

Make and Buy: Outsourcing, Vertical Integration, and Cost Reduction*

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Abstract

Globalization helped reshape supply chains and the boundaries of firms in favor of outsourcing. Now, even vertically integrated firms procure substantially from external suppliers. We study a procurement model in which vertical integration grants a downstream customer the *option* to source internally, which is advantageous because it sometimes avoids paying a markup, but disadvantageous because it discourages investments in cost reductions by independent suppliers. The trade-off is a solution to Williamson’s puzzle of selective intervention; the integrated firm can do the same as the two stand-alone entities, and can sometimes do better by intervening selectively, but this ability to do better discourages cost-reduction by independent suppliers. The investment-discouragement effect is more likely to outweigh the markup-avoidance benefits of vertical integration if the upstream market is more competitive, as is so in a more global economy.

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1 Introduction

A dramatic transformation of American manufacturing occurred at the end of the twentieth century, away from vertical integration and toward outsourcing (Whitford, 2005). By the 1990's, outsourcing was widespread, to the point that even vertically integrated firms relied heavily on independent suppliers (Atalay, Hortacsu, and Syverson, 2014). This transformation increasingly went hand in hand with offshoring, as foreign outsourcing increased from 15% in 1997 to 23% in 2007, even though the outsourced share of material expenditures remained around 75% (Magyari, 2016). The rise of outsourcing and the trend toward offshoring gives renewed salience to the puzzle of selective intervention posed by Williamson (1985): Why can't a merged firm do everything that two separate firms can do, and do strictly better by intervening selectively?

The recent evidence suggests the wide prevalence of a "make and buy" sourcing strategy, that is, an integrated firm's reliance both on internal and external procurement of material inputs. For example, Atalay, Hortacsu, and Syverson (2014) show that about 50% of vertically integrated U.S. manufacturing firms don't source from their upstream unit. Magyari (2016) shows that the frequency of make-and-buy within industrial categories for representative U.S. manufacturing firms was above 40% between 1997 and 2007, and above 70% in the transportation equipment sector. These facts suggest that vertical integration creates the opportunity but not the necessity to procure internally.

Accounting for a make-and-buy sourcing strategy requires embedding vertical integration in a multi-lateral supply setting. We build a procurement model that gives a vertical integrated firm the option to source internally or from an independent supplier, with its choice depending on which is more cost effective. The advantage of vertical integration is that the ability to source internally avoids paying a markup to independent suppliers. The disadvantage is that a sourcing distortion in favor of internal supply discourages the independent suppliers from non-contractible investments in cost reduction. This tradeoff between markup avoidance and investment discouragement answers Williamson's puzzle of selective intervention. At the same time, multi-lateral settings generate make-and-buy behavior by integrated firms.

The general procurement environment we have in mind is motivated by Whitford (2005)'s description of customer-supplier relationships that shifted and blurred the boundaries of firms, as original equipment manufacturers increasingly relied on independent suppliers for both production and design of specialized parts. In our model, a "customer" seeks to commercialize a new product, or to improve (or expand distribution of) an existing one in a downstream market for which the design of a specialized input or process potentially has significant cost consequences. The customer has access to a group of qualified suppliers with different ideas and capabilities, who invest in product and process design to prepare proposals for supplying the input. The customer selects the most attractive supply source, and a vertically integrated customer has the option to source internally if its production cost is below the price of external procurement.

Automobile manufacturing is a good example of this kind of procurement environment. A typical procurement cycle for a new automobile model includes a development phase during which blueprints are created, followed by production phase based on fixed blueprints for component inputs. Importantly, independent suppliers' design investments are not contractible during the development phase, even though input specifications are contractible at the production phase. Calzolari, Felli, Koenen, Spagnolo, and Stahl (2015, pp. 22-23) elaborate as follows:

In series production, suppliers work with existing blueprints and completely designed (or existing) tools to produce the part in question. The product and services can be clearly specified through contracts, determining in detail, for example, acceptable failure rates and delivery conditions. None of this is possible in the model-specific development phase. While the desired functionality of a part can be described, highly complex interfaces with other parts (often under development simultaneously) cannot be specified *ex ante*. Blueprints for the part do not exist at the beginning of the design phase; indeed they are the outcome of such a phase.

Our model captures this contracting dichotomy between design and production by assuming potential input suppliers invest unobservable effort to develop and propose acceptable cost-reducing designs to meet an input requirement of a customer, and, as a result of this design effort, the supplier gains private information about the cost of producing the input according to those particular specifications.¹ For simplicity, the model assumes that all acceptable proposed designs have the same functionality, thus abstracting from the possibility that design efforts result in observable quality differences.

The model reveals the following benefits and costs of vertical integration. On the one hand, there are rent seeking and possible efficiency advantages of internal sourcing from avoiding a markup otherwise paid to independent suppliers. Markup avoidance shifts rents away from lower-cost independent suppliers by distorting the sourcing decision, and may also increase efficiency because the project is pursued whenever its value exceeds the cost of internal sourcing. On the other hand, vertical integration has a disadvantageous "discouragement effect" on the investment incentives of the independent suppliers. Because the procurement process is tilted in favor of internal sourcing, independent suppliers are less inclined to make cost-reducing investments in the preparation of proposals. Furthermore, it is socially costly for the integrated firm to compensate for discouragement effect by increasing its own *ex ante* investment, and, if the cost of the investment discouragement effect outweighs the benefit of markup avoidance advantages, then the customer has reason to divest its internal supply division as a way to commit to a level playing field.

¹Our model is also relevant for an array of other applications. For example, the customer could be PepsiCo, who required a special sort of potatoes as input for its expanding potato chip business in China, and had the option of integrating with local producers or of sourcing externally from independent suppliers (Tap, Lu, and Loo, 2008). Alternatively, the customer could be AT&T, who needed to procure telecommunications equipment from an upstream industry, including Ericsson and Nortel, as well Lucent which AT&T originally owned but eventually divested (Lazonick and March, 2011).

We use a specific basic model to weigh these tradeoffs of vertical integration. There is a buyer who procures a fixed input from a set of upstream suppliers via a tender. Prior to the tender, all suppliers make cost-reducing investments that shift the support of the distribution from which costs are drawn. Absent integration, all suppliers then bid in a first-price auction, and the buyer selects the supplier with the lowest bid. For tractability, the basic model assumes inelastic demand, a quadratic cost of investment, and an exponential distribution of production costs. Under vertical integration, the buyer and one of the suppliers are under common ownership. The tender is still a first-price reverse auction, but now the integrated supplier is preferred supplier, producing whenever cost of internal supply is less than the lowest bid from the remaining independent suppliers. Otherwise, the integrated customer sources from the independent supplier with the lowest bid.

Keeping investments fixed, vertical integration is always profitable as it allows the buyer to shift rents from independent suppliers by avoiding to pay the bid markup whenever she sources internally. Vertical integration is also detrimental to social welfare in the model with inelastic demand, because the lowest cost supplier does not produce the input when an independent supplier draws the lowest cost but bids above the cost of the integrated supplier. In contrast, in the absence of vertical integration, production is always efficient because the unique equilibrium of the first-price auction is symmetric and monotone. Moreover, as in Rogerson (1992), the socially optimal investments, given that sourcing is efficient, are always an equilibrium outcome with non-integration. Because it distorts the buyer's sourcing decision, vertical integration also moves the incentives to invest in cost reductions away from the social optimum. In equilibrium, the integrated supplier overinvests, while the independent suppliers underinvest, compared to both the first-best social optimum and to a second-best solution to the social planner's problem, which takes sourcing distortions as given and maximizes welfare over investments. Because investment costs are convex, the additional costs that accrue to the integrated firm from this excessive investment in equilibrium can be large enough to outweigh the benefits from integration.

Our theory of make-and-buy sensibly predicts that greater upstream competition disfavors vertical integration. The basic model yields two comparative variants of this hypothesis. First, an increase in the number of symmetric upstream suppliers reduces the rents of the independent sector, making the markup avoidance benefit of vertical integration less compelling. Second, holding the number of suppliers constant, less uncertainty about upstream costs reduces *ex post* supplier heterogeneity, similarly squeezing markups and reducing the rents of independent suppliers. That more outsourcing opportunities encourages vertical divestiture is broadly consistent with hand-in-hand trends toward outsourcing and offshoring. That divestiture is more attractive in a less uncertain environment is consistent with the idea that vertical divestiture occurs in maturing industries in which the prospects for dramatic cost reduction are falling.

Our theory builds on previous literature while differing in significant ways. Vertical integration in our model effectively establishes a preferred supplier, tendering a bid after all independent suppliers have submitted their bids. The allocative distortions from a preferred supplier are similar to those in the first-price auction model of Burguet and

Perry (2009).² However, due to endogenous investments in cost reduction in our model, the preferred supplier in equilibrium has a more favorable cost distribution than the independent suppliers.³

Our emphasis on multilateral supply relationships, and particularly our argument that vertical integration is motivated by rent-seeking, is reminiscent of Bolton and Whinston (1993).⁴ The Bolton-Whinston model assumes an efficient bargaining process under complete information to allocate scarce supplies. Vertical integration creates an “outside option” of the bargaining process that for given investments only influences the division of rents. In contrast, our model features incomplete information about costs, and, for given investments, vertical integration affects the sourcing decision as well as the division of rents. Moreover, in our model the rent-seeking advantage of vertical integration leads to *ex post* sourcing distortions, which in turn distorts *ex ante* investments relative to the first best. In contrast, in the Bolton-Whinston model, the integrated downstream firm overinvests to create a more powerful outside option when bargaining with independent customers, but the *ex post* allocation decision is efficient conditional on investments. Consequently, the two models give rise to starkly different conclusions. For the case that corresponds to the unit-demand model featured in our basic model, Bolton and Whinston (1993) finds that non-integration is never an equilibrium market structure although it is social efficient.⁵

Following Williamson (1985), the property rights literature based on the Grossman and Hart (1986) model typically views vertical integration as a “make or buy” decision in a bilateral setting, focusing on how agency problems inside an integrated firm compare with contracting problems across separate firms.⁶ As Cremer (2010) explains, the key to

²Bikhchandani, Lippmann and Reade (2005) analyze second-price auctions. As Burguet and Perry (2009, p. 284) observe, “a second-price auction is not an appropriate model for a market when the buyer has no ability to design and commit to rules of trade,” while a first-price auction is a natural model for a market in which “suppliers make price offers to the buyer, who then simple decides which offer to take.”

³Burguet and Perry (2009) assumes fixed identical cost distributions. Burguet and Perry (2014), Lee (2008), and Thomas (2011) study the right of first refusal (or vertical merger) in cases of two suppliers with exogenous asymmetric cost distributions, whereas we endogenize the asymmetry with unobservable investments. Bag (1997) and Che, Iossa, and Rey (2015) study the optimal use of favoritism in auction design to incentivize unobservable investments by suppliers, assuming that the buyer can commit to a procurement mechanism prior to investments. In contrast, we assume that a procurement mechanism is not contractible until after relationship-specific investments are sunk, due to an inability sufficiently to describe acceptable designs *ex ante*. Arozamena and Cantillon (2004) study procurement auctions preceded by observable investments, and Tan (1992) compares first-price and second-price procurement auctions preceded by unobservable cost-reducing investments. Neither consider preferred providers.

⁴See Farrell and Katz (2000) for a related model of integration in systems markets. Integration also occurs in a multilateral setting in the models of Riordan (1998) and Loertscher and Reisinger (2014), focusing on possible foreclosure effects of vertical integration.

⁵See Proposition 5.2 in Bolton and Whinston (1993), where $\lambda = 1$ corresponds to our unit demand case.

⁶See Hart (1995) for an overview of the Grossman and Hart (1986) property rights theory of the firm. Antras (2013) surveys how this theory has influenced the International Trade literature on global sourcing by multinational firms. Hart and Moore (1990) provide a multi-lateral generalization of the Grossman and Hart (1986) setup, but like Grossman and Hart (1986) and Bolton and Whinston (1993) maintain the assumption that bargaining is efficient.

these theories is that the “principal does not quit the stage” after vertical integration, meaning that contracts between the owner (principal) and managers are unavoidably incomplete. Thus, anticipating expropriation by an owner who is unable to commit, an employee-manager has lower powered incentives to invest in the relationship than does an independent owner-manager. This approach to understanding vertical integration is most compelling for evaluating incentive tradeoffs surrounding the vertical acquisition of owner-managed firm. As observed by Williamson (1985), however, a tradeoff between vertical integration and arms length contracting is more elusive when a separation of ownership and control prevails irrespective of the identity of the owner.

Our model allows for a separation of ownership and control by interpreting the investment cost function as the cost to a risk-neutral owner of inducing a risk-averse manager to undertake a given level of effort (Grossman and Hart, 1983). Thus, by placing the make-or-buy problem in a multilateral setting, by abstracting from any asymmetry in the agency problems for vertically integrated and independent suppliers, and by distinguishing the vertical integration decision from the sourcing decision (i.e. allowing for “make and buy”), our model identifies a vertical integration tradeoff between markup avoidance and investment discouragement. If, however, the vertical integrated firm had a less favorable investment cost function, perhaps due to more a more severe agency problem inside the firm, then this additional cost of integration would also weigh in the balance.⁷

If the vertically integrated firm simply replicated the way it produced before integrating, the profit of the integrated entity would just equal the joint profit of the two independent firms. However, just like Williamson (1985) argued, it can do strictly better than that because it can now avoid paying the markup for procuring from outside suppliers whenever the cost of internal supply is below the lowest bid of the outside suppliers. In this sense, the vertically integrated firm’s flexibility to change its behavior after integration is to its short-run benefit. This contrasts sharply with the previous literature, where the vertically integrated firm’s inability to commit may render integration unprofitable (Cremer, 2010). But it raises the question why vertical integration would not always be profitable in our model. The answer is that, because the integrated firm favors internal sourcing, the independent suppliers incentives to invest in cost reduction are diminished. This investment discouragement effect can be strong enough to dominate the benefits from vertical integration. It is exactly the opportunistic ability of the vertically integrated firm to do better than it does without integration that ultimately may hinder it from so doing, because this ability changes the investment behavior of the outside suppliers, which is outside the control of the integrated firm. Thus the relative disadvantage of the vertically integrated firm in our model stems not from its inability to make commitments to its managers, but rather its inability to commit not to source internally when it is attractive to do so. This critical assumption makes most sense for procurements environments, like automobile manufacturing, involving compet-

⁷Our model assumes that the expected production cost associated with a firm-specific design is known inside the firm, but is unobserved by outside parties. As discussed by Riordan (1990), such information is proprietary to the firm, and not contractible across firms. The property rights theory provides some foundations for this assumption (Hart 1995, Riordan 1990).

ing complex designs that cannot be described in advance sufficiently to be contractible (Grossman and Hart, 1983), that are not easily comparable, and for which expected production costs are unverifiable. Similarly, the difficulties of describing and verifying efforts and resources spent on superior designs for complex products make *ex ante* investment non contractible.

Our solution to the puzzle of selective intervention might be interpreted as joining the rent-seeking theory of the firm with the property-rights theory (Gibbons, 2005). Emphasizing the standard assumption of efficient *ex post* bargaining in the property rights literature, Gibbons (2005, p. 205) summarizes the difference between the two theories as follows: “[I]n the property rights theory, the integration decision determines *ex ante* investments and hence total surplus, whereas in the rent-seeking theory, the integration decision determines *ex post* haggling and hence total surplus.” Our version of the rent-seeking theory builds on Burguet and Perry (2009) to explain how a preferred integrated supplier creates a sourcing distortion, and hence changes the magnitude of the joint surplus of an upstream industry and a downstream customer.⁸ Our version of the property rights theory builds on Riordan (1990) to explain how inefficient *ex post* sourcing changes *ex ante* investments which also determine the joint surplus.⁹ To our knowledge, our paper is the first to combine these two opposing perspectives in an integrated model of the costs and benefits of vertical integration.

Lastly, the multilateral setting at the heart of our model suggests a formalization of Stigler (1951)’s interpretation of Adam Smith’s dictum that “the extent of the market is limited by the division of labor.” In our setup, if the extent of the market, measured by the number of suppliers, is small, there is a strong incentive for the customer to integrate vertically, and to source internally only when profitable. As the extent of market increases, the incentive for internal sourcing diminishes, and the division of labor, measured by the frequency of outsourcing, increases.

The remainder of our paper is organized as follows. Section 2 lays out the basic

⁸This theory is reminiscent of an older industrial organization literature that focuses on how vertical integration changes the exercise of market power. This literature, surveyed by Perry (1989), has different strands. For example, backward vertical integration is motivated by a downstream firm’s incentive to avoid paying above-cost input prices. In the double markups strand, vertical integration of successive monopolies improves efficiency by reducing the final price to the single monopoly level. In the variable proportions strand, a non-integrated firm inefficiently substitutes away from a monopoly-provided input, and vertical integration corrects this input distortion. In our model, while alternative suppliers offer substitute inputs, there is no input distortion because upstream market power is symmetric.

