

**AN EFFICIENCY EXPLANATION  
FOR WHY FIRMS SECOND SOURCE**

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## **AN EFFICIENCY EXPLANATION FOR WHY FIRMS SECOND SOURCE**

### **Abstract**

**This paper scrutinizes the practice of second-sourcing, or contracting-out of production to competitors, by firms facing technological and demand uncertainty. In contrast to the existing literature which focuses on precluding opportunistic behavior by monopoly suppliers, I show how sellers and buyers can both benefit from the practice. Second-sourcing allows producers to avoid firm-specific uncertainty (eg., R&D risk), and to increase their flexibility in responding to industry-wide uncertainty (eg., demand risk). Buyers benefit through a reduced probability of stock-outs and a lower average cost for their inputs. The semiconductor industry serves as an illustrative example throughout.**

## I . INTRODUCTION

This paper investigates the practice of second-sourcing by firms facing technological and demand uncertainty. Second-sourcing encompasses agreements between buyers and sellers requiring that a firm license its proprietary technology to rivals, as well as agreements among potential suppliers to share production facilities under particular circumstances. The first type of agreement is usually explained in the literature as guaranteeing buyers “a secure supply at a fair price.” A critical feature of this type of second-sourcing is that control over production and pricing decisions resides with each supplier. The second type of agreement, where control over these decisions remains with the owner of the production technology, has largely been overlooked by the literature. A primary motivation for this type of second-sourcing, I will argue, is to rationalize firms’ investment and production decisions to achieve a more efficient matching between productive capacity and market demand. The purpose of this paper is to indicate that both buyers and sellers in a market can benefit from this latter type of second-sourcing agreement, to identify the sources of these potential benefits, and to identify the conditions under which these potential gains will actually be realized.

The central argument of the paper may be summarized as follows. Consider an industry operating in an environment of R&D and demand uncertainty. Each firm’s decision about how much to invest in R&D and production inputs (plant capacity) will depend upon its expectation of the probability of winning an R&D (patent) race, and upon its expectation of future downstream demand. Acting non-cooperatively, firms will “over-invest” in R&D because of the usual common pool problem. Additionally, under plausible expectational and cost assumptions, the firm that wins the R&D race will have insufficient internal production capacity to satisfy expected demand. Conversely, ‘losers’ will be left with idle production capacity. Under a variety of cost and demand conditions to be specified, each firm can expect to earn higher profits if producers agree collectively to second-source unsatisfied demand. In equilibrium, some demand will be met from the production facilities of the losers in the R&D race, allowing a more efficient allocation of industry demand across aggregate installed capacity. Furthermore, if firms agree to

second-source prior to selecting their optimal capacities, they can plan to have an appropriate *aggregate* level of capacity to service expected demand, unlike in the non-cooperative equilibrium. The problem of socially-inefficient R&D investment, however, may either be alleviated or exacerbated by second-sourcing. Downstream buyers will also benefit from second-sourcing. The increased allocative efficiency leads to a reduced probability of stock-outs and a lower average cost for their purchases. Moreover, second-sourcing can prevent post-contractual opportunistic behavior by sellers towards buyers.

Until very recently, second-sourcing had attracted surprisingly little interest among economists despite its adoption by firms in a wide range of industries. Moreover, the existing literature has analyzed second-sourcing exclusively in a principal-agent setting, focusing upon purchasers' desire to prevent opportunistic behavior by a monopoly supplier. For example, Anton and Yao [1987] consider a setting in which, mid-way through the production stage, a potential second source bids against the developer for the right to supply the remaining demand. In their model, second-sourcing can induce developers to reveal private cost information, forcing bid prices closer to firms' true average costs. Demski, Sappington and Spiller [1987] also show how second-sourcing can discipline an incumbent's behavior by providing buyers with an informative signal about the developer's costs that limits its rents. Rob [1986] and Riordan and Sappington [1989] study similar problems and while they identify pro-competitive effects, they also note that second-sourcing could adversely affect firms' R&D efforts and thereby increase production costs. The authors disagree about the net consumer welfare effect of second-sourcing. Each of the above analyses focuses upon situations in which the interests of purchasers and suppliers are directly opposed. Second-sourcing is intended to pit multiple suppliers against one another in order to drive prices closer to average cost.

