcome is a higher-than-optimal-cutoff (r_A^*) price for the raw material, and the subscript of u_1^L refers to the first derivative. Now, $\frac{\partial r_A^*}{\partial c_A} = \frac{-\partial H/\partial c_A}{\partial H/\partial r_A^*}$, where $H \equiv (w^H - w^L)F(r_A^*) - \int_{r_0}^{r_a^*} F(p)dp$, the condition for optimal r_A^* from equation 7.24. $\frac{\partial H}{\partial c_A} = F(r_A^*)\left(\frac{1-F(r_A^*)}{F(r_A^*)}\frac{1}{u_1^H} + \frac{1}{u_1^L}\right)$, where $u^H = u(w^H(r_A^*))$, i.e. the wages paid when outcome is a lower-than-optimal-cutoff (r_A^*) price for the raw material, and the subscript of u_1^L refers to the first derivative. $\frac{\partial H}{\partial r_A^*} = \frac{1}{u_1^H}\left(\frac{-c_A f(r_A^*)}{(F(r_A^*))^2}\right)F(r_A^*) + (w^H - w^L)f(r_A^*) - F(r_A^*)$. Since $(w^H - w^L)F(r_A^*) = \int_{r_0}^{r_a^*} F(p)dp$ (from equation 7.24) and $c_A = u_1(w^H(r_A^*))\int_{r_0}^{r_A^*} F^*(p)dp$ (from equation 7.26), we have $\frac{\partial H}{\partial r_A^*} = -F(r_A^*)$, and

$$\frac{\partial r_A^*}{\partial c_A} = \frac{-\partial H/\partial c_A}{\partial H/\partial r_A^*} = \frac{1-F(r_A^*)}{F(r_A^*)}\frac{1}{u_1^H} + \frac{1}{u_1^L} \tag{8.6}$$

and $\frac{\partial G}{\partial c_A} = \frac{\partial r_A^*}{\partial c_A}(2F(r_A^*) - (F(r_A^*))^2) + \frac{1}{u_1^L} = (\frac{1-F(r_A^*)}{F(r_A^*)}\frac{1}{u_1^H} + \frac{1}{u_1^L})(2F(r_A^*) - (F(r_A^*))^2) + \frac{1}{u_1^L}$. Since $\frac{1}{u_1^H} = \lambda_1 + \frac{\lambda_2}{2-F(r_A)}$ (from equation 7.15) and $\frac{1}{u_1^L} = \lambda_1$ (from equation 7.16), we have

$$G_{c_A} = (1 - F(r_A^*))(\lambda_1 + \lambda_2) \tag{8.7}$$

Therefore,

$$\frac{dc_A}{dc_P} = -\frac{G_{c_P}}{G_{c_A}} = \frac{-1 + \frac{1}{\mu} - \frac{(1-\mu)^2}{2\mu^3}(\frac{r_P}{r_A} - 1 - \log\frac{r_P}{r_A})}{(1 - F(r_A^*))(\lambda_1 + \lambda_2)} \tag{8.8}$$

Denoting $\frac{\partial G}{\partial c_P} = G_{c_P}, \frac{\partial G}{\partial c_A} = G_{c_A}, \frac{\partial^2 G}{\partial c_P^2} = G_{c_p,c_p}, \frac{\partial^2 G}{\partial c_A^2} = G_{c_A,c_A}, \frac{\partial^2 G}{\partial c_A \partial c_P} = G_{c_A,c_P}$, we have

$$\frac{d^2 c_A}{dc_P^2} = \frac{2G_{c_P}G_{c_A c_P} - G_{c_A}G_{c_P,c_P} - (G_{c_P})^2\left(\frac{G_{c_A,c_A}}{G_{c_A}}\right)}{G_{c_A}^2} \tag{8.9}$$

$$G_{c_P c_P} = \frac{\partial G_{c_P}}{\partial c_P} = \frac{\partial(1 - \frac{1}{\mu} + \frac{(1-\mu)^2}{2\mu^3}(\frac{r_P}{r_A} - 1 - \log\frac{r_P}{r_A}))}{\partial c_P} = \frac{(1-\mu)^2}{2\mu^3}(\frac{1}{r_A} - \frac{1}{r_P})\frac{\partial r_P}{\partial c_P}.$$

Since $c_P = r_P \left[1 - \left(\frac{1-\mu}{2\mu}\right) \log\left(\frac{1+\mu}{1-\mu}\right)\right]$ from equation 3.4, we have $\frac{\partial r_P}{\partial c_P} \simeq \frac{1}{\mu}$, and

$$G_{c_A c_P} = \frac{(1-\mu)^2}{2\mu^4}\left(\frac{1}{r_A} - \frac{1}{r_P}\right) \tag{8.10}$$