⁹The property rights literature focuses on how vertical integration matters for relationship specific investments, typically under the assumption of efficient bargaining, which of course implies efficient sourcing *ex post*. Williamson (1985) argues that asset specificity, incomplete contracts, and opportunism conspire to undermine efficient investments. Grossman and Hart (1986) and Hart and Moore (1990) formalize the argument by modeling how asset specificity and incomplete contracting cause a holdup problem that diminishes the investment incentives of the party lacking control rights over productive assets, while Bolton and Whinston (1993) add that vertical integration may cause investment distortions motivated by the pursuit of bargaining advantage. Riordan (1990) argues in a different vein, not assuming efficient bargaining, but still consistent with Cremer (2010)’s interpretation of contemporary theories, that the changed information structure of a vertically integrated firm creates a holdup problem because the owner cannot commit to incentives for the employee-manager. The basic technological assumptions in our model extend those of Riordan (1990) to a multilateral setting.

model of procurement and vertical integration. Section 3 analyzes equilibrium bidding and investment with and without vertical integration, derives a condition for vertical integration to be jointly profitable for an upstream supplier and the downstream customer, performs first- and second- best welfare analyses, and develops intuition for our conclusion that vertical integration is unprofitable if the upstream market is sufficiently competitive. Section 4 analyzes bargaining games that determine the vertical market structure endogenously. Section 5 explores the robustness of the rent-avoidance/investment-discouragement tradeoff by relaxing assumptions and extending the model in various ways: alternative cost distributions, interpreting the cost of investment as an agency cost, elastic demand, reserve prices, and second-price auctions. Section 6 concludes, and proofs are in the Appendix.

2 Basic Model

There is one downstream firm, called the customer, who demands a fixed requirement of a specialized input for a project, and there are n upstream firms, called suppliers, capable of providing possibly different versions of the required input. Each of the suppliers makes a non-contractible investment in designing the input by exerting effort before making a proposal. *Ex ante*, that is, prior to the investment in effort, a supplier's cost of producing the input is uncertain. *Ex post*, that is after the investment, every supplier privately observes his cost realization. More effort shifts the supplier's cost distribution downward in the sense of first-order stochastic dominance, reducing the mean.

In the basic model, we assume that the customer's demand is inelastic. More precisely, we suppose the buyer has a willingness to pay v , and consider the limiting case as v goes to infinity. This implies that in equilibrium the customer buys the input from the cheapest supplier. This formulation captures in the extreme the idea that the likely value of the downstream good is very large relative to the likely cost of the input. This might be so for a highly valuable and differentiated downstream product. In Section 5, we extend the model to allow for elastic demand by assuming that the customer's value for the project is random.

There are two possible modes of vertical market organization. The customer either is independent of the n suppliers, which is referred to as "non-integration," or is under common ownership with one of the suppliers, which is referred to as "integration." Allowing the customer to combine with only one supplier serves to focus the analysis on vertical rather than horizontal market structure.

Timing We begin by studying a two-stage game in which the vertical market structure – integration or non-integration – is given at the outset and common knowledge.

Stage 1: In stage 1, all suppliers i simultaneously make non-negative investments x_i , $i = 1, \dots, n$. The cost of investment x is $\Psi(x) = \frac{a}{2}x^2$, where $a > 0$ is a given parameter. The effect of investment x_i on costs is that it shifts the mean of the distribution $G(\cdot)$ with support $[\beta - x_i, \infty)$ from which i 's cost of production c_i will be drawn in stage 2.

Specifically, we assume that

$$G(c_i + x_i) = 1 - e^{-\mu(c+x_i-\beta)}.$$

where $\mu > 0$ and $\beta > 0$ are parameters of the exponential distribution.¹⁰

The distribution of the minimum cost with n suppliers with a vector of investments $\mathbf{x} = (x_1, \dots, x_n)$ satisfying $x_1 \geq x_2 \geq \dots \geq x_n$ is, for $c \geq \beta - x_n$,

$$L(c; \mathbf{x}) = 1 - \prod_{i=1}^n [1 - G(c + x_i)] = 1 - e^{-n\mu(c-\beta) - \mu \sum_{i=1}^n x_i} \quad (1)$$

and, for $c \in [\beta - x_j, \beta - x_{j+1}]$ with $j \geq 1$, it is

$$L(c; \mathbf{x}) = 1 - e^{-j\mu(c-\beta) - \mu \sum_{i=1}^j x_i}.$$

If the investments are symmetric, that is, if $x_i = x$ for all i , then the minimum cost distribution is

$$L(c + x, n) \equiv 1 - [1 - G(c + x)]^n = 1 - e^{-n\mu(c+x-\beta)}.$$

All distribution functions are defined on an extended support, so that, for example, $G(c + x) = 0$ and $L(c + x, n) = 0$ for all $c \leq \beta - x$. The investment x_i and the cost realization c_i are private information of supplier i . The mean-shifting investments in our basic model are the same as in the Laffont and Tirole (1993) model of procurement. In contrast to the typical Laffont-Tirole model, however, supplier heterogeneity is realized after investments, and the realized cost is the private information of the supplier.

Stage 2: In stage 2, the customer solicits bids from the suppliers in a reverse auction. For now, we assume that there is no reserve price, which can be justified on the ground that the precise input specifications are non-contractible *ex ante*, and the buyer cannot commit to reject a profitable offer. All suppliers i , $i = 1, \dots, n$, privately observe their *ex post* costs c_i .

Under non-integration, each supplier bids a price b_i in a first-price auction. The bids $\mathbf{b} = (b_1, \dots, b_n)$ are simultaneous. The customer selects the low-bid supplier. Under integration, supplier 1 and the customer are under common ownership. The remaining $n - 1$ independent suppliers simultaneously each submit a bid b_i . The customer sources internally if $c_1 \leq \min\{\mathbf{b}_{-1}\}$, and purchases from the low-bid independent supplier if $\min\{\mathbf{b}_{-1}\} \leq \min\{c_1\}$. In Section 4, we endogenize the market structure by analyzing a bargaining model by adding an initial stage in which the buyer makes take-it-or-leave-it offers for acquiring or divesting the supply unit.

Section 5 considers robustness to various extensions: non-quadratic cost of investment, different parametric cost distributions, downward sloping demand, reserve prices, and agency problems inside the firm. Many of our results and, more importantly, the general nature of the tradeoffs between non-integration and vertical integration depend

¹⁰By choice of monetary units, one can normalize either the parameter μ or a .

neither on exponential cost distributions nor on quadratic investment costs. However, the comparison of the benefits and costs of alternative organizations of procurement requires parametric functional forms, and the quadratic-exponential specification is particularly convenient.

What it means exactly to put the customer and supplier 1 under common ownership is a matter of interpretation. In the spirit of the property-rights theory of the firm (Grossman and Hart 1986, Hart and Moore 1990), one can think of the customer as having control rights over a downstream production process, and vertical integration as the acquisition of those control rights by one of the suppliers, who thus gains the ability to exclude rivals from supplying the customer. Admittedly, under the assumption of inelastic demand, it is awkward to imagine control rights with infinite value, but the awkwardness is removed by allowing for downward-sloping demand. Alternatively, one can think of the customer as acquiring the assets of an upstream supplier. This interpretation seems deficient because it abstracts from the problem of motivating the integrated supplier to invest, but the apparent deficiency is remedied by interpreting the cost of investment to include agency costs.

3 Analysis

We now turn to the equilibrium analysis of our basic model and derive the conditions under which either vertical integration or non-integration is the most profitable organizational structure. We first derive the equilibrium bidding function of the independent suppliers, which is independent of the vertical market structure. Then we derive in turn the equilibrium investments under non-integration and vertical integration, respectively. In Section 3.4, we compare the benefits and costs of vertical integration relative to non-integration from the perspective of the customer and the integrated supplier. Section 3.5 studies the planner's investment problem under first- and second-best scenarios, and Section 3.6 develops intuition for the results. Throughout the analysis of the baseline model, we assume that $\frac{\mu}{a} < \frac{n}{n-1}$, which guarantees that a symmetric equilibrium exists.

3.1 Bidding

Bidding under Non-Integration The equilibrium bidding function $b_{NI}(c)$ under non-integration when all n independent suppliers invest the same amount x is well known from auction theory. The auction being a first-price procurement auction, $b_{NI}(c)$ is equal to the expected value of the lowest cost of any of the $n - 1$ competitors, conditional on this cost being larger than c . That is

$$b_{NI}(c) = \frac{\int_c^\infty y dL(y + x, n - 1)}{1 - L(c + x, n - 1)} = c + \frac{1}{\mu(n - 1)}.$$

The constant hazard rate of the exponential results in constant markup bidding.

Given that we confine attention to symmetric equilibria, the focus on symmetric investments x for the equilibrium bidding function is without loss of generality: supplier

i 's deviation to some $x_i \neq x$ will not be observed by any of its competitors, and any bidder i 's equilibrium bid does not depend on its own distribution, only on its own cost realization. Consequently, if i deviates to some $x_i < x$, it will optimally bid according to $b_{NI}(c)$ for any possible cost realization. On the other hand, if $x_i > x$, i 's optimal bid will simply be $b_{NI}(\beta - x)$ for all $c \in [\beta - x_i, \beta - x]$ and $b_{NI}(c)$ for all $c > \beta - x$.

Bidding under Vertical Integration Vertical integration effectively establishes a preferred supplier, who serves to limit the market power of non-integrated suppliers as in Burguet and Perry (2009). Let x_1 be the equilibrium investment level of the integrated supplier and x_2 be the symmetric investment level of all independent suppliers.

The equilibrium bidding function $b_I(c)$ of the independent suppliers is then such that

$$c = \arg \max_z \{ [b_I(z) - c] [1 - G(b_I(z) + x_1)] [1 - G(z + x_2)]^{n-2} \}.$$

As G is exponential and assuming $x_1 \geq x_2$, $b_I(c)$ is such that

$$c = \arg \max_z \{ [b_I(z) - c] e^{-\mu(b_I(z) + (n-2)z)k} \},$$

where $k = e^{-\mu(x_1 + (n-2)x_2 - (n-1)\beta)}$ is a constant (that is, independent of z and $b_I(z)$). The first-order condition, evaluated at $z = c$, is

$$[b'_I(c) - \mu(b_I(c) - c)(b'_I(c) + n - 2)] [e^{-\mu(b_I(c) + (n-2)c)k}] = 0.$$

Imposing the bounded-markup condition $\lim_{c \rightarrow \infty} b_I(c)/c = 1$, this differential equation has the unique solution

$$b_I(c) = c + \frac{1}{\mu(n-1)}. \quad (2)$$

Observe that $b_I(c) = b_{NI}(c)$. That is, provided $x_1 \geq x_2$, equilibrium bidding by the independent suppliers does not change with the vertical market structure.

Below we will show that there is an equilibrium satisfying $x_1 \geq x_2$. Showing that $x_1 \geq x_2$ in equilibrium is straightforward as unilateral deviations from a prescribed equilibrium level x_1 will not be observed by the non-integrated suppliers and will thus not affect equilibrium bidding off the equilibrium path. As with non-integration, downwards deviations $x_i < x_2$ by $i = 2, \dots, n$ will never induce i to bid differently from what $b_I(c)$ prescribes. If the independent supplier i invested more than x_2 , he will, obviously, bid according to $b_I(c_i)$ for all $c_i \geq \beta - x_2$ for nothing changes in his optimization problem at the bidding stage compared to the case where $x_i = x_2$. If $x_i > x_2$, cost realizations $c_i < \beta - x_2$ occur with positive probability. For these realizations, the optimal bidding for i is as described in the following lemma.

Lemma 1 *Under vertical integration, for cost realizations $c_i < \beta - x_2$, bidder i 's optimal bid $b(c_i)$ satisfies*

$$b(c_i) = \begin{cases} b_I(\beta - x_2) & \text{if } \beta - x_2 \geq c_i \geq \beta - x_2 - \frac{1}{\mu} \frac{n-2}{n-1} \\ c_i + \frac{1}{\mu} & \text{if } \beta - x_2 - \frac{1}{\mu} \frac{n-2}{n-1} \geq c_i \geq \beta - x_1 - \frac{1}{\mu} \\ \beta - x_1 & \text{otherwise} \end{cases}$$

if all other independent suppliers invest x_2 and the integrated supplier invests x_1 with $x_1 \geq x_2$.

The bidding function $b(c_i)$ is useful for analyzing deviations from a candidate equilibrium in which independent suppliers invest symmetrically. For cost draws close to but below $\beta - x_2$, a supplier who deviated at the investment stage submits the bid $b_I(\beta - x_2)$, which guarantees that i never loses to an independent supplier. For smaller costs, supplier i competes only against the integrated supplier by bidding $c_i + \frac{1}{\mu}$, provided $c_i + \frac{1}{\mu} > \beta - x_1$. Otherwise, i bids the lowest possible cost of the integrated supplier $\beta - x_1$.

3.2 Non-Integration

The expected profit at the investment stage under non-integration of supplier i when investing x_i while each of the $n - 1$ competitors invests x , anticipating that he will bid according to $b_{NI}(c_i)$ when his cost is c_i with $c_i \geq \beta - x$, and $b_{NI}(\beta - x)$ whenever $c_i < \beta - x$ is

$$\begin{aligned}\Pi_{NI}(x_i, x) &= \int_{\beta-x}^{\infty} [b_{NI}(c) - c][1 - G(c + x)]^{n-1} dG(c + x) + \int_{\beta-x_i}^{\beta-x} [b_{NI}(\beta - x) - c] dG(c + x) - \frac{a}{2} x_i^2 \\ &= x_i - x - \frac{1}{\mu} \frac{n-2}{n-1} + \frac{n-1}{\mu n} e^{-\mu(x_i-x)} - \frac{a}{2} x_i^2\end{aligned}$$

for $x_i \geq x$, and

$$\begin{aligned}\Pi_{NI}(x_i, x) &= \int_{\beta-x_i}^{\infty} [b_{NI}(c) - c][1 - G(c + x)]^{n-1} dG(c + x) - \frac{a}{2} x_i^2 \\ &= \frac{1}{\mu n(n-1)} e^{-\mu(n-1)(x-x_i)} - \frac{a}{2} x_i^2\end{aligned}$$

for $x_i < x$. The first-order condition for a symmetric equilibrium with $x_i = x^*$ is thus

$$\frac{\partial \Pi_{NI}(x^*, x^*)}{\partial x_i} = \frac{1}{n} - ax^* = 0,$$

yielding $x^* = \frac{1}{an}$ as investment levels in any candidate symmetric equilibrium. That is, in equilibrium, marginal costs of investment are equal to expected market shares. This result – that marginal costs of investment are equal to market shares – holds much more generally than for the exponential distribution and quadratic cost functions we assume here. By the envelope theorem, it holds for any symmetric equilibrium in a model with mean shifting investments.

The equilibrium expected procurement cost to the customer under non-integration equals the expected low bid. Given symmetric investment levels x , the formula for the equilibrium expected procurement cost is

$$PC_{NI}(x) = \int_{\beta-x}^{\infty} b(c) dL(c + x, n) = \beta - x + \frac{1}{\mu n} + \frac{1}{\mu(n-1)},$$

where $\beta - x + \frac{1}{\mu n}$ is the expected cost production cost given investments x and $\frac{1}{\mu(n-1)}$ is the markup. Evaluating at the equilibrium value under non-integration, that is at $x = \frac{1}{an}$, we thus get the equilibrium value of expected procurement cost of the customer and the expected profit of a representative supplier as follows:

Lemma 2 *In symmetric equilibrium under non-integration, the expected procurement cost PC_{NI}^* of the customer is*

$$PC_{NI}^* = \beta - \frac{1}{an} + \frac{1}{\mu n} + \frac{1}{\mu(n-1)},$$

and the expected profit of a representative supplier is

$$\Pi_{NI}^* = \frac{1}{\mu n(n-1)} - \frac{1}{2an^2}.$$

Symmetric equilibrium exists if and only if $\frac{\mu}{a} < \frac{n}{n-1}$. In this equilibrium, the procurement cost PC_{NI}^ and the suppliers' equilibrium profit Π_{NI}^* decrease in n .*

These formulas have very intuitive interpretations. Expected procurement costs PC_{NI}^* are equal to the expected cost of production plus the markup. A supplier's expected equilibrium profit Π_{NI}^* is equal to the markup, times the probability of winning, minus the investment costs.

3.3 Vertical Integration

We now turn to the equilibrium analysis when the customer is vertically integrated with supplier 1. The integrated firm's maximization problem is now to choose its investment x_1 to minimize the sum of expected procurement costs and investment costs $\frac{a}{2}x_1^2$, denoted $PC_I(x_1, x_2)$, anticipating that the $n-1$ independent suppliers invest x_2 and bid according to $b_I(c)$ and that it will source externally if and only if the lowest bid of the independent suppliers is below its own cost realization c_1 . The expected procurement cost given $x_1 \geq x_2$ is

$$\begin{aligned} PC_I(x_1, x_2) &= \frac{a}{2}x_1^2 + \int_{\beta-x_1}^{\infty} c_1 dG(c_1 + x_1) \\ &\quad - \int_{\beta-x_2+\frac{1}{\mu(n-1)}}^{\infty} \int_{\beta-x_2}^{c_1-\frac{1}{\mu(n-1)}} \left[c_1 - \left(c_2 + \frac{1}{\mu(n-1)} \right) \right] dL(c_2 + x_2, n-1) dG(c_1 + x_1) \\ &= \beta - x_1 + \frac{1}{\mu} - \frac{1}{\mu} \frac{n-1}{n} e^{-\mu(x_1-x_2)-\frac{1}{n-1}} + \frac{a}{2}x_1^2, \end{aligned}$$

which consists of the expected cost of production $\beta - x_1 + \frac{1}{\mu}$ if the customer always sourced internally, minus the cost savings from procuring externally $\frac{1}{\mu} \frac{n-1}{n} e^{-\mu(x_1-x_2)-\frac{1}{n-1}}$, plus the effort cost $ax_1^2/2$. A necessary condition for $PC_I(x_1, x_2)$ to be minimized over x_1 is therefore that

$$-1 + \frac{n-1}{n} e^{-\mu(x_1-x_2)-\frac{1}{n-1}} + ax_1 = 0. \quad (3)$$

Notice that the second-order condition for a minimum is $-\mu \frac{n-1}{n} e^{-\mu(x_1-x_2)-\frac{1}{n-1}} + a \geq 0$. Since $e^{-\mu(x_1-x_2)-\frac{1}{n-1}} \leq 1$, a sufficient condition for this to be the case is $\frac{\mu}{a} \leq \frac{n}{n-1}$, our maintained assumption guaranteeing existence of a symmetric equilibrium under non-integration.