A slightly different emphasis is provided by Farrell and Gallini [1988] and Shepard [1987] who develop models explaining why a monopoly supplier may itself introduce second-sourcing. Here, second-sourcing can signal a commitment by the monopolist not to behave opportunistically in the future by raising price or debasing product quality.<sup>1</sup> If the commitment is

credible, the monopolist can earn higher expected profits despite creating product market competition for itself. Importantly, the source of these higher expected profits lies in increased revenues and not in lower production costs. Again, therefore, second-sourcing is viewed as a production arrangement favored either by suppliers or purchasers, but not both.

While such models do explain some second-sourcing activity they do not explain why in many industries we observe four, five or even six second-sourced suppliers.<sup>2</sup> The presence of two or three competing suppliers in a market should be sufficient to discipline developers' contract bidding strategies or to induce firms to reveal private cost information. Indeed, the models of Anton and Yao [1987], Demski, Sappington and Spiller [1987], Riordan and Sappington [1989] and Rob [1986] all rely upon the presence of multiple firms at the *bidding* stage, not on competition in the actual *production* of the good, to discipline suppliers' behavior.<sup>3</sup> This focus on competition in bidding is reminiscent of Demsetz [1968]'s competition among "potential rivals."

The multiplicity of second-sources in many industries therefore poses an empirical dilemma for the existing literature. To explain this apparent puzzle, I suggest an alternative explanation for second-sourcing that shows why sellers may voluntarily opt for such arrangements and why *multiple* second-sources will be preferred. The explanation offered centers upon the ability of second-sourcing to enable potential suppliers to avoid firm-specific risk (eg., R&D uncertainty) and to increase their flexibility in responding to non-diversifiable or industry-wide risk (eg., demand uncertainty). It explains therefore why second-sourcing can be an efficient market organization for producers to adopt. The paper analyzes second-sourcing in a market setting rather than within the usual principal-agent framework, and this shift in emphasis accounts for much of the difference in the two approaches' conclusions.

To motivate the model and illustrate the paper's main findings, it is helpful to consider the example of computer chip production, an industry where suppliers have often relied upon second-sourcing. Developers of a particular chip frequently contract-out production to their competitors according to the terms of a pre-arranged second-sourcing agreement.

Semiconductor firms typically begin construction of plant capacity (“clean rooms”) shortly after starting the R&D for a new chip design, and well before they have completed development of the circuitry for the chip that will be produced in those facilities. The sizable financial costs associated with production delays and relative ease of installing chip-producing equipment after plant capacity is built make such a strategy optimal. Firms’ investments in plant capacity are thus based on their subjective probability of winning the race to develop the new chip, and on their expectation of downstream demand. Because of the R&D uncertainty and unsalvageability of much of its plant investment should it not win the patent race, the winning firm’s capacity will often be insufficient to satisfy actual demand for the new chip. Idle capacity held by losing firms is typically the cheapest and most readily available source of additional production capacity for the winning firm. Second-sourcing requires supplying duplicates of the templates for stamping out the chip’s circuitry to firms with idle capacity.<sup>4</sup> Retooling of those firms’ plants to produce a competitor’s design is a relatively straightforward task. Importantly, control over production and pricing decisions remains with the chip’s original developer.

The paper is organized as follows. Section II presents a model of competition under technological and demand uncertainty. The industry non-cooperative equilibrium is derived in Section III. Section IV derives the corresponding equilibrium with second-sourcing and outlines the conditions under which producers will choose to second-source. The evidence on second-sourcing activity in the semiconductor industry is found to support the model’s central predictions. In Section V, I discuss the benefits received by purchasers from second-sourcing and contrast their relative importance with the opportunism argument stressed in the existing literature. Section VI contains some concluding remarks.