$G_{c_A c_P} = \frac{\partial G_{c_P}}{\partial c_A} = \frac{\partial(1-\frac{1}{\mu}+\frac{(1-\mu)^2}{2\mu^3}(\frac{r_P}{r_A}-1-\log\frac{r_P}{r_A}))}{\partial c_A} = \frac{(1-\mu)^2}{2\mu^3}(-\frac{\partial r_A^*}{\partial c_A}\frac{r_P}{(r_A^*)^2} + \frac{1}{r_A^*}\frac{\partial r_A^*}{\partial c_A}) < 0$ since $r_A^* < r_P$. Substituting for $\frac{\partial r_A^*}{\partial c_A}$ from equation 8.6 and simplifying,

$$G_{c_A c_P} = \frac{(1-\mu)^2}{2\mu^3}\left(\frac{1-F(r_A^*)}{F(r_A^*)}\frac{1}{u_1^H} + \frac{1}{u_1^L}\right)\frac{1}{(r_A^*)^2}(r_A^* - r_P) \tag{8.11}$$

$G_{c_A c_A} = \frac{\partial G_{c_A}}{\partial c_A} = \frac{\partial((1-F(r_A^*))(\lambda_1+\lambda_2))}{\partial c_A} = -f(r_A^*)\frac{\partial r_A^*}{\partial c_A}(\lambda_1+\lambda_2)$. Substituting for $\frac{\partial r_A^*}{\partial c_A}$ from equation 8.6, and for $\lambda_1+\lambda_2$ from equations 7.15 and 7.16, and simplifying,

$$G_{c_A c_A} = -f(r_A^*)\left(\frac{1-F(r_A^*)}{F(r_A^*)}\frac{1}{u_1^H} + \frac{1}{u_1^L}\right)\left(\frac{1}{u_1^L} + (2-F(r_A^*))\left(\frac{1}{u_1^H} - \frac{1}{u_1^L}\right)\right) \tag{8.12}$$

To show that $\frac{d^2 c_A}{dc_P^2} > 0$ is equivalent to showing that $2G_{c_P}G_{c_A c_P} - G_{c_A}G_{c_P,c_P} + (G_{c_P})^2\left(\frac{G_{c_A,c_A}}{G_{c_A}}\right)$ is positive, from equation 8.9. The first term may be re-written as $2(-G_{c_P})(-G_{c_A c_P})$ where $-G_{c_P} > 0$ (see discussion following equation **??**), and $-G_{c_A c_P} > 0$. Because $-G_{c_P} = -1 + \frac{1}{\mu} - \frac{(1-\mu)^2}{2\mu^3}(\frac{r_P}{r_A} - 1 - \log\frac{r_P}{r_A})$, it is sufficient to define $-G^o_{c_P} = -1 + \frac{1}{\mu} - \frac{(1-\mu)^2}{2\mu^3}(\frac{r_P}{r_A} - 1)$ and show that $2G^o_{c_P}G_{c_A c_P} - G_{c_A}G_{c_P,c_P} + (G_{c_P})^2\left(\frac{G_{c_A,c_A}}{G_{c_A}}\right)$ is positive. (Removing the $\log\frac{r_P}{r_A}$ term makes the computation easier.) Expanding the term $2G^o_{c_P}G_{c_A c_P} - G_{c_A}G_{c_P,c_P} + (G_{c_P})^2\left(\frac{G_{c_A,c_A}}{G_{c_A}}\right)$ yields the expression: $\frac{(-1+\mu)^2\,(A+B+C)}{8\,\mu^6\,{r_A}^3\,(r_A-r_P)}$, where $v_H = \frac{1}{u_1^H}$ and $v_L = \frac{1}{u_1^L}$, and

$A = \frac{(-1+\mu)\,(r_A-r_P)^3\,((1-\mu)\,r_P\,(v_H-v_L)+r_A\,((-1+3\,\mu)\,v_H-(-1+\mu)\,v_L))}{r_P}$

$B = \frac{2\,r_P\,\left(\left(1-\mu+2\,\mu^2\right)r_A+(-1+\mu)\,r_P\right)^2((-1+\mu)\,r_P\,(v_H-v_L)-r_A\,((-1+\mu)\,v_H+(1+\mu)\,v_L))}{(1+\mu)\,r_A+(-1+\mu)\,r_P}$