Consider next a representative non-integrated supplier. Given investments x_1 by the integrated supplier and x_2 by the $n-2$ competing independent suppliers, the expected profit $\Pi_I(x_i, x_1, x_2)$ of an independent supplier i when investing $x_i \leq x_2$ is

$$\Pi_I(x_i, x_1, x_2) = \frac{1}{\mu n(n-1)} e^{-\mu(x_1-x_2)-\frac{1}{n-1}+\mu(n-1)(x_i-x_2)} - \frac{a}{2} x_i^2. \quad (4)$$

As shown in the Appendix, the derivative of the expected profit function with respect to x_i is continuous at x_2 . Therefore, a necessary condition for a symmetric equilibrium (symmetric in the investment level x_2 of the independent suppliers) with $x_1 \geq x_2$ is

$$\left. \frac{\partial \Pi_I(x_i, x_1, x_2)}{\partial x_i} \right|_{x_i=x_2} = \frac{1}{n} e^{-\mu(x_1-x_2)-\frac{1}{n-1}} - a x_2 = 0. \quad (5)$$

The following lemma characterizes the equilibrium investments x_1 and x_2 given by the first-order conditions and derives their comparative statics with respect to μ and n .

Lemma 3 *The equilibrium values for x_1 and x_2 , given by the first-order conditions (3) and (5), are*

$$x_1 = \frac{1}{an} + \frac{n-1}{n} \Delta^I(n, \mu) \quad \text{and} \quad x_2 = \frac{1}{an} - \frac{1}{n} \Delta^I(n, \mu), \quad (6)$$

where $\Delta^I(n, \mu) = x_1 = x_2$ is the unique non-negative solution to

$$a \Delta^I = 1 - e^{-\mu \Delta^I - \frac{1}{n-1}}. \quad (7)$$

For any n , aggregate investments add up to $1/a$, i.e. $x_1 + (n-1)x_2 = 1/a$. Moreover, x_1 increases in μ and decreases in n .

Observe that Lemma 3 implies that

$$x_1 > x^* > x_2.$$

This distortion in equilibrium investments is one of the keys to the following results.

Evaluating $PC_I(x_1, x_2)$ and $\Pi_I(x_1, x_2)$ at the equilibrium investment levels, we get that the expected equilibrium procurement cost $PC_I^* \equiv PC_I(x_1, x_2)$ and the expected equilibrium profit $\Pi_I^* \equiv \Pi_I(x_1, x_2)$ of an independent supplier are as follows:

Lemma 4 *A symmetric equilibrium under integration exists if a symmetric equilibrium exists under non-integration. The expected cost of procurement of the integrated firm is*

$$PC_I^* = \beta + \frac{a-\mu}{\mu} x_1 + \frac{a}{2} x_1^2$$

while the expected of profit of a non-integrated supplier is

$$\Pi_I^* = \frac{1}{\mu(n-1)} a x_2 - \frac{a}{2} x_2^2,$$

where x_1 and x_2 are defined by (7) and (6).

3.4 Comparison

Vertical divestiture, or non-integration, is mutually profitable for the customer and an integrated supplier if $PC_I^* + \Pi_{NI}^* > PC_{NI}^*$. The supplier profit under non-integration Π_{NI}^* can be thought of as part of the opportunity cost of vertically integrated procurement. This amounts to assuming that the integrated firm can sell its supply unit to an independent outside supplier, thereby increasing the number of non-integrated suppliers from $n - 1$ to n .

Proposition 1 *Assuming a symmetric equilibrium exists under non-integration, divestiture of the vertically integrated supplier is jointly profitable if and only if*

$$\Phi := \frac{a}{2} \left(\frac{n-1}{n} \right)^2 (\Delta^I)^2 + \frac{n-1}{n} \left(\frac{a-\mu}{\mu} + \frac{1}{n} \right) \Delta^I - \frac{1}{\mu n} > 0. \quad (8)$$

where $\Delta^I = \Delta^I(n, \mu)$ is the positive solution to (7).

Figure 1 illustrates Proposition 1 for the normalization $a = 1$.¹¹ It shows that the benefits of divestiture increase as n increase when vertical integration is the more profitable organization structure, and that the benefits from divestiture stay positive once they are positive. Divestiture also becomes more attractive as μ increases. This is intuitive because higher μ means a lower variance and therefore less rents accruing to independent suppliers. Finally, for $\mu \leq 1/2$, vertical integration dominates divestiture for any n .

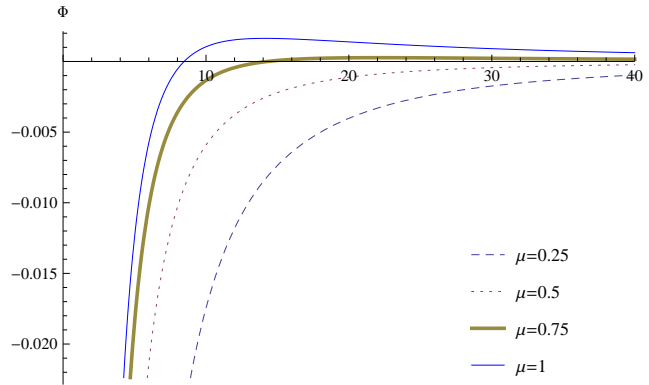


Figure 1: Φ evaluated at $\mu \in \{0.25, 0.5, 0.75, 1\}$ and $a = 1$ as a function of n .

To appreciate this result, it is important to understand the powerful advantages of vertical integration. With inelastic demand and quadratic effort cost, the aggregate investment in effort is the same under non-integration and integration. This follows because the equilibrium marginal costs of effort are equal to market shares which sum

¹¹To see that the normalization is innocuous, observe that (7) can be solved for $a\Delta^I$ as function of n and μ/a , and therefore $a\Phi$ is a function of n and μ/a . The relevant range of parameters for which a symmetric equilibrium exists under non-integration is $\frac{\mu}{a} \leq \frac{n}{n-1}$.

to one. Furthermore, since the exponential distribution has a constant hazard rate, the distribution of minimum production cost is more favorable under vertical integration. The support of the minimum cost distribution is the union of the supports of the cost distributions of the integrated and independent suppliers, and depends only on aggregate investment on the support of an independent firm. Because the additional investment of the integrated firm shifts its support downward, however, the minimum cost distribution shifts to the left. On top of that advantage of vertical integration, the integrated firm self-sources in some instances, thereby avoiding paying a markup and further reducing its procurement cost compared to non-integration.

From this perspective, the downside to vertical integration might seem more modest. Because the cost of effort is convex, the total effort cost increases as the same total investment is redistributed from independent suppliers to the integrated supplier. In other words, even though the vertically integrated firm fully compensates for the investment discouragement of the independent suppliers, it does so at a higher cost. The proposition shows that the higher total investment cost can be enough to substantially offset and even outweigh the benefits of vertical integration.

Notice that a “revealed preference argument” that the customer can do no worse by changing its conduct under vertical integration does not apply to this situation because of the response of the independent suppliers. Even though the integrated firm could keep its investment at the pre-integration level but chooses not to, and the integrated firm could source its requirements the same way as under non-integration but chooses not to, the other firms nevertheless reduce their investments in equilibrium. All we can conclude from revealed preference is that, given that the other firms reduce their investments, the integrated buyer prefers more to less investment, but this does not allow us to conclude that it is better off with integration.

3.5 Planner’s Problem

First-Best It is instructive to compare equilibrium outcomes with those that would obtain if a social planner made the investment and sourcing decisions. The planner’s objective is to minimize the total expected cost. Since the planner would always select the supplier with the lowest realized cost, the expected production cost is

$$EC(\mathbf{x}) = \int_{\underline{c}(\mathbf{x})}^{\infty} c dL(c; \mathbf{x}),$$

where $\mathbf{x} = (x_1, \dots, x_n)$ and $\underline{c}(\mathbf{x}) = \beta - \min\{x_1, \dots, x_n\}$. The planner’s problem then is

$$\min_{\mathbf{x}} EC(\mathbf{x}) + \frac{a}{2} \sum_{i=1}^n x_i^2. \quad (9)$$

Proposition 2 *The solution to the planner’s problem (9) is symmetric and satisfies $x_i^{FB} = \frac{1}{an}$ for all $i = 1, \dots, n$ if and only if $\mu \leq a$. For $\mu > a$, the socially optimal investments are asymmetric and satisfy $x_1^{FB} = \frac{1}{an} + \frac{n-1}{n} \Delta^{FB}$ and $x_i^{FB} = \frac{1}{an} - \frac{1}{n} \Delta^{FB}$ for $i = 2, \dots, n$, where Δ^{FB} is the unique positive number satisfying*

$$a\Delta^{FB} = 1 - e^{-\mu\Delta^{FB}}.$$

Observe that the planner's problem has a unique solution. Notice also that $\Delta^{FB} = 0$ at $\mu = a$ and that Δ^{FB} increases in μ for $\mu > a$.¹² The symmetric solution corresponds to the symmetric equilibrium investments under non-integration, which exists for $\frac{\mu}{a} < \frac{n}{n-1}$. In other words, the symmetric equilibrium under non-integration exists even for a parameter range – for $1 < \frac{\mu}{a} < \frac{n}{n-1}$ – for which it is not socially optimal. In contrast, the asymmetric solution differs from the equilibrium investment levels under vertical integration in that in equilibrium the difference between investments is larger than would be socially optimal, that is $\Delta^I > \Delta^{FB}$ holds. This difference is driven by the sourcing distortion under vertical integration.

Second-Best Likewise, it is of interest to look at the second-best scenario, according to which the planner can choose the investment level x_1 for the integrated supplier and the investment levels x_2 for the $n - 1$ independent suppliers, taking as given that there is a sourcing distortion resulting from the markup $\frac{1}{\mu(n-1)}$. Denote by x_1^{SB} and x_2^{SB} the solution values to the planner's second-best problem and let $\Delta^{SB} \equiv x_1^{SB} - x_2^{SB}$.

Proposition 3 *The solution to the planner's second-best problem Δ^{SB} is given by the unique positive number satisfying*

$$1 - \frac{n}{n-1} e^{-\mu\Delta^{SB} - \frac{1}{n-1}} = \Delta^{SB}$$

and satisfies $0 < \Delta^{SB} < \Delta^I$.

That is, in equilibrium there is excessive investment by the integrated supplier and too little investment by the independent suppliers even relative to the second-best solutions. However, because $\Delta^{SB} > 0$, the symmetric equilibrium investment levels under non-integration are not socially optimal if there is a sourcing distortion because the buyer has a preferred supplier.

3.6 Discussion

The unique solution to the planner's first-best investment problem coincides with the symmetric equilibrium outcome under non-integration when supplier heterogeneity is sufficiently great, that is, when μ is small. Despite the social undesirability of vertical integration, however, the buyer has the incentive to rely exclusively on outside supply only when heterogeneity in the upstream industry is not too great and when the upstream market is not too concentrated. The general intuition for this result is that, by creating a preferred supplier, vertical integration squeezes the profits of the upstream sector by avoiding paying markups, and this benefit dominates the higher production costs that result from sourcing distortions and the reallocation of suppliers' investments in cost reduction. More precisely there is a positive incentive for vertical integration if the

¹²To see that $\Delta^{FB} = 0$ at $\mu = a$, notice that in this case the equality $a\Delta = 1 - e^{-\mu\Delta}$ can be written as $z = 1 - e^{-z}$ with $z = a\Delta$, which only holds if $z = 0$. An easy way to see that Δ^{FB} increases in μ for $\mu \geq a$ is to observe that the function $a\Delta$ is trivially independent of μ while the function $1 - e^{-\mu\Delta}$ increases in μ . Thus, the fixed point Δ^{FB} must increase in μ .

reduction in rents paid to the independent firms exceeds the increase in the total cost of production.

To deepen this intuition, re-consider the second-best planning problem, in which supplier 1 is a preferred supplier of the sort studied by Burguet and Perry (2009), and suppose that the planner is able to reallocate investments away from the independent sector, toward the preferred supplier. Normalizing $a = 1$, the total amount of investment equals one, and $\Delta = 0$ corresponds to symmetric investments equal to $x_i = \frac{1}{n}$ for $i = 1, \dots, n$, while $1 \geq \Delta > 0$ corresponds to an investment of $x_1 = \frac{1}{n} + \frac{n-1}{n}\Delta$ for the preferred supplier and $x_2 = \frac{1}{n} - \frac{1}{n}\Delta$ for each of the independent suppliers. We restrict attention to those circumstances in which symmetric investments are first-best, i.e. $0 < \mu \leq 1$, and focus on the boundary case $\mu = 1$. In the boundary case, any lesser degree of supplier heterogeneity – that is, any larger values of μ – would lead the social planner to an asymmetric solution under first-best. That is, the planner would designate one of the suppliers to invest more in cost reduction than the others. For this boundary case, figure 2 illustrates the costs and benefits of establishing a preferred supplier as a function of Δ for the case with $n = 4$.

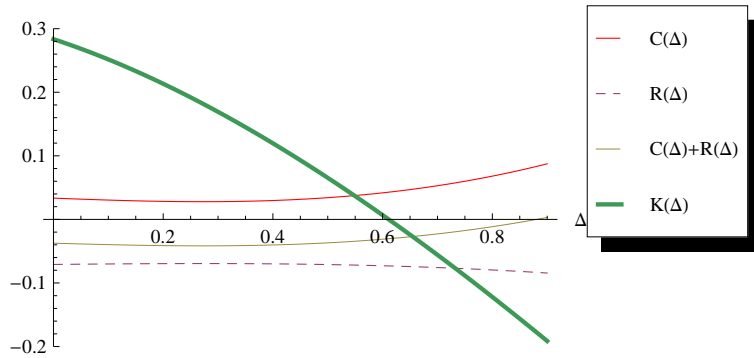


Figure 2: Profitability of Vertical Integration for $\mu = 1$ and $n = 4$.

First, observe that $\Delta = 0$ corresponds to the Burguet and Perry (2009) model in which the preferred supplier has the same cost distribution as independent suppliers. Given the sourcing distortion, the planner has an incentive to reallocate investments toward the preferred supplier, resulting in asymmetric cost distributions. Holding the sourcing distortion constant, the planner's incentive to reallocate is shown by the downward sloping concave curve in figure 2, which has the functional form

$$K(\Delta) = 1 - e^{-\mu\Delta - \frac{1}{n-1}} - \Delta.$$

This curve graphs the difference between the marginal return to investment by the preferred supplier and the marginal return to investment of an independent supplier at a given allocation Δ . We interpret $K(\Delta)$ to measure the "efficiency effect" of a small investment re-allocation, that is, the marginal reduction in expected total production cost given the market shares of the preferred supplier and the independent firms.

Second, notice that $K(\Delta)$ also indicates the difference in private incentives for investment under vertical integration. If $K(\Delta) > 0$, then a vertically-integrated supplier has a unilateral incentive to invest more, and an independent supplier has a unilateral incentive to invest less, whereas if $K(\Delta) < 0$ the opposite is true. The equilibrium difference in investment levels Δ^I occurs precisely at the point such that $K(\Delta^I) = 0$. In other words, equilibrium under vertical integration is equivalent to establishing a preferred supplier and reallocating investments such that the efficiency effect is zero.

Third, consider how investment reallocations impact expected total production cost if market shares are not held constant. A sourcing distortion in favor of a preferred supplier raises total cost by sometimes shifting production to the more costly preferred provider. The overall consequences of an investment reallocation on production cost depend on the magnitudes of this sourcing effect and the efficiency effect. The tradeoff between the two effects is demonstrated in figure 2 with the convex curve labeled $C(\Delta)$, which graphs the increase in total cost that results from creating a preferred supplier and reallocating investment so that the preferred supplier invests Δ more each of the others. This cost distortion relative to the first-best has the following functional form:

$$C(\Delta) = \frac{1}{\mu} \left(1 - e^{-\mu\Delta - \frac{1}{n-1}} \right) + \frac{n-1}{2n} (\Delta - 1)^2 - \frac{1}{\mu n} - \frac{n-1}{2n}.$$

For $\Delta < \Delta^I$, the efficiency effect and sourcing effect have opposite signs. The efficiency effect dominates for sufficiently small Δ , and $C(\Delta)$ declines to its minimum at $\Delta = \Delta^{SB}$ where the two effect exactly balance, while for $\Delta^I > \Delta > \Delta^{SB}$ the adverse sourcing effect overcomes the beneficial efficiency effect to push up total cost. For $\Delta > \Delta^I$, both effects are negative. Therefore, Δ^{SB} solves the second-best planning problem.

Fourth, consider the extent to which the creation of a preferred supplier squeezes the profits of its competitors. The sourcing distortion reduces rents paid to non-preferred suppliers by avoiding a markup whenever the cost of the preferred supplier is below the lowest bid. Furthermore, the profits are squeezed further as investment is reallocated toward the preferred supplier, as illustrated by the curve labeled $R(\Delta)$. The functional form for the boundary case yields a relatively flat curve:

$$R(\Delta) = -\frac{1}{\mu n} \left(1 - e^{-\mu\Delta - \frac{1}{n-1}} \right) - \frac{n-1}{2n^2} (\Delta - 1)^2 + \frac{n-1}{2n^2}.$$

In other words, the creation of a preferred supplier has a significant profit squeezing effect, but the magnitude of the effect is not very sensitive to an investment reallocation. Observe that $R(\Delta) = -\frac{1}{n}C(\Delta) - \frac{1}{\mu n}$.