## II . THE MODEL

In this section, I present a simple three-period model of competition under R&D and demand uncertainty. The three periods of competition are the research stage, capacity acquisition stage, and production era. The model’s timing is summarized in Figure 1. Suppose that a group of

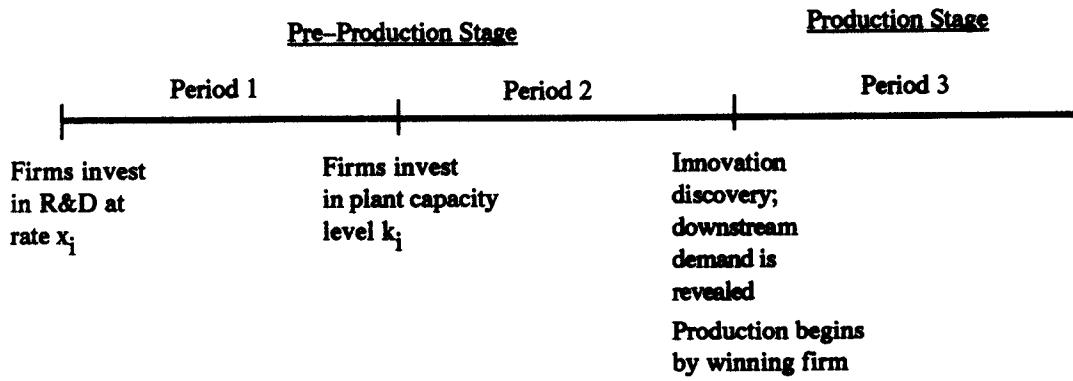
downstream producers require an essential factor of production for their manufacturing process, and suppose further that they find it more efficient to contract-out its development and production than to perform these activities in-house.<sup>5</sup> The number of potential suppliers for this factor of production is taken as given throughout the analysis.

### **INSERT FIGURE 1 ABOUT HERE**

In period one, upstream firms compete to develop the input and its production technology. The R&D race is of the winner-take-all form: the firm that develops the (joint product and process) innovation first is assumed to be able to protect its property rights fully, either by keeping the innovation secret or through the patent system.<sup>6</sup> Alternatively, reverse-engineering or inventing around a patent may be prohibitively costly, either in terms of financial resources or delay costs. In either case, only the winner of the R&D race will advance to the production stage in period three.

In period two, after selecting their R&D programs but prior to knowing the outcome of the race, firms select a stock of an essential production input in anticipation of the subsequent production stage. This essential input might be special production facilities, skilled production workers, or some other key intermediate input. For concreteness, I will refer to it as “plant capacity” to underscore the fact that the input’s stock places an upper bound on the upstream firm’s output rate. An important assumption is that some fraction of the firm’s capacity must be committed to at the beginning of the second period. Moreover, acquisition of additional internal capacity after the pre-production stage will be assumed to involve a sufficiently long delay (relative to the length of the product cycle) or sufficiently higher cost to firms so as to render it unprofitable.<sup>7</sup> These two assumptions are reasonable for many industries in which one observes second-sourcing agreements, including semiconductors, fashion apparel, robotics and biotechnology. Firms will thus base their capacity investment decision on two variables: the probability of their winning the R&D race (and thus proceeding to the production stage), and expected demand by downstream buyers.

**Figure 1**  
**The Model's Timing**





Finally, period three — the production era — begins once one firm makes the requisite innovation discovery. Industry demand becomes known, and the firm that won the R&D race chooses its rate of production.<sup>8</sup> While the winning firm acts as a monopoly supplier in this period, its output rate is potentially constrained by its installed capacity. If the monopoly output rate is less than the firm's capacity, the constraint does not bind. If the reverse is true, the monopolist produces at its capacity.

The essential components of the model — the R&D contest, the specification of industry demand and the nature of firms' costs — are now formally specified.

- **The R&D Contest:** Following Lee and Wilde [1980], firms compete in an R&D race by investing in research at the (constant) rate of  $x_i$  dollars until a discovery is made by one firm in the industry. By incurring the flow cost  $x_i$ , the  $i^{\text{th}}$  firm ( $i = 1, \dots, n$ ) in effect "purchases" a random variable  $\tau(x_i)$  that denotes its uncertain discovery date for the innovation.<sup>9</sup> This discovery date is distributed exponentially according to the relationship:<sup>10</sup>

$$(1) \quad \text{Prob}(\tau \leq t) = F(t; x_i) = 1 - e^{-v(x_i)t},$$

where  $v(x_i)$  is the instantaneous probability of discovery when the firm spends  $x_i$  on R&D (the hazard rate). This firm's expected innovation discovery date,  $E[\tau(x_i)]$ , is  $v(x_i)^{-1}$ , a decreasing function of its R&D investment. The industry's expected discovery date,  $E[\min \tau(x_j)]$ , is given by  $[\sum_{j=1}^n v(x_j)]^{-1}$ . I make the usual assumptions for this class of R&D models that  $v(x_i)$  is twice

differentiable, strictly increasing, and may exhibit a range of initially increasing returns to scale.<sup>11</sup> The probability that the  $i^{\text{th}}$  firm wins the R&D game,  $p_i$ , can be shown to equal

$$(2) \quad p(x_i, \sum_{j \neq i} x_j) = p_i = v(x_i) / \sum_{j=1}^n v(x_j).$$

Finally, this firm's expected R&D investment is given by  $(x_i / \sum_{j=1}^n v(x_j))$ .<sup>12</sup>