$C = \frac{4\,(-1+\mu)\,(r_A-r_P)^2\left(\left(1-\mu+2\,\mu^2\right)r_A+(-1+\mu)\,r_P\right)((1-\mu)\,r_P\,(v_H-v_L)+r_A\,((-1+\mu)\,v_H+(1+\mu)\,v_L))}{(1+\mu)\,r_A+(-1+\mu)\,r_P}$

Because $(r_A - r_P) < 0$, the task is to show that $(A+B+C)$ is negative. The denominator of the common term that represents the sum $(A+B+C)$ is

$(1+\mu)\,r_A - (1-\mu)\,r_P = (1-\mu)\left[\frac{(1+\mu)}{(1-\mu)}r_A - r_P\right] = (1-\mu)\left[\frac{r_P}{r_0}r_A - r_P\right] > 0$ since $r_A > r_0$. Therefore the task reduces to proving that the numerator of the common term that represents the sum $(A+B+C)$ is negative. This numerator is given by:

$-\left[(-1+\mu)^3\,{r_P}^5\,(v_H - v_L)\right]$

$+\left[(-1+\mu)^2\,r_A\,{r_P}^4\,(5\,(-1+\mu)\,v_H + (5-3\,\mu)\,v_L)\right]$

$+\left[\left(-1+\mu^2\right)\,{r_A}^5\,((-1+3\,\mu)\,v_H - (-1+\mu)\,v_L)\right]$

$+\left[(-1+\mu)\,{r_A}^4\,r_P\,((1+\mu\,(-2+\mu\,(-19+8\,\mu)))\,v_H + (-1+\mu\,(2+\mu\,(7+8\,\mu)))\,v_L)\right]$

$+\left[4\,{r_A}^2\,{r_P}^3\,\left(\left(2+\mu\,\left(-6+\mu\,\left(9-7\,\mu+2\,\mu^3\right)\right)\right)v_H - 2\left(1+\mu\left(-2+\mu\left(2-2\,\mu+\mu^3\right)\right)\right)v_L\right)\right]$

$$-\left[4\,{r_A}^3\,{r_P}^2\,\left(\begin{array}{c}(-1+\mu)\,(-1+2\,(-1+\mu)\,\mu\,(-1+\mu\,(3+\mu)))\,v_H\\ +(-1+\mu\,(1+\mu\,(-3+\mu\,(3+2\,\mu\,(1+\mu)))))\,v_L\end{array}\right)\right]$$

which, after suppressing terms with μ^2 and higher powers of μ, simplifies to:

$-\left((r_A-r_P)^2\,\left({r_A}^2+2\,r_A\,r_P-{r_P}^2\right)\,((-1+3\,\mu)\,(r_A-r_P)\,v_H-((-1+\mu)\,r_A+(1-3\,\mu)\,r_P)\,v_L)\right)$

Because $(r_A-r_P)^2>0$, the task reduces to proving that

$\left({r_A}^2+2\,r_A\,r_P-{r_P}^2\right)\,((-1+3\,\mu)\,(r_A-r_P)\,v_H-((-1+\mu)\,r_A+(1-3\,\mu)\,r_P)\,v_L)>0.$

This expression can be re-arranged as:

$r_P^2\left(\left(1+\frac{r_A}{r_P}\right)^2-2\right)[\,(1-3\,\mu)\,(r_P-r_A)\,(v_H-v_L)+2\,\mu\,r_A\,v_L]$

Since $r_P>r_A$, and by assumption, $\mu<\frac{1}{3}$, we have

$[\,(1-3\,\mu)\,(r_P-r_A)\,(v_H-v_L)+2\,\mu\,r_A\,v_L]>0$

Further, the least value that $\left(1+\frac{r_A}{r_P}\right)^2$ can take is when $r_A=r_0$, which implies that

$$\begin{aligned}\left[\left(1+\frac{r_A}{r_P}\right)^2-2\right]_{MIN} &= \left[\left(1+\frac{r_0}{r_P}\right)^2-2\right]\\ &= \left[\left(1+\frac{1-\mu}{1+\mu}\right)^2-2\right]\\ &= \left[\frac{4}{(1+\mu)^2}-2\right]>0\forall\mu<\sqrt{2}-1.\end{aligned}$$

Hence $\left[\left(1+\frac{r_A}{r_P}\right)^2-2\right]>0$ for each r_A, r_P, and

$$r_P^2\left(\left(1+\frac{r_A}{r_P}\right)^2-2\right)[\,(1-3\,\mu)\,(r_P-r_A)\,(v_H-v_L)+2\,\mu\,r_A\,v_L]>0, \tag{8.13}$$

which completes the proof.. ■