Finally, consider the incentive for vertical integration versus non-integration. Integration is profitable for the buyer and supplier 1 if and only if $C(\Delta) + R(\Delta) \geq 0$, which occurs for values of Δ below a critical value $\hat{\Delta}$. Establishing a pure preferred supplier in an industry with symmetric investments, and therefore symmetric cost distributions, is always profitable, i.e. $C(0) < -R(0)$, as shown by Burguet and Perry (2009). Asymmetric cost distributions resulting from increasingly reallocating investments toward the preferred supplier, however, eventually turn the tide against vertical integration, because the cost distortion rises much faster than rents are reduced. The net cost $C(\Delta) + R(\Delta)$

intersects the horizontal axis at a critical investment allocation $\hat{\Delta}$ above which the advantages of creating a preferred supplier with a superior cost distribution are outweighed by higher investment costs. The investments rise with reallocation because of the convexity of the investment cost function. Therefore, the profitability of vertical integration compared to non-integration depends on whether the equilibrium point (Δ^I) occurs to the right or to the left of $\hat{\Delta}$. Figure 2 illustrates a particular upstream market structure in which the equilibrium intersection occurs to the left of $\hat{\Delta}$, and so vertical integration is profitable.

Figure 2 is drawn for a concentrated upstream industry ($n = 4$) in which high markups make the returns from reducing rents very high relative to the cost penalty resulting from sourcing distortions. As the number of suppliers increases, the $C(\Delta) + R(\Delta)$ -curve and the $K(\Delta)$ -curve both shift upward, but the latter more so. Eventually the equilibrium value of Δ , Δ^I , moves to the right of $\hat{\Delta}$, and non-integration becomes the preferred vertical structure. The reason for this is that, while there is not much rent to be squeezed in an unconcentrated industry, there nevertheless is a relatively large cost penalty from vertical integration because of a still significant sourcing distortion and resulting investment reallocation. This point is illustrated in figure 3 for $n = 12$.

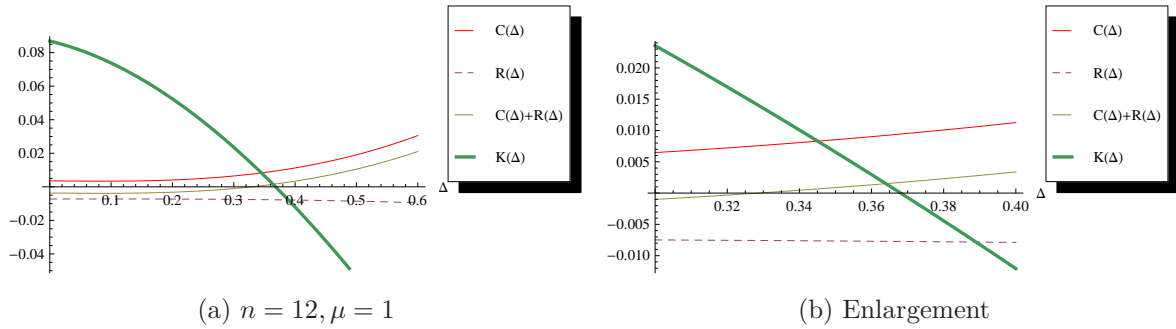


Figure 3: Profitability of Non-Integration for $\mu = 1$ and $n = 12$

In fact, there is a threshold value \hat{n} such that vertical integration is preferred for $n > \hat{n}$, and non-integration is preferred for $n < \hat{n}$. The threshold value \hat{n} can be computed as follows. Let $\hat{\Delta}(n, \mu)$ be the value of Δ for which $C(\Delta) + R(\Delta) = 0$ and substitute $\hat{\Delta}(n, \mu)$ into the function $K(\Delta)$ to define the function $\hat{K}(n, \mu) = K(\hat{\Delta}(n, \mu))$. The value \hat{n} is then defined as the number (if it exists) satisfying $\hat{K}(\hat{n}, \mu) = 0$. The function $\hat{K}(n, \mu)$ is illustrated in figure 4 for three different value of μ . For $\mu = 1$, $\hat{n} \approx 8.78$, so non-integration is preferred when there are 9 or more upstream suppliers. For $\mu = 1/3$, $\hat{K}(n, \mu) < 0$ for all $n \geq 2$, implying that vertical integration is always the buyer's preferred market structure. This is another way to state the result in Proposition 1.

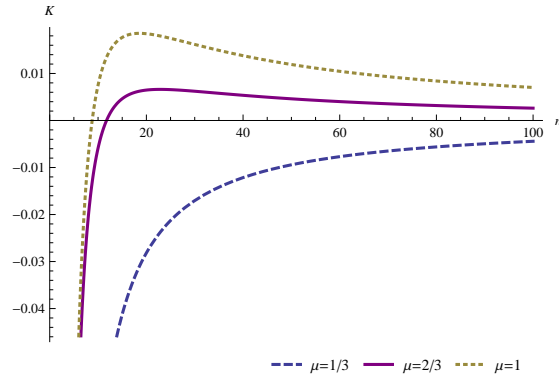


Figure 4: The function $\hat{K}(n, \mu)$ for $\mu \in \{1/3, 2/3, 1\}$.

4 Endogenous Market Structure

We now analyze bargaining games in which the market structure is determined endogenously. We first analyze an acquisition game.

Acquisition Game The starting assumption is that the underlying parameters are as above and common knowledge. At the outset, the market structure is non-integration. The customer then makes sequential take-it-or-leave-it offers t_i to the independent suppliers $i = 1, \dots, n$. The sequence in which offers are made is pre-determined but since suppliers are symmetric *ex ante* this is arbitrary. Without loss of generality, we assume that supplier i receives the i -th offer. If i accepts, the acquisition game ends and the game with vertical integration analyzed above ensues. If firm $i < n$ rejects, the customer makes the offer t_{i+1} to firm $i + 1$. If supplier n receives an offer but rejects it, the game with non-integration analyzed above ensues.

The equilibrium behavior is readily determined. Suppose first that $\Phi(n, \mu) < 0$. That is, vertical integration is jointly profitable. Then the subgame perfect equilibrium offers are $t_i = \Pi_I^*$ for $i < n$ and $t_n = \Pi_{NI}^*$. On and off the equilibrium path, these offers are accepted. Notice that in order for supplier n to accept the offer he receives, he must be offered $t_n \geq \Pi_{NI}^*$ because the alternative to his rejecting is that the game with the non-integrated market structure ensues, in which case he nets Π_{NI}^* . Anticipating that the last supplier would accept the offer if and only if he is offered Π_{NI}^* , the alternative for any supplier $i < n$ when rejecting is that the ensuing market structure will be non-integration if $\Phi < 0$ and integration, with i as an independent supplier netting Π_I^* otherwise. Therefore, it suffices to offer $t_i = \Pi_I^*$ to i with $i = 1, \dots, n - 1$, provided $t_n = \Pi_{NI}^*$. But as the latter is only a credible threat if $\Phi(n, \mu) \leq 0$, it follows that vertical integration is more profitable than the necessary (and sufficient) condition for it to be an equilibrium outcome suggests: $\Phi(n, \mu) \leq 0$ must be the case for integration to occur on the equilibrium path, but if $\Phi(n, \mu) \leq 0$, the profit of integration to the customer is actually strictly larger than $-\Phi(n, \mu)$ because she has to pay less than Π_{NI}^* on the equilibrium path.

Lastly, if $\Phi(n, \mu) > 0$, vertical integration is not jointly profitable and the customer will only make offers that will be rejected (e.g. $t_i \leq 0$ for all i would be a sequence of such offers).

Divestiture Game Suppose now that the initial market structure is vertical integration and that the customer and the integrated supplier jointly would be better off with non-integration (i.e. $\Phi(n, \mu) > 0$). Assuming the customer can make an offer to an outsider who is willing to pay any price that allows him to break even, the customer can sell her supply unit at the price Π_{NI}^* .

Bargaining with Externalities The acquisition process involves bargaining with externalities: A supplier's reservation price for selling is different when he is assured that if he does not sell no other supplier will sell, and if he has no such assurance. This reservation price is given by the profit under non-integration, that is, when the supplier does not sell, minus the reduction in profits when another supplier sells. In our acquisition game with sequential take-it-or-leave-it offers, this is reflected by the higher offer the last supplier receives (off the equilibrium path), for whom the reduction in profits is zero if he does not accept the offer because no other offer will be made subsequently. The equilibrium in this acquisition game is unique because of the sequential nature of moves and the power of subgame perfection. For the same reason, the equilibrium outcome remains unique when $\Phi(n, \mu) > 0$ even though equilibrium no longer is simply because any sequence of offers that will be rejected are part of an equilibrium. Notice also that in our acquisition and divestiture games, the equilibrium conditions are such that whenever there is an incentive to integrate, there is no incentive to divest, and conversely.

Of course, alternative bargaining procedures are conceivable. For example, following Jehiel and Moldovanu (1999) one could consider a second-price auction in which all suppliers simultaneously submit bids, and the bidder with the lowest bid wins and is paid the second-lowest bid. Suppose first that the buyer has the right to reject all offers but does not set a reserve. If $\Phi(n, \mu) < 0$, the unique equilibrium outcome is such that the buyer acquires a supply unit at the price Π_I^* essentially because of the standard Bertrand (or second-price auction) arguments. In contrast, when $\Phi(n, \mu) > 0 > \hat{\Phi}(n, \mu) := PC_I^* + \Pi_I^* - PC_{NI}^*$ the equilibrium outcome is no longer unique. Observe that $-\hat{\Phi}(n, \mu)$ is the profit from vertical integration accruing to the buyer when he only has to pay the price Π_I^* instead of Π_{NI}^* to acquire the supply unit.¹³ This game now has two equilibrium outcomes. In every equilibrium leading to the first one, every supplier submits such a high bid that it will be rejected by the buyer, and no acquisition occurs just like in the acquisition game with sequential take-it-or-leave-it offers. However, there are also equilibria in which two or more suppliers submit bids equal to Π_I^* and the buyer selects one of these lowest price bidders at random. For suppliers, however, these equilibria are Pareto dominated by any equilibrium in which no acquisition occurs. Suppose now that the buyer can commit to a reserve price R with the usual meaning that the buyer is committed to buy from (one of the lowest) bidders whenever the lowest

¹³It can be shown that $\hat{\Phi}(n, \mu)$ can be negative or positive as a function of μ and n . In fact, the emerging picture is very similar to figure 1 except that all curves are slightly shifted downwards.

bid is at or below R but not otherwise. For $\hat{\Phi}(n, \mu) < 0$, the buyer always acquires a unit at the price Π_I^* . By setting the reserve $R = \Pi_{NI}^*$, the buyer induces the suppliers to bid very aggressively. Notice that under the condition $\hat{\Phi}(n, \mu) < 0 < \Phi(n, \mu)$, this requires the buyer to set a reserve above her willingness to pay.¹⁴

Finally, interpreting integration as forward integration by a supplier, it is natural to assume that the sellers bid for the right to acquire the downstream unit, with the buyer selling to the supplier with the highest bid. The equilibrium conditions for acquisition to occur, and the scope for multiplicity of equilibrium outcomes, are the same as in the second-price auction without a reserve just described.¹⁵

5 Extensions

In this section, we study a number of extensions to demonstrate robustness of the main insights derived from the model with inelastic demand, exponentially distributed costs, quadratic costs of effort, and no reserve price.

5.1 Alternative Cost Distributions

Generalized Shifting Support Model The exponential cost distribution is convenient because it allows a closed form solution of the bid function under vertical integration. More generally, consider a cost distribution of the form $G(c + x)$ with support $[\beta - x, \infty)$ and density $g(c + x)$, satisfying $\lim_{c \rightarrow \infty} cg(c + x) = 0$. The shifting-support model has the convenient property that $\frac{\partial G(c+x)}{\partial x} = g(c + x)$. Thus, cost-reducing investment maintains the shape of the cost distribution while shifting its support downward.

Equilibrium bidding under non-integration with symmetric suppliers can be derived in the usual way. Suppose n suppliers have the same cost distribution $G(c+x)$, and consider a representative firm with cost realization c when rival bidders use an invertible bid strategy $b(c)$. A representative firm i chooses b_i to maximize $(b_i - c)[1 - G(b^{-1}(b_i) + x)]^{n-1}$. Therefore, a symmetric equilibrium bidding strategy $b_{NI}(c)$ satisfies

$$c = \arg \max_z \{ [b_{NI}(z) - c] [1 - G(c + x)]^{n-1} \},$$

or, equivalently,

$$b_{NI}(c) = c + \frac{\int_c^\infty [1 - G(z + x)]^{n-1} dz}{[1 - G(c + x)]^{n-1}}.$$

¹⁴This reflects the insight of Jehiel and Moldovanu (1999) that with negative externalities in a sale auction, the seller may optimally set a reserve below his value.

¹⁵Somewhat intriguingly, whenever acquisitions occur in equilibrium for a broader range of parameter values than divestitures occur, there is a potential Ponzi scheme inherent in the model. For example, with a reserve price and a second-price auction, the buyer could buy at the price Π_I^* and would be willing and able to sell at the price Π_{NI}^* under the condition $\hat{\Phi}(n, \mu) < 0 < \Phi(n, \mu)$, suggesting that with such bargaining procedures the model would need to be extended to rule out the existence of money-pumps.

Note that $b_{NI}(c)$ is an increasing function and is indeed invertible on the support of $G(\cdot)$. Assuming that first-order conditions are necessary and sufficient for equilibrium investments, it is straightforward that each independent supplier invests $x = \frac{1}{an}$ in equilibrium.

Under vertical integration with investment x_1 by the integrated supplier and x_2 by each independent supplier, the equilibrium bidding function $b_I(c)$ satisfies

$$b_I(c) = c + \frac{\int_c^\infty (1 - G(z + x_2))^{n-2} (1 - G(b_I(z) + x_1)) dz}{(1 - G(c + x_2))^{n-2} (1 - G(b_I(c) + x_1))}.$$

Letting $L(c + x, n) \equiv 1 - [1 - G(c + x)]^n$ denote the distribution of the minimum order statistic with n independent suppliers, equilibrium investments satisfy¹⁶

$$ax_2 = \frac{1}{n-1} \int_{-\infty}^\infty [1 - G(b_I(c) + x_1)] dL(c + x_2, n-1)$$

and

$$ax_1 = \int_{-\infty}^\infty G(b_I(c) + x_1) dL(c + x_2, n-1).$$

As we show in Proposition 4 below, the shifting support model retains the “adding-up condition” $a(n-1)x_2 + ax_1 = 1$.

Difficulties with this more general formulation arise because the bidding function under vertical integration does not in general admit a closed form solution, which makes it challenging to characterize procurement costs under vertical integration. The exponential case is exceptional because it yields a constant markup bidding function for any $n \geq 2$.

Uniform Special Case A model in which G is a uniform distribution and n is equal to 2 is another special case that admits a closed form solution for b_I . That is, suppose that given investment x_i supplier i 's costs are uniformly distributed on $[\beta - x_i, 1 + \beta - x_i]$. Facing a competing supplier who invests $x \geq x_i$, an independent bidder bids according to

$$b(c) = \frac{c + 1 + \beta - x}{2}$$

for $c \in [\beta - x, 1 + \beta - x]$ and submits an arbitrary bid $b > 1 + \beta - x$ for $c > 1 + \beta - x$ with and without integration.

For $n = 2$, vertical integration reduces procurement costs relative to the symmetric equilibrium under non-integration, which exists whenever $a \geq 1$.¹⁷ A numerical analysis of the uniform case for larger values of n requires nesting a numerical solution for the bidding function, which has no closed form solution under vertical integration because the cost distributions differ. Figure 5 plots the benefits from non-integration minus the payoff from vertical integration, $\Phi(n)$, as a function of n for $a = 1.75$.

An intuitive conjecture is that vertical integration has the advantage of squeezing (rather than just avoiding) markups. Analysis of the shifting support exponential model

¹⁶The equilibrium condition for integrated firm uses the fact that the marginal return to cost reduction when b is the minimum bid of the independent sector is $G(b + x_1)$.

¹⁷See the Online Appendix for details.

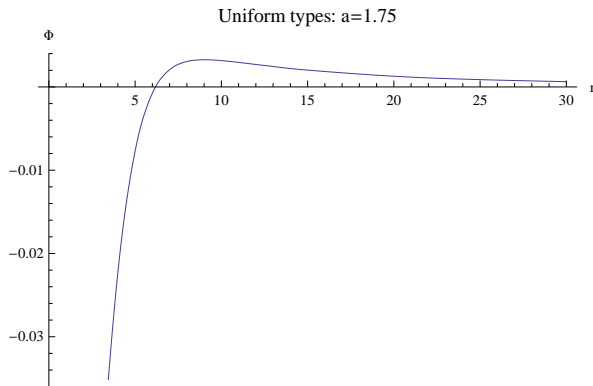


Figure 5: Profitable Non-integration for Uniformly Distributed Costs.

has already shown that this intuition is not correct in general, as markups are constant in that case.¹⁸ For the uniform case, equilibrium bid markups indeed decrease with vertical integration seemingly in line with the intuition. However, closer analysis reveals that the reason for this is the effect of vertical structure on equilibrium investments because, keeping investments fixed, the vertical structure does not affect equilibrium bidding.¹⁹ Figure 6 depicts the equilibrium bids given equilibrium investments.

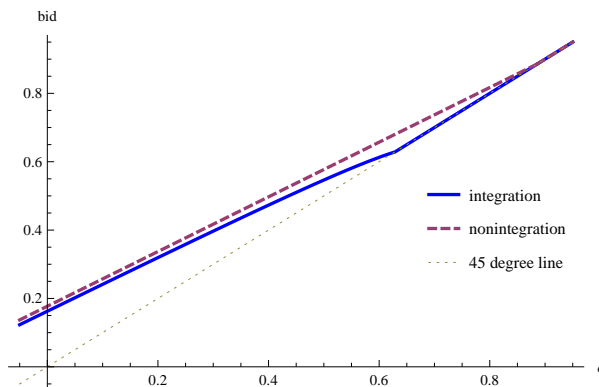


Figure 6: Equilibrium bidding with uniformly distributed costs.