- **Industry Demand:** Upstream firms compete for the right to supply the essential production input to downstream manufacturers. Industry demand for this downstream input, however, is not known with complete certainty. The simplest demand specification that captures the essential

aspects of the problem assumes that there exists an uncertain number of potential buyers, each willing to purchase one unit of the input at a price not exceeding  $r$  dollars. Let  $q$  be the *actual* number of buyers (units sold), with  $q$  distributed uniformly over the interval  $[b, B]$ . The density function for the distribution of market demand is thus

$$(3) \quad \phi(q) = \begin{cases} \frac{1}{(B-b)} & \text{for } q \in [b, B], \\ 0 & \text{otherwise.} \end{cases}$$

Both the assumption that demand is perfectly elastic up to a point and then perfectly inelastic and the choice of the density function  $\phi(q)$  could easily be modified without altering any of the paper's qualitative conclusions (see, for example, Sharkey [1977]).<sup>13</sup>

- Firms' Costs: Potential upstream suppliers' total costs can be divided into three components: fixed, variable and avoidable costs. A firm's fixed costs in the production stage arise from building plant capacity and are given by a linear function of its capacity ( $k$ ):  $F = f + gk$ . Variable costs are linearly homogeneous, with the marginal cost of production equal to  $c$ . Avoidable costs are those incurred only when a plant is active. These setup costs are a function solely of the firm's capacity and may be avoided by shutting down production altogether. The firm's avoidable cost is  $hk$ , and it establishes a minimum scale of production activity, given by  $hk/(r-c)$ .<sup>14</sup> The firm's total cost function can thus be written as:

$$(4) \quad TC = \begin{cases} (f + gk) + cq + hk & \text{for } hk / (r-c) \leq q, \\ (f + gk) & \text{otherwise.} \end{cases}$$

This completes the description of the formal model.

### III . THE NON-COOPERATIVE EQUILIBRIUM

To provide a benchmark for comparison, this section considers the industry's non-cooperative equilibrium on the assumption that firms follow Cournot-Nash strategies. Suppose that there were no market for trading potential suppliers' capacity in this industry.<sup>15</sup> Combined with the earlier assumption that additional capacity cannot be built after the pre-production stage, this places an upper limit of  $k_i$  upon the  $i$  *th* firm's possible rate of production. In making its

capacity investment decision, then, each firm will weigh the opportunity cost of having insufficient internal capacity to satisfy demand should it advance to the production stage, against the opportunity cost of having idle capacity either because it lost the patent race or because downstream demand was unexpectedly weak.

A firm's expected profits equal the probability of winning the patent race times its expected profits under each state of demand, minus its expected R&D investment, minus its capacity-building expenditures. Three possible states of demand are relevant. If demand lies in the region  $[b, hk_i/(r-c)]$ , the patent-holder will not find it profitable to produce.<sup>16</sup> If demand falls in the interval  $[hk_i/(r-c), k_i]$ , the firm satisfies total demand. Finally, if demand exceeds the winner's capacity, the firm is constrained to produce at  $k_i$  units. The winning firm's expected revenues net of variable and avoidable costs are therefore:

$$\int_{\frac{b}{(r-c)}k_i}^{k_i} ((r-c)q - hk_i) \frac{1}{(B-b)} dq + \int_{k_i}^B (r-c-h)k_i \frac{1}{(B-b)} dq.$$

Let  $W(k_i)$  denote these profits gross of fixed costs. Each potential supplier's net expected revenues can thus be written as:

$$(5) \quad E\pi(k_i, x_i) = \frac{W(k_i) v(x_i) - x_i}{\sum_{j=1}^n v(x_j)} - (f + gk_i).$$

The three-period optimization problem is solved recursively. In period three, the winning firm will maximize profits subject to the capacity constraint that it faces. This firm will produce either zero,  $q$  or  $k_i$  units of output depending upon which of the three possible states of demand arises. In each of the two pre-production periods, firms act as Cournot-Nash competitors. In period two, each potential supplier selects a capacity level to maximize its expected profits given in (5). R&D budgets have already been selected and in the symmetric equilibrium each firm has a  $p_i = 1/n$  probability of advancing to the production stage. Expected profits can therefore be rewritten solely as a function of the firm's capacity as:

$$(6) \quad E\pi(k_i, \hat{x}_i) = \frac{1}{n} \int_{\frac{hk_i}{(r-c)}}^{k_i} ((r-c)q - hk_i) \frac{1}{(B-b)} dq + \frac{1}{n} \int_{k_i}^B (r-c-h)k_i \frac{1}{(B-b)} dq$$

$$- (f + gk_i) - \hat{x}_i / \sum_{j=1}^n v(\hat{x}_j) .$$

where  $\hat{x}_i$  denotes the firm's optimal R&D investment rate in the non-cooperative equilibrium.

The firm's optimal capacity choice is then:

$$(7) \quad \hat{k}_i = \frac{B(r-c)(r-c-h) - gn(B-b)(r-c)}{(r-c-h)(r-c+h)} = \frac{B(r-c)}{(r-c+h)} - \frac{gn(B-b)(r-c)}{(r-c-h)(r-c+h)} < B.$$

Because of the exclusive patent, this also equals total available industry capacity,  $\hat{K}$ .

From (7), note that  $\hat{k}_i < B$  unless the marginal costs of building and operating capacity are both zero ( $g=h=0$ ). Firms will thus find it optimal to choose a capacity that may leave some demand unsatisfied. The firm incurs a risk of not being able to recoup (fully) its fixed capacity costs should it lose the R&D race or, even if it does advance to the production stage, should downstream demand be lower than expected. Both considerations lead the firm to select a capacity level that precludes production at the profit-maximizing rate in high demand states ( $q > k_i$ ).<sup>17</sup> Furthermore, it is easily verified that the higher is the marginal cost of building capacity ( $g$ ) and the larger is the capacity-use charge ( $h$ ), the larger will be the expected fraction of demand left unsatisfied. Conversely, the larger is the markup over variable costs on the input ( $r-c$ ), the smaller will be the fraction of potentially unfulfilled demand because the cost of not satisfying all buyers rises relative to the cost of holding idle capacity. Thus, the risk of stock-outs *falls* as the good's markup rises. Finally, a mean-preserving increase in demand uncertainty unambiguously raises the probability of a stock-out's occurrence, and optimal capacity is decreasing in the number of potential suppliers to downstream firms ( $n$ ).

In period one, firms select their research budgets by maximizing the expression in (5) under the assumption that capacity is chosen optimally in the subsequent period ( $k_i = \hat{k}_i$ ). Each firm's optimal R&D outlay under the Nash strategy,  $\hat{x}_i$ , is then implicitly defined by the condition:

$$(8) \quad W(\hat{k}_1) = \frac{\sum_{j=1}^n v(\hat{x}_j) - v'(\hat{x}_1) \hat{x}_1}{v'(\hat{x}_1) \sum_{j=1}^n v(\hat{x}_j)} = \frac{n v(\hat{x}_1) - v'(\hat{x}_1) \hat{x}_1}{(n-1) v'(\hat{x}_1) v(\hat{x}_1)} .$$

Substitution of (8) into (5) indicates that a necessary condition for non-negative expected profits is that firms be in the region of decreasing returns from R&D.<sup>18</sup> This result is usually known as the “common pool” or “fisheries” problem, and it arises here because the private and social productivities of R&D expenditures diverge for each firm. Each firm bases its R&D choice on the *average* probability of winning the R&D race, while what matters from the industry-wide standpoint is a firm’s *marginal* effect on R&D success. Lee and Wilde [1980, theorems 2 and 3] show that in this general class of models, unrestricted entry leads to too many firms, too much aggregate R&D investment and premature discovery of the innovation on average, relative to the cooperative solution.