¹⁸For the case of a fixed cost distribution with a convex decreasing inverse hazard rate, Burguet and Perry (2009) argue that a right of first refusal granted to a preferred supplier is profitable in part because it causes independent suppliers to bid more aggressively. The exponential cost distribution is a limiting case, in which the hazard rate is constant and the bid distribution does not change with vertical integration, consistent a more basic markup avoidance motive for granting a right of first refusal.

¹⁹To see this, notice that in a standard first-price procurement auction with n bidders and costs independently drawn from the uniform distribution with support $[\underline{c}, \bar{c}]$ the equilibrium bidding function is $\beta(c) = \bar{c}/n + (n-1)c/n$. With one integrated supplier whose bid is equal to his realized cost c_1 and $n-2$ competing independent suppliers who all bid according to $\beta_I(c) = \alpha_0 + \alpha_1 c$, satisfying the the boundary condition $\beta_I(\bar{c}) = \bar{c}$ (which implies $\alpha_0 = \bar{c}(1 - \alpha_1)$), the optimal bid of a representative independent bidder i , b_i , solves the problem of maximizing $(1/\alpha_1)^{n-2} (1/(\bar{c} - \underline{c}))^{n-1} (\bar{c} - b_i)^{n-1} (b_i - c_i)$, yielding $b_i = \bar{c}/n + (n-1)c_i/n$. The second-order condition is readily seen to be satisfied.

Fixed-Support Exponential Model Another interesting alternative cost distribution is an exponential distribution with fixed support. For an arbitrary investment x , let

$$G(c; x) = 1 - e^{-\mu x(c-\beta)}$$

be the distribution of costs where $\mu > 0$ and $\beta \geq 0$. In contrast to our baseline shifting support exponential model, in the fixed support exponential model investment shifts the scale parameter μx rather than the location parameter β , thereby shifting both the mean, $\frac{1}{\mu x} + x\beta$, and the standard deviation, $\frac{1}{\mu x}$, of the cost distribution. The fixed support exponential cost distribution function has an appealing interpretation: production requires some design effort, and greater design effort reduces the frequency of high cost outcomes. We maintain the assumption that the cost of investment is quadratic, i.e. $\Psi(x) = \frac{a}{2}x^2$ with $a > 0$. We set $a = 1$ and $\mu = 1$, which is without loss of generality by appropriately choosing units of measurement for c and x . We also set $\beta = 0$ to simplify derivations.

Equilibrium bids by independent suppliers are again a constant markup on cost. The difference from the baseline model is that the markups depend endogenously on investments. In the case of non-integration the bid function is

$$b_{NI}(c) = c + \frac{1}{(n-1)x_{NI}},$$

where x_{NI} is the symmetric investment of n independent suppliers. In the case of vertical integration, the bid function is

$$b_I(c) = c + \frac{1}{x_1 + (n-2)x_2},$$

where x_1 is the investment of the integrated supplier and x_2 the symmetric investment of the $n-1$ independent suppliers.

Equilibrium investments are derived from first-order conditions as before. In a symmetric equilibrium of the non-integrated environment, each of the suppliers invests an amount equal to 1 over the cube root on n^2 , that is, $x_{NI} = \frac{1}{\sqrt[3]{n^2}}$. For the integrated environment, let $z = \frac{x_2}{x_1}$. The symmetric best response investments can be written as functions of z , $x_1 = x_1(z)$ and $x_2 = x_2(z)$, respectively. Equilibrium investments are then given by $x_1 = x_1(z(n))$ and $x_2 = x_2(z(n))$, where $z(n)$ is the unique fixed point to the equation²⁰

$$z = \frac{x_2(z)}{x_1(z)}.$$

A simple graphical analysis shows that $z(n)$ is increasing in n .

Under non-integration, the equilibrium (expected) procurement cost of the buyer as a function of symmetric supplier investments x_{NI} is

$$PC_{NI} = \int_0^\infty b_{NI}(c) dG(c; nx_{NI}) = \frac{2n-1}{n(n-1)x_{NI}}$$

²⁰The closed forms of the functions $x_1(z)$ and $x_2(z)$ and the equation determining the fixed point $z(n)$ are given in the appendix.

and the (expected) profit of a supplier is

$$\Pi_{NI} = \int_0^\infty [b_{NI}(c) - c][1 - G(c; (n-1)x_{NI})]dG(c; x_{NI}) - \frac{1}{2}x_{NI}^2 = \frac{1}{n(n-1)x_{NI}} - \frac{1}{2}x_{NI}^2.$$

Substituting $x_{NI}(n)$ into these expressions yields equilibrium values of procurement cost and profits as functions of the number of suppliers

$$PC_{NI}(n) = \frac{2n-1}{(n-1)\sqrt[3]{n}} \quad \text{and} \quad \Pi_{NI}(n) = \frac{n+1}{2n(n-1)\sqrt[3]{n}}.$$

Procurement cost under vertical integration can be expressed as a function of x_1 and z :

$$\begin{aligned} PC_I &= \int_0^{x_1} cdG(c; x_1) + \frac{1}{2}x_1^2 \\ &- \int_{\frac{1}{x_1+(n-2)x_2}}^\infty \int_0^{c_1 - \frac{1}{x_1+(n-2)x_2}} [c - b_I(c)]dG(c; (n-1)x_1z)dG(c_1; x_1) \\ &= \frac{1}{x_1} + \frac{1}{2}x_1^2 - \frac{(n-1)ze^{-\frac{1}{1+(n-2)z}}}{1+(n-1)z}. \end{aligned}$$

Substituting $x_1 = x_1(z(n))$ and $z = z(n)$ yields procurement cost $PC_I(n)$ as a function of n . Since $z(n)$ lacks a closed form solution, so does $PC_I(n)$.

Divestiture is more profitable than vertical integration if

$$\Phi(n) \equiv PC_I(n) + \Pi_{NI}(n) - PC_{NI}(n)$$

is positive. Figure 7 shows that $\Phi(n) < 0$ if and only if $n < 10$. Thus, as in the baseline model, non-integration and a complete reliance on outsourcing is more profitable than vertical integration if the upstream market is sufficiently competitive.

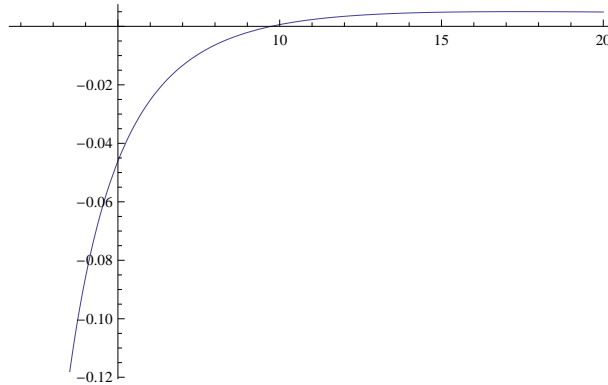


Figure 7: The benefit from divestiture, $\Phi(n)$ for the fixed-support exponential model.

It is also interesting to compare the independent bid functions under integration and non-integration. The difference in markups is

$$\Delta b(n) = \frac{1}{(x_1(z(n)) + (n-2)x_2(z(n)))} - \frac{1}{((n-1)x_{NI}(n))}$$

Figure 8 shows that $\Delta b(n) < 0$ if and only if $n < 6$. That is, the equilibrium markup is lower under vertical integration if and only if upstream competition is limited. Surprisingly, vertical integration fails to reduce markups for more competitive upstream market structures. The reason is an additional negative consequence of the investment discouragement effect: reduced investment by independent suppliers increases cost heterogeneity, causing the independent firms to bid less aggressively.

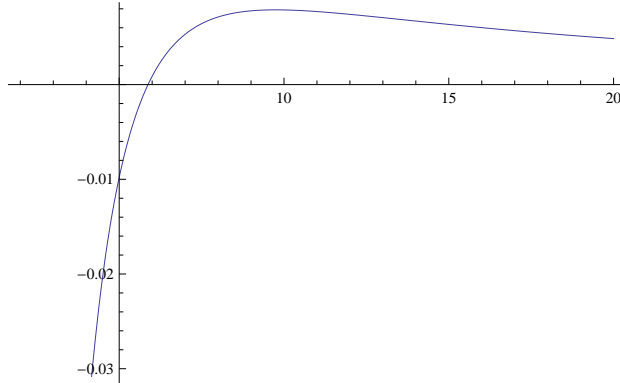


Figure 8: The function $\Delta b(n)$.

Furthermore, it can be shown that the adding-up property fails in this case and that vertical integration always decreases total investment, i.e. $x_1(z(n)) + (n - 1)x_2(z(n)) < nx_{NI}(n)$.

5.2 Investment Cost Functions

A quadratic cost of investment function is convenient for our analysis because, in the shifting support model, it implies the adding-up condition. Normalizing $a = 1$, equilibrium investments in cost reduction sum to 1 under both non-integration and integration. This “adding-up” result follows because, in equilibrium, each supplier equates the marginal cost of its investment to its expected market share (i.e. probability of production). Since the marginal cost is equal to the level of investment under the quadratic specification, and since market shares sum to 1 under inelastic demand, it follows immediately that total investment must equal 1. Consequently the equilibrium effect of vertical integration on investments is only to reallocate investment from the independent supply sector to the integrated supplier, while holding total investment constant.

Now consider a more general marginal cost of investment function $\psi(x)$. The symmetric equilibrium investment x under non-integration satisfies

$$\psi(x) = \frac{1}{n}$$

while the equilibrium investment conditions under vertical integration become

$$\begin{aligned}\psi(x_2) &= \frac{1}{n-1} \int_{-\infty}^{\infty} [1 - G(b(c) + x_1)] dL(c + x_2, n-1), \\ \psi(x_1) &= \int_{-\infty}^{\infty} G(b(c) + x_1) dL(c + x_2, n-1)\end{aligned}$$

and

$$(n-1)\psi(x_2) + \psi(x_1) = 1. \quad (10)$$

Thus equilibrium aggregate investment depends on the shape of the effort cost function.²¹

Proposition 4 *Aggregate effort under vertical integration is the same, higher or lower than without vertical integration if, respectively, $\psi''(x) = 0$, $\psi''(x) < 0$ or $\psi''(x) > 0$ for all $x \geq 0$.*

Equilibrium investments under vertical integration depart from those under non-integration in two important ways. First, if $\psi''(x) \neq 0$, then equilibrium aggregate effort is either higher or lower under vertical integration. Second, even assuming $\psi''(x) = 0$ so that aggregate effort is fixed, vertical integration redeploys effort to the integrated supplier, which is inefficient if $\mu \leq a$ in the shifting support exponential model. This misallocation increases total cost because the marginal cost of effort is increasing.

Using the exponential distribution with a shifting support and assuming an invertible marginal cost of investment function, the equilibrium difference in investments $\Delta = x_1 - x_2$ under vertical integration solves

$$\Delta = \psi^{-1}\left(1 - \frac{n-1}{n} e^{-\mu\Delta - \frac{1}{n-1}}\right) - \psi^{-1}\left(\frac{1}{n} e^{-\mu\Delta - \frac{1}{n-1}}\right)$$

and equilibrium investments are

$$x_1 = \psi^{-1}\left(1 - \frac{n-1}{n} e^{-\mu\Delta - \frac{1}{n-1}}\right) \quad \text{and} \quad x_2 = \psi^{-1}\left(\frac{1}{n} e^{-\mu\Delta - \frac{1}{n-1}}\right).$$

To illustrate how the tradeoffs between vertical integration and non-integration change with the shape of the cost of investment function, consider

$$\psi(x) = \begin{cases} x & \text{for } x \leq \frac{1}{n} \\ x + \gamma(x - \frac{1}{n})^2 & \text{for } x > \frac{1}{n} \end{cases}$$

This marginal cost function adds a quadratic component to the linear marginal cost function for investment levels above equilibrium investment under non-integration, $\frac{1}{n}$. The exponential-quadratic model corresponds to $\gamma = 0$. In that model, if $\mu = 1$, vertical integration raises procurement costs for $n \geq 8$. If $\gamma = 1$, however, non-integration is preferred for $n > 6$. Thus, a more steeply rising marginal cost above the efficient level of investment reduces the attractiveness of vertical integration, because the equilibrium cost-reduction by the integrated firm fails to compensate for the discouragement effect of the sourcing distortion on the investments of the independent sector.

²¹Observe that in the derivation of (10) no specific assumption on G was used. Therefore, Proposition 4 does not hinge on the distribution being exponential.

5.3 Agency Problems

So far we have abstracted from agency problems inside the firm. A conceptually straightforward way to introduce agency costs into the model is to assume a separation of ownership and control for suppliers. Specifically, suppose that the owner of an upstream firm is a risk-neutral principal who delegates cost reducing effort to a risk-averse agent. The utility function of the agent is $U(w) - \Psi(x)$, where $U(w)$ is a strictly increasing and concave function of the wage w and $\Psi(x)$ is the increasing and convex cost of effort. The principal sets the wage as a function of the realized cost, i.e. $w = w(c)$. To implement a particular effort x , the principal chooses a wage function to minimize the expected wage subject to an incentive constraint and a participation constraint (Grossman and Hart, 1983). The solution to this problem determines an expected cost, $C(x)$, that incorporates agency cost. The key point is that the same agency problem exists under non-integration and vertical integration. Thus, the comparative organization analysis can proceed along the same lines as before, replacing $\Psi(x)$ by $C(x)$.

While the exponential cost distribution puts considerable structure on the agency problem, the usual first-order approach to solve a principal-agent problem (Rogerson, 1985) does not apply. This is true for the shifting-support model because out-of-support observations are perfectly informative and, slightly more subtly, for the fixed-support model because large cost observations become extremely informative as the likelihood ratio goes to infinity. In such cases, the principal can get arbitrarily closely to a first-best outcome, and the agency cost goes to zero.

A tractable model to account for a positive agency cost is the truncated fixed-support exponential model, in which given effort x the costs are distributed on the interval $[0, T]$ according to the density $xe^{-cx}/(1 - e^{-Tx})$ with mean $E[c] = \frac{1}{x} + \frac{T}{1 - e^{-Tx}}$, where $T > 0$ is the given point of truncation. It can be shown that this specification satisfies Jewitt's (1988) sufficient conditions for the first-order approach to be valid when T and x are not too large and when $U(w)$ exhibits constant relative risk aversion with a coefficient larger than one half. Intuitively, small values of T and x make the density more uniform, so that no single observation is particularly informative. (The distribution is exactly uniform for $x = 0$.) For a given value of x , the first-order condition for $w(c)$ for cost realization c is

$$\frac{1}{U'(w(c))} = \lambda + \gamma \left[\frac{1}{x} - c + \frac{T}{1 - e^{-Tx}} \right] = \lambda + \gamma [E[c] - c],$$

where λ and γ are Lagrange-multipliers. For $U(w) = \ln w$, which corresponds to a CRRA utility function with a coefficient of relative risk aversion of one, the optimal linear contract

$$w_x(c) = \lambda + \gamma \left[\frac{1}{x} - c + \frac{T}{1 - e^{-Tx}} \right] = \lambda + \gamma [E[c] - c]$$

is linear in realized cost. The cost-of-effort function that is relevant for the principal's investment decision, denoted $C(x)$, is the variable expected cost of inducing the agent to exert effort x . This function is given as $C(x) = E[w_x(c) - w_0]$, where the expectation

is taken using the density $xe^{-cx}/(1 - e^{-Tx})$ and where w_0 is the reservation wage of the agent.²² Thus,

$$C(x) = \lambda^*(x) - w_0,$$

where $\lambda^*(x)$ is the solution value of the Lagrange-multiplier associated with the individual rationality constraint. This function is convex in x for a number of natural specifications. Figure 9 displays $C(x)$ when the agent's cost of effort function is $\Psi(x) = x^2/2$ for $x \leq 0.5$ as a dashed line, the utility of his outside option is 0 and $T = 5$. Rather than being disjoint from our model, agency-problems can thus be accounted for by adjusting (and endogenizing) the investment cost function, if necessary with appropriate adjustments in the cost distributions. Moreover, the near perfect fit of the quadratic approximation $ax^2/2$ to the endogenous investment cost function $C(x)$ suggests that the first-order effect of agency problems is similar to increasing the cost coefficient a in the exogenous cost function $\Psi(x)$. Recall that in the shifting support exponential model larger values of a have the same effect as decreases in μ , which tend to favor vertical integration because they increase cost variance and thereby suppliers' rents. Thus, a natural conjecture is that agency effects tend to favor integration as well because they decrease investments and thereby increase suppliers' rents.²³

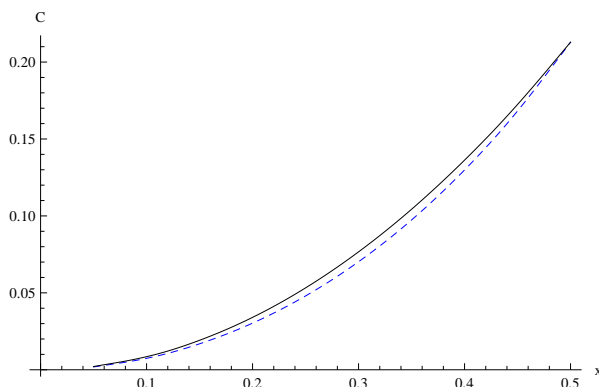


Figure 9: The endogenous investment cost function (dashed) and its quadratic approximation (solid).