#### IV. THE EQUILIBRIUM WITH SECOND-SOURCING

Now suppose that firms may buy and sell capacity during the production stage. The second-sourcing agreement, entered into by firms prior to the first period, stipulates that the patent winner may purchase idle capacity from the “losers” at a constant price  $\lambda$  per unit, should that firm have insufficient internal capacity to satisfy demand. The agreement endows each firm with call and put options on productive capacity. The call option offers the winning firm higher profits by allowing it to lease rivals’ idle capacity in the event that market demand exceeds its internal capacity. The put option represents the right of losing firms to lease (some portion of) their idle capacity should the winning firm be unable to fully satisfy demand. It allows these firms to recover at least part of their sunk investment in plant capacity. Whether firms exercise their second-sourcing options will depend jointly upon the outcome of the R&D race and the level of realized demand.

Cooperation among firms is limited to the production stage; in periods one and two they continue to make independent R&D and capacity choices. If firms were allowed to coordinate

their capacity-building decisions, they could replicate the multi-plant monopolist's solution and their joint profits would be still greater. However, current antitrust restrictions in the United States essentially preclude explicit cooperation of this form.<sup>19</sup> For this reason, I confine attention to non-cooperative capacity-building decisions throughout the paper.<sup>20</sup> Alternatively, upstream firms could coordinate their research and development investments. Recently-liberalized antitrust restrictions on research joint ventures make this type of cooperation a more likely occurrence. I discuss the relative merits of research joint ventures and second-sourcing in Section IV(ii), and therefore for present purposes I maintain the assumption of non-cooperation in the first two periods. A final possibility would be for firms to agree to second-source only after R&D and demand uncertainty were resolved. However, this type of agreement would restrict firms only to choose the optimal allocation of output across plants of given capacities, denying the benefits that stem from adjustments to individual capacities in stage two. An *ex-ante* second-sourcing agreement will, as Section V shows, allow firms to satisfy almost any given rate of industry demand at a lower average cost than in the non-cooperative equilibrium.

This section explains how second-sourcing enables firms to diversify-away one form of uncertainty and to lower the cost of adjusting to another. First, by agreeing to license idle capacity to whomever wins the R&D race should realized demand exceed the winner's capacity ( $q > \hat{k}_i$ ), firms will move closer to the profit-maximizing solution in the absence of R&D uncertainty. While each firm individually faces research risk, *aggregate* R&D risk is eliminated if all firms in the industry participate in the second-sourcing agreement.<sup>21</sup> Second, the agreement enables firms to increase their flexibility in responding to demand uncertainty. Specifically, the firm that wins the exclusive patent will no longer be constrained to produce at or below its internal capacity. The upper limit on its output rate will instead be the industry's aggregate capacity, allowing the winning firm to satisfy an unexpectedly-high rate of demand by purchasing capacity from its R&D-stage rivals.

#### IV(i). FIRMS' EXPECTED PROFITS UNDER SECOND-SOURCING

Under the second-sourcing agreement, a representative firm's expected profits are:

$$\begin{aligned}
E\pi(k_i, x_i) &= \frac{v(x_i)}{\sum_{j=1}^n v(x_j)} \left\{ \int_{hk_i}^{k_i} ((r-c)q - hk_i) \frac{1}{(B-b)} dq + \int_{k_i}^{\sum k_i} ((r-c-h)k_i + (r-c-\lambda)(q-k_i)) \right. \\
(9) \quad &\quad \left. - h(1 + \left[ \frac{q-k_i}{k_i} \right]) \cdot k_i \right) \frac{1}{(B-b)} dq + \int_{\sum k_i}^B ((r-c-h)k_i + (r-c-h-\lambda)(\sum k_i - k_i)) \frac{1}{(B-b)} dq \Big\} \\
&+ \left( 1 - \frac{v(x_i)}{\sum_{j=1}^n v(x_j)} \right) \left\{ \int_{k_j}^{\sum k_i} \frac{\lambda}{(n-1)} \frac{(q-k_j)}{(B-b)} dq + \int_{\sum k_i}^B \lambda k_i \frac{1}{(B-b)} dq \right\} - (f + gk_i) - \frac{x_i}{\sum_{j=1}^n v(x_j)}
\end{aligned}$$