5.4 Elastic Demand

While inelastic demand is a useful simplifying assumption that helps illuminate the main tradeoffs between non-integration and integration, it is of course more realistic for the buyer to abandon the project entirely if costs are prohibitively high. Fortunately, it is

²²If the value of the agent's outside option is \bar{u} , w_0 is such that $\ln(w_0) = \bar{u}$. Because the value of the outside option is 0, even hiring an agent who exerts zero effort involves a fixed cost of 1.

²³Because we have not expanded the full equilibrium analysis to the truncated fixed support exponential model, this remains a conjecture. An obstacle to expanding the equilibrium analysis to this setup is that it does not appear to permit closed-form solutions for the equilibrium bidding function under integration.

reasonably straightforward to generalize the analysis to allow for a downward sloping demand curve.

Setup We now assume that the customer has value v for the input, drawn from an exponential probability distribution $F(v) = 1 - e^{-\lambda(v-\alpha)}$ with support $[\alpha, \infty)$. The mean of the exponential distribution is $\alpha + \frac{1}{\lambda}$ and can be interpreted to indicate the expected profitability of the downstream market. The variance, which is $\frac{1}{\lambda^2}$, can be interpreted to indicate uncertainty about product differentiation. This model converges to the inelastic case as $\lambda \rightarrow 0$. The customer learns the realization of v before making the purchase (or production) decision.

Under vertical integration, the investment x_1 in cost reductions is made before the customer learns the realized v . Independent suppliers know F but not v . All other assumptions regarding timing and investment costs are as in Sections 2 and 3. In particular, the cost of exerting effort x is $\frac{a}{2}x^2$ and given investment x_i supplier i 's cost is drawn from the exponential distribution $1 - e^{-\mu(c+x_i-\beta)}$ with support $[\beta - x_i, \infty)$ for all $i = 1, \dots, n$ and with $\mu \leq a$. To simplify the equilibrium analysis, we impose the parameter restriction

$$\beta - \alpha \geq \frac{\mu}{a(\lambda + n\mu)} - \frac{1}{\lambda + (n-1)\mu}, \quad (11)$$

which makes sure that under non-integration the lowest equilibrium bid is always larger than the lowest possible draw of v . Observe that the righthand side in (11) is negative, so that $\beta \geq \alpha$ is sufficient for the condition to be satisfied.²⁴

Bidding As in the inelastic demand case, the bidding function is the same with or without vertical integration. The bidding function with elastic demand is denoted as $b_E(c)$ and given by

$$b_E(c) = c + \frac{1}{\lambda + \mu(n-1)} \quad (12)$$

for $c \geq \alpha - \frac{1}{\lambda + (n-1)\mu}$.²⁵

Profits Consider first non-integration when the symmetric investments of the independent suppliers are x . The profit $\Pi_{EN}^B(x)$ accruing to the buyer is

$$\Pi_{EN}^B(x) = n \int_{b_E(\beta-x)}^{\infty} \int_{\beta-x}^{y(v)} [v - b_E(c)][1 - G(c+x)]^{n-1} dG(c+x) dF(v),$$

²⁴Our analysis can be extended beyond the specific parametrization satisfying (11) and beyond the case where v is drawn from an exponential distribution. However, these generalizations come at the costs of added complexity, which do not appear to be outweighed by sufficient benefits of additional insights.

²⁵To see that $b_E(c)$ is also the bidding function under integration, notice that the customer will buy from the independent suppliers if and only if the lowest submitted bid b is less than $\hat{v} = \min\{v, c_1\}$, where v is the customer's realized value and c_1 the cost draw of the integrated supplier. The distribution of \hat{v} is $1 - (1 - F(\hat{v}))(1 - G(\hat{v} + x_1))$. For our exponential specifications, the probability that $b \leq \hat{v}$ is thus $1 - e^{-(\mu \max\{\hat{v} + x_1 - \beta, 0\} + \lambda \max\{\hat{v} - \alpha, 0\})}$. Arguments that are analogous to those that led to the expression (2) can then be invoked to conclude that $b_E(c)$ is also the bidding function under integration.

where $y(v) = v - \frac{1}{\lambda + \mu(n-1)}$ denotes the inverse of the bidding function $b_E(c)$.

The expected profit $\Pi_{EN}(x_i, x)$ of an independent supplier under non-integration who invests x_i while each of the other suppliers is expected to invest x with $x_i \leq x$ is²⁶

$$\Pi_{EN}(x_i, x) = \int_{b_E(\beta-x_i)}^{\infty} \int_{\beta-x_i}^{y(v)} [b_E(c) - c][1 - G(c+x)]^{n-1} dG(c+x_i) dF(v) - \frac{a}{2} x_i^2.$$

With integration, the buyer's profit is

$$\begin{aligned} \Pi_{EI}^B(x_1, x_2) &= \int_{\alpha}^{\infty} \int_{\beta-x_1}^{\max\{v, \beta-x_1\}} [v - c_1] dG(c_1 + x_1) dF(v) \\ &+ \int_{\beta-x_1}^{\infty} (1 - F(c_1)) \int_{\beta-x_2}^{\max\{y(c_1), \beta-x_2\}} [c_1 - b_E(c_2)] dL(c_2 + x_2, n-1) dG(c_1 + x_1) \\ &+ \int_{\alpha}^{\infty} (1 - G(v + x_1)) \int_{\beta-x_2}^{\max\{y(v), \beta-x_2\}} [v - b_E(c_2)] dL(c_2 + x_2, n-1) dF(v) - \frac{a}{2} x_1^2. \end{aligned}$$

This profit is computed by deriving the expected profit from internal sourcing, which is done in the first line in the above expression, by then adding the cost savings from sourcing from the independent supplier with the lowest bid, which is captured in the second line, and by finally adding in the third line the expansion effect of external sourcing that arises whenever $c_1 > v$ and $b_E(\min\{c_j\}) < v$ with $j \neq 1$.

Given its own investment x_i , investments $x_2 \geq x_i$ by all other non-integrated suppliers and x_1 by the integrated supplier, the expected profit $\Pi_{EI}(x_i, x_1, x_2)$ of an independent supplier under vertical integration is

$$\begin{aligned} \Pi_{EI}(x_i, x_1, x_2) &= \int_{\beta-x_i}^{\infty} [b_E(c) - c][1 - F(b_E(c))][1 - G(b_E(c) + x_1)][1 - G(c + x_2)]^{n-2} dG(c + x_i) \\ &- \frac{a}{2} x_i^2. \end{aligned}$$

Equilibrium Investments Under non-integration, the necessary first-order conditions for the symmetric equilibrium investment x is

$$x = \frac{1}{a} \frac{\mu}{\lambda + n\mu} e^{-\lambda \left[\frac{1}{\lambda + (n-1)\mu} + \beta - \alpha - x \right]}. \quad (13)$$

With vertical integration, the vertically integrated supplier invests x_1 and all $n-1$ independent suppliers invest x_2 satisfying

$$x_1 = x_2 + \frac{1}{a} \frac{\mu}{\lambda + \mu} e^{-\mu(x_1-x_2)} \left[e^{\mu(\beta-\alpha-x_2)} - e^{-\lambda(\beta-\alpha-x_2) - \frac{\lambda+\mu}{\lambda+(n-1)\mu}} \right] \quad (14)$$

and

$$x_2 = \frac{1}{a} \frac{\mu}{\lambda + n\mu} e^{-\lambda(\beta-\alpha-x_2) - \mu(x_1-x_2) - \frac{\lambda+\mu}{\lambda+(n-1)\mu}} \quad (15)$$

according to the necessary first-order conditions for equilibrium. We assume that the second-order conditions are satisfied.

²⁶For $x_i = x + \varepsilon$ with $\varepsilon > 0$ small, the expected profit function has a different functional form. However, the profit function $\Pi_{EN}(x_i, x)$ is continuously differentiable at $x_i = x$.

Profitability of Non-Integration Evaluating (13), (14) and (15) numerically we can determine the buyer's and the independent suppliers' equilibrium profits under non-integration and vertical integration. Denoting these equilibrium payoffs with an asterisk, the analogue for the case of elastic demand to the function $\Phi(n, \mu)$ defined in (8) is

$$\Phi_E(n, \mu, \alpha, \lambda, \beta) := \Pi_{EN}^{B*} + \Pi_{EN}^* - \Pi_{EI}^{B*}.$$

Figure 10 contains contour sets of $\Phi_E(n, \mu, \alpha, \lambda) = 0$ for different values of n in (α, λ) -

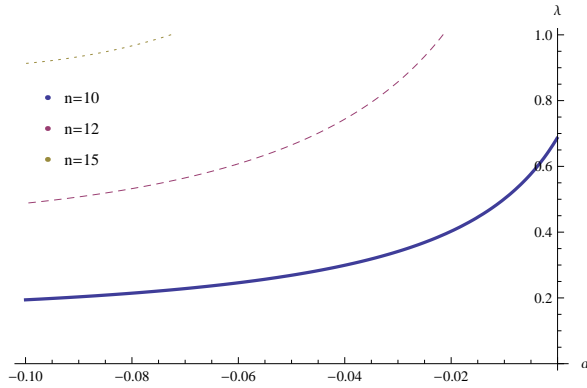


Figure 10: $\Phi_E(n, \mu, \alpha, \lambda) = 0$ for selected parameters.

space with $\mu = 1$ and $\beta = 0$. Non-integration is profitable for a given n for values of α and λ below the corresponding curve.

Social Welfare Effects In the baseline model with inelastic demand, non-integration is always socially optimal because it minimizes the sum of expected costs of production and investment although it is not always an equilibrium outcome. In contrast, with elastic demand vertical integration has an additional, socially beneficial effect because it increases the market demand by inducing production for realizations of costs and values for which there is no production under non-integration, (and because it decreases the lowest cost of production by increasing investment by the integrated supplier).

The numerical analysis for the shifting support exponential model with elastic demand, displayed in Figure 11, reveals that vertical integration is better than non-integration when n is small. As before Φ is the private benefit from divestiture while ΔW is the difference between social welfare under divestiture and under vertical integration. The figure plots Φ and ΔW for $\beta = 0$ and $a = 1$. The figure illustrates a substantial range of upstream market structures for which vertical integration is privately optimal but socially inefficient.

5.5 Reserve Prices

A simple first-price auction models a standard pattern of commercial negotiations that requires minimal commitments. Suppliers make offers and the customer accepts the best

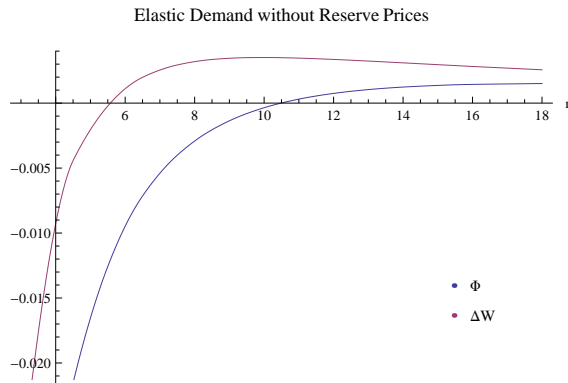


Figure 11: Φ and ΔW as function of n without reserves.

offer. Such a transparent procurement process also is consonant with our motivation that suppliers compete on ideas as well as price, i.e. suppliers innovate on the design of the input in order to reduce costs. In such a setting, our analysis demonstrates a tradeoff between extracting rents and motivating investments of independent suppliers.

If the required input were more standardized, so that acceptable designs were contractible, then the customer plausibly could exercise monopsony power by committing to a reserve price. For the case of inelastic demand, a positive reserve price is suboptimal under non-integration, because the risk of failing to procure the input is disastrous. A reserve price is valuable under vertical integration, however, because the monopsonist is able to fall back on internal sourcing if independent suppliers cannot beat the reserve price. Thus, the ability to set a credible reserve price option appears to favor vertical integration under inelastic demand. Nevertheless, as we show below, a similar benefit-cost trade-off emerges, albeit with more stringent conditions for the superiority of non-integration.

We perform the analysis of the effect of reserve prices within our baseline model with inelastic demand, exponentially distributed costs, and a quadratic cost of effort function with $a = 1$. Suppose that the vertically integrated customer commits to a reserve price r after learning the cost of internal supply c_1 . Given the symmetric equilibrium investment of independent firms x_2 , the optimal reserve price satisfies

$$c_1 = r + \frac{G(r + x_2)}{g(r + x_2)} \equiv \Gamma_{x_2}(r)$$

while the symmetric bidding function $b(c, r)$ depends on the reserve price r according to²⁷

$$b(c, r) = c + \frac{1}{\mu(n-1)} [1 - e^{-\mu(n-1)(r-c)}].$$

In equilibrium, the vertically integrated firm chooses its own investment x_1 to minimize expected procurement cost given x_2 , and each independent supplier invests to

²⁷In the exponential case, the virtual cost function $\Gamma_{x_2}(r)$ is strictly increasing in r for given x_2 , and therefore invertible. We denote its inverse by $\Gamma_{x_2}^{-1}(c_1)$. The bid function $b(c, r)$ solves the usual necessary differential equation for optimal bidding with the boundary condition $b(r, r) = r$.

maximize expected profit given x_1 and x_2 . The optimal reserve given $c_1 \geq \beta - x_2$ then satisfies

$$r(c_1) := \Gamma_{x_2}^{-1}(c_1). \quad (16)$$

Total equilibrium procurement cost (net of investment cost) is equal to the expected cost of internal supply, denoted $E_{x_1}[c_1] = \beta - x_1 + \frac{1}{\mu}$, minus the expected cost savings from sourcing externally:

$$E_{x_1}[c_1] - \int_{\beta-x_2}^{\infty} \int_{\beta-x_2}^{r(c_1)} [c_1 - b(c, r(c_1))] dL(c + x_2, n - 1) dG(c_1 + x_1). \quad (17)$$

Assuming $x_1 > x_2$, the expected profit of a representative independent firm choosing x in the neighborhood of x_2 is equal to the expected value of the markup times the probability of winning the auction:

$$\int_{\beta-x_2}^{\infty} \int_{\beta-x}^{r(c_1)} [b(c, r(c_1)) - c][1 - L(c + x_2, n - 2)] dG(c + x) dG(c_1 + x_1)$$

In equilibrium each independent supplier chooses $x = x_2$.²⁸

The condition for non-integration to be preferred to vertical integration is similar to before. The difference between expected procurement costs under vertical integration and under non-integration must be less than expected supplier profit under non-integration. Figure 12 graphs the difference Φ as a function of n for $\mu = 1$ and compares it to the case without reserves, depicted also in Figure 1. The curve is shifted to the right compared to the base model in which there is no reserve price. Although an optimal reserve price does lower procurement costs under vertical integration, non-integration nevertheless is preferred for n sufficiently large.

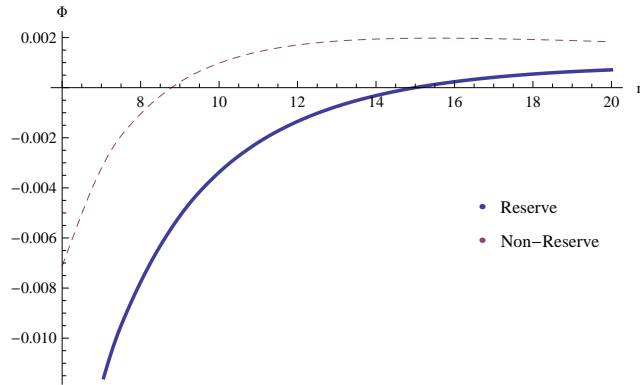


Figure 12: The function Φ with and without reserves for $\mu = 1$.

²⁸We compute the equilibrium investment levels (x_1, x) solving the necessary first-order conditions, presuming the appropriate second-order conditions are satisfied.

Elastic Demand with Reserve The analysis with elastic demand can also be extended to account for optimal reserves. Under non-integration, the optimal reserve will be a function of the realized value v and will be given by the function $r(\cdot)$ defined in (16). With vertical integration, the optimal reserve will be given by the same function $r(\cdot)$, which is now evaluated at $\hat{v} := \min\{c_1, v\}$. Because of continuity, it is intuitive that, with elastic demand and optimal reserves, non-integration will be profitable in the neighborhood of the parameter region for which it is profitable with perfectly inelastic demand and a reserve, that is, for values of λ close to zero. This intuition is corroborated by numerical analysis. Figure 13 plots the buyer's gain from non-integration with reserves, denoted Φ_{ER} , and her gain from non-integration without reserves, Φ_E , as a function of λ for $n = 16$ and $\alpha = \beta = 0$.

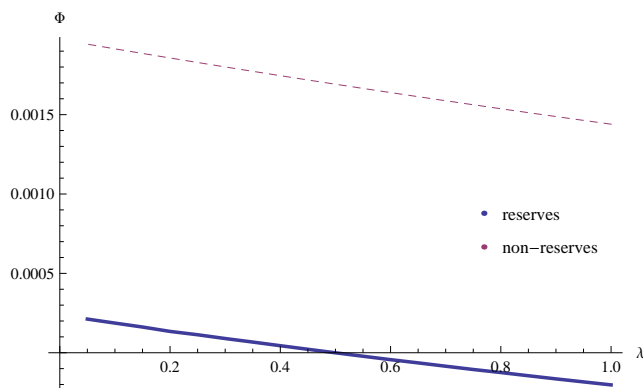


Figure 13: Φ_{ER} and Φ_E as function of λ .

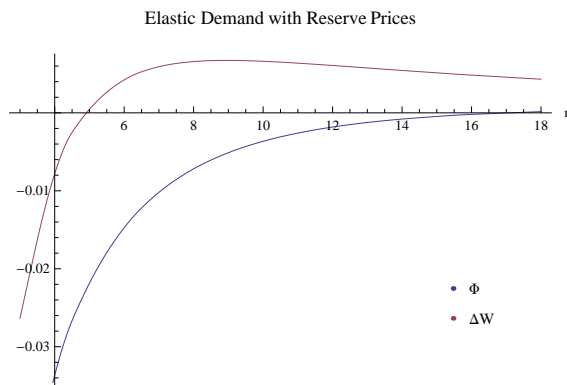


Figure 14: Φ and ΔW as function of n with reserves.

Figure 14 plots the social welfare effects of and the private incentives for divestiture for elastic demand when the customer can set a reserve. Comparing Figure 11 to Figure 14 reveals that the ability to set a reserve hardly matters for the social welfare effects but increases the private benefits from vertical integration, thereby increasing the range in which vertical integration is an equilibrium outcome but not socially desirable.

5.6 Second-price auctions

Of course, we can also extend our model to allow for second-price auctions if we assume, as in the previous subsection with reserves, that the input is sufficiently standardized, so that paying the winner the second lowest bid is meaningful. Without reserves, vertical integration has no effect on the joint surplus of the customer and the integrated supplier, as observed by Bikhchandani, Lippmann and Reade (2005) in the context of preferred suppliers. Consequently, it will not affect investments. Furthermore, a second-price auction with an optimally chosen reserve price has the same outcomes as a first-price auction.²⁹

6 Conclusion

We develop a “make and buy” theory of vertical integration according to which vertical integration creates the opportunity, but not the necessity, to source inputs internally. The comparative theory of non-integration and vertical integration features a key tradeoff between markup avoidance and investment discouragement. In our two-stage model of procurement, upstream suppliers make relationship-specific investments in cost reduction before bidding to supply an input requirement to a downstream customer. Since neither the investment nor the cost realization are observable, independent suppliers exercise some degree of market power by bidding above-cost prices. By unifying the customer and one of the suppliers under common ownership, vertical integration improves their joint profits because it enables the customer to avoid the markup by sourcing internally, keeping investments fixed. Moreover, if the procurer’s demand is elastic, integration increases efficiency and further increases profits, keeping investments fixed, because the markup avoidance also leads to an output expansion. Therefore, just like in Williamson (1985)’s famous puzzle of selective intervention, an integrated firm can do the same as the separate entities do, and sometimes it can do strictly better. This would seemingly lead to the conclusion that vertical integration is inevitably profitable.

In our model, however, vertical integration is not always profitable because it changes the incentives to invest for the suppliers, making equilibrium investment levels smaller for non-integrated suppliers and larger for the integrated supplier. Thus vertical integration effectively reallocates investment away from independent suppliers and toward the integrated supplier. Such a reallocation raises total investment costs because the marginal cost of investment is increasing. The discouragement effect on cost-reducing investments of independent suppliers can be so costly for the integrated firm that it outweighs the aforementioned benefits from vertical integration. Not only does vertical integration change the behavior of the integrated entity in the way suggested by Williamson, but, exactly because it does so, it also changes the behavior of the non-integrated firms. Put differently, vertical integration occurs within a competitive procurement environment,

²⁹Because equilibrium bidding is straightforward under a second-price auction, one might think that a modeling approach based on second-price auctions has computational advantages. However, because typically the optimal reserve cannot be expressed in closed form, one still needs to compute expected profits in equilibrium numerically, so that the gains in tractability are limited.

and depending on how this environment's behavior is affected by vertical integration, vertical integration or non-integration may be the procurer's preferred organizational structure.

The usual statement of Williamson's puzzle interprets the vertical integration decision in a narrow bilateral context, implicitly holding constant the conduct of outside parties. All that seems to matter for the decision are the incentives of the manager of the supply division and the ability of the integrated firm to adapt to the external environment. Accounting for the investment response of independent suppliers, however, creates a tradeoff between the advantages of markup avoidance on the one hand, and the cost disadvantage of realigned investment incentives on the other. In this multilateral setting, the puzzle vanishes. The tradeoff favors vertical integration in some circumstances, and vertical divestiture in others.

Our procurement model is motivated by the idea that specialized suppliers make non-contractible investments in cost-reducing product and process design, consistent with Whitford (2005)'s description of the type of customer-supplier relationships that emerged in manufacturing at the end of the 20th century. Whitford (2005) calls the new organizational form "contested collaboration", colorfully describing it as a "waltz" whereby customer-supplier pairs cooperate gracefully on cost-reducing design innovations, but contest awkwardly over price. The investment stage of our model captures in a stylized way that an original equipment manufacturer outsources cost-reducing design innovations, while bidding in a procurement auction against a preferred supplier captures in a stylized way that supply negotiations do not always proceed efficiently. From this perspective, vertical divestiture is a commitment to a level playing field that encourages independent suppliers to invest in cost reduction.

Our theory of make-and-buy sourcing helps explain a trend toward non-integration in an increasingly global economy marked by faster technological change and shorter product cycles. As original equipment manufacturers improve products incorporating new technologies and functions, the costs of specialized inputs become crucial for productivity. Our theory predicts that vertical divestiture is under certain circumstances an attractive strategy to encourage cost-reducing investments by independent suppliers as it shifts rents in their direction. The conditions favoring vertical divestiture include a moderate cost variance across a greater number of potential suppliers, and greater demand uncertainty. These conditions contribute to reducing supplier markups, thus weakening the markup avoidance advantages of vertical integration. By increasing the competitiveness of upstream markets, globalization strengthens the attraction of non-integration. Recent narrowing of labor cost advantages in China and elsewhere can be interpreted as decreases in upstream competition, favoring more vertical integration going forward.

Our theory also helps explain the documented prevalence of external sourcing in American manufacturing even by vertically integrated firms. In our model, a vertically integrated firm chooses to source externally whenever doing so can meet its input requirements less expensively than self supply. A high variance of costs across potential upstream suppliers with differing design and process approaches is consistent with substantial external sourcing by downstream manufacturers, including those who have the option to source internally. Our theory is also broadly consistent with Stigler's (1951)

idea that vertical integration becomes less attractive as upstream industries mature and become more competitive.

A promising direction for further research is to explore how repeated interaction alters the tradeoff between markup avoidance and investment discouragement. Our one-shot procurement model plausibly captures a procurement environment with infrequent repeated interactions due to relatively long product cycles. A shorter product cycle, however, provides scope for relational contracting to improve incentives.

Embedding the present setup with a single customer into a larger market environment is another promising research direction. In particular, if independent suppliers have other potential customers that benefit from the suppliers' investments, vertical integration could lead to competitive harm as it will still diminish the incentives to invest of independent suppliers. This might lead to a raising-rivals' costs theory of vertical foreclosure in the spirit of Ordoover, Saloner, and Salop (1992).

References

Enghin Atalay, Ali Hortaçsu and Chad Syverson (2014), "Vertical Integration and Input Flows," *American Economic Review*, 104, 1120-1148.

Leandro Arozamena and Estelle Cantillon (2004), "Investment incentives in procurement auctions," *The Review of Economic Studies*, 71 (1), 1-18.

Marie-Laure Allain, Claire Chambolle and Patrick Rey (2016), "Vertical Integration as a Source of Hold-up," *Review of Economic Studies*, 83 (1), 1-25.

Pol Antràs and Davin Chor (2013), "Organizing the Global Value Chain," *Econometrica*, 81 (6), 2127-2204.

Parimal Kanti Bag (1997), "Optimal auction design and R&D," *European Economic Review*, 41, 1655-1674.

Patrick Bolton and Michael Whinston (1993), "Incomplete Contracts, Vertical Integration, and Supply Assurance," *Review of Economic Studies*, 60, 121-148.

Sushil Bikhchandani, Steven Lippmann, and Ryan Reade (2005), "On the Right-of-First-Refusal," *Advances in Theoretical Economics*, 5(1).

Roberto Burguet and Martin Perry (2009), "Preferred Suppliers in Auction Markets," *RAND Journal of Economics*, 40, 283-95.

Roberto Burguet and Martin Perry (2014), "Preferred Suppliers in Asymmetric Auction Markets," *Barcelona GSE Working Paper Series Working Paper # 791*.

Giacomo Calzolari, Leonardo Felli, Johannes Koenen, Giancarlo Spagnolo, and Konrad O. Stahl (2015), "Trust, Competition and Innovation: Theory and Evidence from German Car Manufacturers," *Mimeo*.

- Yeon-Koo Che, Elisabetta Iossa, and Patrick Rey (2015), "Prizes versus Contracts as Incentives for Innovation," *CEIS Working Paper No. 358*.
- Jacques Crémer (2010), "Solving the 'Selective Intervention' Puzzle," *Revue d'Economie Industrielle*, 129/130, 43-56.
- Joseph Farrell and Michael L. Katz (2000), "Innovation, Rent Extraction, and Integration in Systems Markets," *Journal of Industrial Economics* XLVIII, 4, 413-432.
- Robert Gibbons (2005), "Four formal(izable) theories of the firm?," *Journal of Economic Behavior and Organization*, 58, 200-245.
- Sanford Grossman and Oliver Hart (1983), "An Analysis of the Principal-Agent Problem," *Econometrica*, 51, 7-54.
- Sanford Grossman and Oliver Hart (1986), "The Costs and Benefits of Ownership: A Theory of Vertical and Lateral Integration," *Journal of Political Economy*, 94, 691-719.
- Oliver Hart and John Moore (1990), "Property Rights and the Nature of the Firm," *Journal of Political Economy*, 98, 1119-1158.
- Oliver Hart (1995), *Firms, Contracts, and Financial Structure*, Oxford University Press.
- Ian Jewitt (1988), "Justifying the First-Order Approach to Principal-Agent Problems," *Econometrica*, 56(5), 1177-1190.
- Jean-Jacques Laffont and Jean Tirole (1993), *A Theory of Incentives in Procurement and Regulation*, MIT Press.
- William Lazonick and Edward March (2011), "The Rise and Demise of Lucent Technologies," *Business and Economic History On-Line*, Volume 9.
- Joon-Suk Lee (2008), "Favoritism in asymmetric procurement auctions," *International Journal of Industrial Organization*, 26, 14071424.
- Simon Loertscher and Markus Reisinger (2014), "Market Structure and the Competitive Effects of Vertical Integration," *Rand Journal of Economics*, 45(3), 471-494.
- Ildiko Magyari (2016), "Make and Buy," *Mimeo, Columbia University*.
- Janusz A. Ordover, Garth Saloner, and Steven C. Salop (1990), "Equilibrium Vertical Foreclosure," *American Economic Review*, 80(1), 127-42.
- Martin Perry (1989), "Vertical Integration: Determinants and Effects," in R. Schmalensee and R. Willig (eds.), *Handbook of Industrial Organization*. Volume 1, Chapter 3, Elsevier, 135-82

Michael H. Riordan (1990), "What is Vertical Integration?," in M. Aoki, B. Gustafsson and O. E. Williamson (eds.), *The Firm as a Nexus of Treaties*, Sage Publications, 94-111.

Michael H. Riordan (1998), "Anticompetitive Vertical Integration by a Dominant Firm," *American Economic Review*, 88, 1232 - 48.

William P. Rogerson (1985), "The First-Order Approach to Principal-Agent-Problems," *Econometrica*, 53, 1357 - 1369.

William P. Rogerson (1992), "Contractual Solutions to the Hold-Up Problem," *Review of Economic Studies*, 59, 777 - 794.

Michael Spence (1976), "Product Selection, Fixed Costs, and Monopolistic Competition," *Review of Economic Studies*, 43, 217 - 235.

George J. Stigler (1951), "The Division of Labor is Limited by the Extent of the Market," *Journal of Political Economy*, 59, 185 - 193.

Guofu Tan (1992), "Entry and R & D in procurement contracting," *Journal of Economic Theory*, 58 (1), 41-60.

Zhigang Tao, Jiangyong Lu, and Grace Loo (2008), "Pepsi Grows Potatoes in China", Asia Case Research Centre, University of Hong Kong, #HKU693.

Charles J. Thomas (2011), "Vertical mergers in procurement markets," *International Journal of Industrial Organization*, 29, 200 - 209.

Josh Whitford (2005), *The New Old Economy: Networks, Institutions, and the Organizational Transformation of American Manufacturing*, Oxford University Press.

Oliver Williamson (1985), *The Economic Institutions of Capitalism*, The Free Press.

Appendix

We provide short proofs of our formal results in this Appendix and detailed proofs in an Online Appendix. The exception is the proof of Proposition 2, which we provide in full detail here as it appears of sufficient independent interest. The Mathematica files used to numerically generate Figures 5 through 9 are also available online.

Proof of Lemma 1: The optimal bid on the interval $[\beta - x_1, b_{NI}(\beta - x_2)]$ solves $\max_b (b - c_i)(1 - G(b + x_1))$. The solution is $b^*(c_i) = c_i + \frac{1}{\mu}$ if $c_i \geq \beta - x_1 - \frac{1}{\mu}$, and $b^*(c_i) = \beta - x_1$ otherwise. For $b^*(c_i)$ to be on the interval $[\beta - x_1, b_{NI}(\beta - x_2)]$, it further has to be the case that $c_i \leq \beta - x_2 - \frac{n-2}{\mu(n-1)}$. Otherwise, the optimal bidding strategy is $b_{NI}(c_i)$. ■

Proof of Lemma 3: That x_1 and x_2 are as described in (6) follows immediately from the first-order conditions (3) and (5) and the definition of $\Delta^I(n, \mu)$. To see that a non-negative solution to (7) exists and is unique, observe that both sides of the equation are increasing in Δ . The lefthand side of $a\Delta = 1 - e^{-\mu\Delta - \frac{1}{n-1}}$ is linear in Δ and equal to 0 at $\Delta = 0$ while the righthand side is concave and positive for any finite n at $\Delta = 0$. Therefore, a non-negative solution exists and is unique. The derivative of the lefthand side is a while the derivative of the righthand side with respect to Δ is $\mu(1 - a\Delta)$. Because of the aforementioned properties, at $\Delta = \Delta^I(n, \mu)$ we have $a - \mu(1 - a\Delta) > 0$. This implies that the derivative $\Delta^I(n, \mu)$ with respect to μ is

$$\frac{\partial \Delta^I(n, \mu)}{\partial \mu} = \frac{\Delta^I(n, \mu)(1 - a\Delta^I(n, \mu))}{a - \mu(1 - a\Delta^I(n, \mu))} > 0,$$

while its derivative with respect to n is

$$\frac{\partial \Delta^I(n, \mu)}{\partial n} = -\frac{1}{(n-1)^2} \frac{1 - a\Delta^I(n, \mu)}{a - \mu(1 - a\Delta^I(n, \mu))} < 0.$$

This implies that x_1 increases in μ and decreases in n .

Notice from (7) that $a\Delta^I(n, \mu) < 1$. This is equivalent to $\Delta^I(n, \mu) < 1/a$ and implies that $x_2 > 0$. That adding up holds follows immediately. Jointly, $x_2 > 0$ and adding up imply $x_1 < 1$. ■

Proof of Lemma 2: The necessary conditions have been derived in the main text. The second-order condition is satisfied if and only if $\frac{\mu}{a} < \frac{n}{n-1}$. Furthermore,

$$\frac{\partial PC_{NI}^*}{\partial n} = \frac{(\mu - a)(n - 1)^2 - an^2}{\mu an^2(n - 1)^2}$$

is negative if and only if $\frac{\mu}{a} < 1 + \frac{n^2}{(n-1)^2}$, and

$$\frac{\partial \Pi_{NI}^*}{\partial n} = \frac{\mu(n - 1)^2 - an(2n - 1)}{\mu an^2(n - 1)^2}$$

is negative if and only if $\frac{\mu}{a} < \left(1 + \frac{n}{n-1}\right)$. ■

Proof of Lemma 4: The arguments in the main text imply that PC_I^* and Π_I^* are the equilibrium payoffs of the integrated firm and the independent suppliers with $\Delta = \Delta^I$ given by (7) and x_1 and x_2 given by (6). Furthermore, first-order conditions are satisfied by construction. So it remains to verify that these conditions are sufficient.

Case 1: For $x_i < x_2$, using (4),

$$\frac{\partial^2 \Pi_I(x_i, x_1, x_2)}{\partial x_i^2} = \frac{\mu(n-1)}{n} e^{-\mu\Delta - \frac{1}{n-1} + \mu(n-1)(x_i - x_2)} - a \leq 0$$

if and only if

$$\frac{\mu}{a} \leq \frac{n}{(n-1)(1-a\Delta)}.$$

Since $a\Delta < 1$, this second-order condition is always satisfied if the necessary and sufficient condition for the existence of a symmetric equilibrium under non-integration holds.

Case 2: Let $\hat{x} = x_2 + \frac{n-2}{\mu(n-1)}$ and consider deviations by i such that such that $c_i \in [\beta - \hat{x}, \beta - x_2]$ occur with positive probability, and no lower c_i can occur. From Lemma 1, the optimal bid for cost realizations in this interval is $\beta - x_2 + \frac{1}{\mu(n-1)}$, and for $x_i \in [x_2, \hat{x}]$, the profit function for the deviating supplier i is

$$\Pi_I(x_i, x_1, x_2) = e^{-\mu\Delta - \frac{1}{n-1}} \left[x_i - x_2 - \frac{n-2}{\mu(n-1)} + e^{-\mu(x_i - x_2)} \frac{n-1}{\mu n} \right] - \frac{a}{2} x_i^2.$$

The deviator's profit function is concave in x_i , and maximized at $x_i = x_2$ on this interval if and only if

$$\frac{\mu}{a} < \frac{n}{(n-1)(1-a\Delta)}.$$

Case 3: For $x_i \in [\hat{x}, x_1 + \frac{1}{\mu}]$, defining $y := \mu(x_i - x_2) - \frac{n-2}{n-1}$, we can express the deviator's profit as

$$\hat{\Pi}_I(y, x_1, x_2) = \frac{1-a\Delta}{\mu} \left[e^{-y - \frac{n-2}{n-1}} \frac{n-1}{n} + \frac{1}{2} [e^y - e^{-y}] \right] - \frac{a}{2} \left(\frac{1}{\mu} \left[y + \frac{n-2}{n-1} \right] + \frac{1}{an} (1-a\Delta) \right)^2,$$

for $y \in [0, \mu\Delta + \frac{1}{n-1}]$. This function is decreasing in y for all $y \in [0, \mu\Delta + \frac{1}{n-1}]$.

Case 4: For $x_i > x_1 + \frac{1}{\mu}$, the expected profit of a deviating non-integrated supplier is

$$\Pi_I(x_i, x_1, x_2) = \frac{1}{\mu} \frac{n-1}{n} e^{-\mu\Delta - \frac{1}{n-1} - \mu(x_i - x_2)} + \frac{1}{2\mu} e^{-\mu(x_i - x_1) + 1} \left[1 - e^{-2(\mu\Delta - \frac{1}{n-1})} \right] + x_i - x_1 - \frac{1}{\mu} - \frac{a}{2} x_i^2,$$

which is decreasing in x_i if $\frac{\mu}{a} \leq \frac{n}{n-1}$. ■

Proof of Proposition 1: Inserting the expressions obtained in Lemmas 2 and 4 yields

$$PC_I^* + \Pi_{NI}^* = \beta + \frac{a-\mu}{\mu} x_1 + \frac{a}{2} x_1^2 + \frac{1}{n} \left[\frac{1}{\mu(n-1)} - \frac{1}{2an} \right].$$

As $PC_{NI}^* = \beta - \frac{1}{an} + \frac{1}{\mu} \frac{2n-1}{n(n-1)}$, vertical divestiture is thus jointly profitable if and only if

$$\beta + \frac{a-\mu}{\mu}x_1 + \frac{a}{2}x_1^2 + \frac{1}{n} \left[\frac{1}{\mu(n-1)} - \frac{1}{2an} \right] > \beta - \frac{1}{an} + \frac{1}{\mu} \frac{2n-1}{n(n-1)},$$

which, after substituting $x_1 = \frac{1}{an} + \frac{n-1}{n}\Delta^I$ is equivalent to the inequality in the proposition. ■

Proof of Proposition 2: Substituting the expressions for the exponential case gives us the following expression for the expected production cost:

$$EC(\mathbf{x}) = \mu \sum_{j=1}^n j e^{-\mu X_j} \int_{\beta-x_j}^{\beta-x_{j+1}} c e^{-j\mu(c-\beta)} dc = \sum_{j=1}^n S_j,$$

where $X_j := \sum_{i=1}^j x_i$, $x_{n+1} := -\infty$, and

$$S_j := e^{-\mu(X_j-jx_j)} \left[\beta - x_j + \frac{1}{j\mu} - \left(\beta - x_{j+1} + \frac{1}{j\mu} \right) e^{-j\mu(x_j-x_{j+1})} \right].$$

It follows then that

$$\frac{\partial EC(\mathbf{x})}{\partial x_j} = \mu e^{-\mu(X_j-jx_j)} (\beta - x_j) - \mu \sum_{i=j}^n S_i$$

for all $j = 1, \dots, n$ and

$$\frac{\partial EC(\mathbf{x})}{\partial x_j} - \frac{\partial EC(\mathbf{x})}{\partial x_{j+1}} = -\frac{1}{j} e^{-\mu(X_j-jx_j)} (-1 + e^{-\mu(x_j-x_{j+1})})$$

for all $j < n$.

Finally,

$$\frac{\partial S_n}{\partial x_n} = \mu(n-1) e^{-\mu(X_n-nx_n)} \left(\beta - x_n + \frac{1}{n\mu} \right)$$

and the derivative of $EC(\mathbf{x})$ with respect to x_n is

$$\frac{\partial EC(\mathbf{x})}{\partial x_n} = \frac{\partial S_n}{\partial x_n} + \frac{\partial S_{n-1}}{\partial x_n} = -\frac{1}{n} e^{-\mu(X_n-nx_n)}.$$

Using the first-order condition for x_n , we get the boundary condition

$$\frac{1}{n} e^{-\mu(X_n-nx_n)} = ax_n. \quad (18)$$

We now analyze the second-order conditions for a cost minimum. At symmetry, i.e. with $x_i = x$ for all i , the second partials of the total cost $TC(\mathbf{x}) := EC(\mathbf{x}) + \frac{a}{2} \sum_{i=1}^n x_i^2$ are

$$\frac{\partial^2 TC(\mathbf{x})}{\partial x_n^2} = -\mu \frac{n-1}{n} + a \quad \text{and} \quad \frac{\partial^2 TC(\mathbf{x})}{\partial x_n \partial x_{n-1}} = \frac{\mu}{n}.$$

Thus, at a symmetric solution the Hessian matrix has $a - \mu \frac{n-1}{n}$ on the main diagonal and $\frac{\mu}{n}$ everywhere else. Thus, it is positive semi-definite, and therefore a local minimum, if and only if $a \geq \mu$.

We next show that the symmetric solution is also a global minimum whenever it is a local minimum. Subtracting $\frac{\partial TC(\mathbf{x})}{\partial x_i}$ from $\frac{\partial TC(\mathbf{x})}{\partial x_{i+1}}$ and simplifying yields for $i = 1, \dots, n-2$ with $n > 2$ a system of first-order difference equations

$$\frac{1}{i} e^{-\mu x_i} [e^{i\mu x_{i+1}} - e^{i\mu x_i}] = a(x_{i+1} - x_i) \quad (19)$$

with the boundary condition (18) and the constraints $x_i \geq x_{i+1}$. Notice that the symmetric solution $x_i = \frac{1}{an}$ for all $i = 1, \dots, n$ is always a solution of this system. We are now going to show that for $a \geq \mu$ it is the unique solution.

Notice first that the right-hand side of (19) is, trivially, linear in x_{i+1} with slope a . The left-hand side of (19) is increasing and convex in x_{i+1} with slope μ at symmetry. Fix then an arbitrary x_1 . Provided $\mu \leq a$, $x_2 = x_1$ is the unique solution to (19). Iterating the argument, we get that $x_i = x_1$ is the unique solution to (19) for all $i = 1, \dots, n-1$. Notice then that the left-hand side of (18) is convex and increasing in x_n with slope $\mu \frac{n-1}{n}$ at symmetry. Since $\mu \leq a$ implies $\mu \frac{n-1}{n} < a$, where a is the slope of the right-hand side of (18), it follows that symmetry, i.e. $x_n = x_1$, is the unique solution to (18). But at symmetry, (18) implies $x_n = \frac{1}{an}$. Thus, for $\mu \leq a$, $x_i = \frac{1}{an}$ for all $i = 1, \dots, n$ is the unique solution.

We now characterize the planner's solution for the case $\mu > a$. We first prove a more general "adding-up" result.³⁰ The distribution $L(c; \mathbf{x})$ of the minimum cost c given investments \mathbf{x} is given as

$$L(c; \mathbf{x}) = 1 - \prod_{i=1}^n (1 - G(c + x_i))$$

with support $[\underline{c}(\mathbf{x}), \infty)$; see also (1). The expected cost of production is $EC(\mathbf{x}) = \int_{\underline{c}(\mathbf{x})}^{\infty} c dL(c; \mathbf{x})$ and total cost is $TC(\mathbf{x}) = EC(\mathbf{x}) + \frac{a}{2} \sum_{i=1}^n x_i$.

Integrating $\int_{\underline{c}(\mathbf{x})}^{\infty} c dL(c; \mathbf{x})$ by parts we get $EC(\mathbf{x}) = \underline{c}(\mathbf{x}) + \int_{\underline{c}(\mathbf{x})}^{\infty} [1 - L(c; \mathbf{x})] dc$. Taking the derivative of $EC(\mathbf{x})$ with respect to x_i gives

$$\frac{\partial EC(\mathbf{x})}{\partial x_i} = - \int_{\underline{c}(\mathbf{x})}^{\infty} g(c + x_i) \prod_{j \neq i}^n (1 - G(c + x_j)) dc,$$

where $g(c + x_i)$ is the derivative of $G(c + x_i)$. At an optimum, we have $\frac{\partial EC(\mathbf{x})}{\partial x_i} + ax_i = 0$ for all i . Adding up over all i yields

$$- \int_{\underline{c}(\mathbf{x})}^{\infty} \sum_{i=1}^n g(c + x_i) \prod_{j \neq i}^n (1 - G(c + x_j)) dc + a \sum_{i=1}^n x_i = 0. \quad (20)$$

³⁰The argument that follows does not depend on the cost distribution being exponential.

Observe then that $dL(c; \mathbf{x}) = \sum_{i=1}^n g(c + x_i) \prod_{j \neq i}^n (1 - G(c + x_j)) dc$. Thus, (20) can be written as

$$- \int_{\underline{c}(\mathbf{x})}^{\infty} dL(c; \mathbf{x}) + a \sum_{i=1}^n x_i = 0.$$

Since $\int_{\underline{c}(\mathbf{x})}^{\infty} dL(c; \mathbf{x}) = 1$, this implies that at an optimum investments always add up to a constant, that is

$$\sum_{i=1}^n x_i = \frac{1}{a}. \quad (21)$$

Next we show that the planner's asymmetric solution consists of two different investment levels only. Let $k_1 = \max\{i | x_i = x_1\}$. The difference equation (19) then implies

$$ak_1(x_{k_1+1} - x_1) = e^{-\mu k_1 x_1} (e^{\mu k_1 x_{k_1+1}} - e^{\mu k_1 x_1}) = e^{\mu k_1 (x_{k_1+1} - x_1)} - 1.$$

Letting $\Delta_1 = k_1(x_1 - x_{k_1+1})$ this is the same as

$$a\Delta_1 = 1 - e^{-\mu\Delta_1} > 0. \quad (22)$$

Next let $k_2 = \max\{i | x_i = x_{k_1+1}\}$ and let $\Delta_2 = k_2(x_{k_1} - x_{k_2})$. Then (19) implies

$$a\Delta_2 = e^{-\mu\Delta_1} (e^{\mu\Delta_2} - 1).$$

This equation has two possible solutions: (i) $\Delta_2 = 0$ and (ii) $\Delta_2 > 0$. Solution (i) implies $k_2 = n$. The adding-up constraint (21) implies $\Delta_1 = \frac{1}{a} - nx_n$ and the boundary condition (18) and (22) imply $anx_n = e^{-\mu(1/a - nx_n)}$. Thus, the solution with $\Delta_2 = 0$ is admissible. Next we show that the other solution, i.e. (ii), is not.

To see this, observe that equalities (18) and (22) and the adding-up constraint (21) imply

$$1 \geq a(nx_n + \Delta_1) = 1 - e^{-\mu\Delta_1} + e^{-\mu(1/a - nx_n)},$$

where the inequality is strict if $\Delta_2 > 0$. But this implies

$$e^{-\mu\Delta_1} \geq e^{-\mu(1/a - nx_n)},$$

which in turn implies $1/a - nx_n \leq \Delta_1$. Taken together, this implies

$$\Delta_1 + nx_n = \frac{1}{a}.$$

That is, Δ_1 and nx_n add up to $1/a$. Thus, $\Delta_2 > 0$ would violate the adding-up constraint. Hence, we conclude that $\Delta_2 = 0$ and thus $k_2 = n$.

The final step shows that $k_1 = 1$. We show that by assuming to the contrary that there are $k > 1$ suppliers who invest x_1 and then showing the reallocating $\varepsilon/(k-1) > 0$ from each of them to supplier 1 decreases total costs. Using a change of variables $y = \beta - c$, the part of total costs affected by this reallocation of investment can be shown to be

$$\begin{aligned} & \mu e^{-\mu(x_1 + \varepsilon)} \int_{-x_1}^{-x_2 + \frac{\varepsilon}{k-1}} ye^{-\mu y} dy + (k-1)\mu e^{-\mu(k-1)x_2 + x_1} \int_{-x_2 + \frac{\varepsilon}{k-1}}^{-x_3} ye^{-\mu y} dy \\ & + \frac{a}{2} [(x_1 + \varepsilon)^2 + (k-1)(x_2 + \varepsilon/(k-1))^2]. \end{aligned}$$

Taking the derivative with respect to ε , evaluated at $x_1 = x_2 = x$ and $\varepsilon = 0$, gives

$$\mu x e^{-\mu x} \left[e^{-\mu k x} - \frac{k}{k-1} e^{-\mu x} \right] < 0.$$

Thus, this reallocation of investments decreases total costs. This is a contradiction to $k > 1$ being optimal. ■

Proof of Proposition 3: Taking the sourcing distortion $\frac{1}{\mu(n-1)}$ as given, the expected cost of production given investment levels x_1 and x_2 under the second-best scenario, denoted $EC^{SB}(x_1, x_2)$, is

$$\begin{aligned} EC^{SB}(x_1, x_2) &= \mu \int_{\beta-x_1}^{\beta-x_2+\frac{1}{\mu(n-1)}} c e^{-\mu(c+x_1-\beta)} dc + \mu \int_{\beta-x_2+\frac{1}{\mu(n-1)}}^{\infty} c e^{-\mu(c+x_1-\beta)} e^{-\mu(n-1)(c-\frac{1}{\mu(n-1)}+x_2-\beta)} dc \\ &+ \mu(n-1) \int_{\beta-x_2}^{\infty} c e^{-\mu(c+\frac{1}{\mu(n-1)}+x_1-\beta)} e^{-\mu(n-1)(c+x_2-\beta)} dc. \end{aligned}$$

The first integral captures those cost realizations of the integrated supplier for which this supplier produces with probability 1. The second integral represents the instances in which the integrated supplier produces when the lowest cost draw of the independent suppliers is sufficiently high but not otherwise. The last integral covers those cost realizations for which the independent supplier with the lowest cost draw produces. Integrating and simplifying yields

$$EC^{SB}(x_1, x_2) = \beta - x_1 + \frac{1}{\mu} - \frac{1}{\mu} e^{-\mu(x_1-x_2)-\frac{1}{n-1}}.$$

At an optimum,

$$\frac{\partial EC^{SB}(x_1, x_2)}{\partial x_1} + a x_1 = -1 + e^{-\mu(x_1-x_2)-\frac{1}{n-1}} + a x_1 = 0$$

and

$$\frac{\partial EC^{SB}(x_1, x_2)}{\partial x_2} + (n-1)a x_2 = -e^{-\mu(x_1-x_2)-\frac{1}{n-1}} + (n-1)a x_2 = 0.$$

Taking the difference then gives

$$a(x_1 - x_2) = 1 - \frac{n}{n-1} e^{-\mu(x_1-x_2)-\frac{1}{n-1}}.$$

The solution Δ^{SB} to the equation $a\Delta = 1 - \frac{n}{n-1} e^{-\mu\Delta-\frac{1}{n-1}}$ cannot be 0 because $\frac{n}{n-1} e^{-\frac{1}{n-1}} < 1$ for any finite $n \geq 2$.

To see that $\Delta^{SB} < \Delta^I$, recall that Δ^I is the positive solution to $a\Delta = 1 - e^{-\mu\Delta-\frac{1}{n-1}}$. The left-hand side of both equations being the same (and increasing in Δ) and the right-hand side of either equation being decreasing in Δ but being strictly smaller for the equation that determines Δ^{SB} , the result follows. ■

Proof of Proposition 4: Under nonintegration, equilibrium effort is given by $\psi(x^*) = \frac{1}{n}$. On the other hand, rewriting the consolidated equilibrium condition with vertical integration, (10), as $\frac{n-1}{n}\psi(x_2) + \frac{1}{n}\psi(x_1) = \frac{1}{n}$, it follows from Jensen's inequality that $(n-1)x_2 + x_1 = nx^*$ if $\psi'' = 0$ and $(n-1)x_2 + x_1 > nx^*$ if $\psi'' < 0$ and $(n-1)x_2 + x_1 < nx^*$ if $\psi'' > 0$. ■

Derivation of the bidding function $b_E(c)$ in (12) Under non-integration, given symmetric investments x , the revelation principle requires that a symmetric equilibrium bidding strategy $b(c)$ be such that

$$c = \arg \max_z \{ [b(z) - c] [1 - F(b(z))] [1 - G(c + x)]^{n-1} \}.$$

For F and G exponential, this condition implies that

$$b_{NI}(c) = \begin{cases} c + \frac{1}{(n-1)\mu} - \left[\frac{1}{(n-1)\mu} - \frac{1}{\lambda + (n-1)\mu} \right] e^{-(n-1)\mu(\hat{c}-c)} & \text{if } c \leq \alpha - \frac{1}{\lambda + (n-1)\mu} \\ c + \frac{1}{\lambda + (n-1)\mu} & \text{if } c > \alpha - \frac{1}{\lambda + (n-1)\mu} \end{cases}.$$

For integration, a similar analysis yields the same result. ■

Equilibrium investments under integration in the fixed support model For a given $z > 0$, the integrated supplier optimally invests

$$x_1(z) = \sqrt[3]{1 - \frac{(n-1)z[3 + z(2z-6) + 2n(4 + (n-3)z)]e^{-\frac{1}{1+(n-2)z}}}{[1 + (n-2)z][1 + (n-1)z]^2}}$$

and the independent suppliers symmetrically invest

$$x_2(z) = \sqrt[3]{\frac{z^2 e^{-\frac{1}{1+(n-2)z}}}{[1 + (n-1)z]^2}}$$

Dividing $x_2(z)$ by $x_1(z)$ and simplifying yields the fixed point

$$z = \sqrt[3]{\frac{z^2}{[1 + (n-1)z]^2 e^{\frac{1}{1+(n-2)z}} - \frac{(n-1)\{3z + z^2[(2z-6) + 4n + n(n-3)z]\}}{1+(n-2)z}}}$$