Equation (9) is derived as follows.<sup>22</sup> With probability  $(v(x_i)/\sum v(x_j)) = (1/n)$ , this firm wins the R&D race. If demand lies in the interval  $[hk_i/(r-c), k_i]$ , the firm satisfies it internally and therefore does not exercise its call option to second-source production. If realized demand falls in the range  $[k_i, \sum k_i]$  for  $i = 1, \dots, n$ , then the firm second-sources  $(q-k_i)$  units of production at unit price  $\lambda$ . Finally, if demand exceeds total installed capacity in the industry,  $\sum k_i$ , the firm again second-sources and produces at aggregate industry capacity. Should the  $i$ <sup>th</sup> firm lose the R&D race (with probability  $(1-1/n)$ ), it can exercise its put option to sell capacity to the winning firm at a per unit price  $\lambda$  if realized demand exceeds the winner's capacity,  $k_j$ . In (9), it is assumed that if demand falls in the region  $[k_j, \sum k_i]$  then the second-sourcing demand is allocated among firms by a random device. Thus, *ex-ante* each firm has a  $1/(n-1)$  chance of being a second-source supplier should it lose the R&D race and realized demand fall in this interval. If demand exceeds total industry capacity, the  $i$ <sup>th</sup> firm will rent all of its idle capacity to the winning firm. Finally, the firm's cost of building capacity is  $(f+gk_i)$ , and its R&D costs are  $x_i/\sum v(x_j)$ , regardless of the R&D race's outcome.

The objective function in (9) can be simplified by noting that total receipts must equal total payments for second-sourced capacity in the industry. Moreover, in the symmetric equilibrium, expected net receipts are exactly zero for each firm. Capacity rental fees represent only an *ex-post* redistribution of wealth among firms. Importantly, then, the rental price of capacity  $\lambda$  is not

a determinant of the relative profitability of second-sourcing over sole-sourcing.<sup>23</sup> This does not mean, however, that second-sourcing has no real effects on resource allocation.

Consolidating (9) yields:

$$\begin{aligned}
 E\pi(k_i, x_i) = & \frac{v(x_i)}{\sum_{j=1}^n v(x_j)} \left\{ \int_{\frac{hk_i}{(r-c)}}^{k_i} ((r-c)q - hk_i) \frac{1}{(B-b)} dq + \int_{k_i}^{\sum k_i} ((r-c-h)k_i + (r-c)(q-k_i)) \right. \\
 (10) \quad & \left. - h\left(1 + \left[\frac{q-k_i}{k_i}\right] \cdot k_i\right) \frac{1}{(B-b)} dq + \int_{\sum k_i}^B ((r-c-h)k_i + (r-c-h)(\sum k_i - k_i)) \frac{1}{(B-b)} dq \right\} \\
 & - (f + gk_i) - \frac{x_i}{\sum_{j=1}^n v(x_j)}.
 \end{aligned}$$

Let  $W(k_i)$  denote the expression given in curly brackets in (10). It is the reward to being the first to introduce the new input, given that second-sourcing is permitted. Following (5), equation (10) may be rewritten as:

$$(10)' \quad E\pi(k_i, x_i) = \frac{W(k_i) v(x_i) - x_i}{\sum_{j=1}^n v(x_j)} - (f + gk_i).$$

#### IV(ii) . THE R&D AND CAPACITY CHOICES WITH SECOND-SOURCING

Firms will continue to act as Cournot-Nash competitors in periods one and two. Optimal R&D and capacity decisions are again solved recursively. Consider first a firm's optimal R&D outlay,  $x_i^*$ . For an optimal plant capacity  $k_i^*$ , the R&D choice is defined implicitly by the condition:

$$(11) \quad W(k_i^*) = \frac{\sum_{j=1}^n v(x_j^*) - v'(x_1^*) x_1^*}{v'(x_1^*) \sum_{j \neq 1}^n v(x_j^*)} = \frac{n v(x_1^*) - v'(x_1^*) x_1^*}{(n-1) v'(x_1^*) v(x_1^*)}.$$

Condition (11) is identical in form to (8) from the non-cooperative equilibrium. The optimal R&D choices in the two equilibria will differ only if the expected gain from being first in the



R&D race differs. Specifically, a well-established property of both contractual and non-contractual cost models of R&D is that if  $W(k^*_i) > W(\hat{k}_i)$ , then  $x^*_i > \hat{x}_i$  (for a proof, see Kamien and Schwartz [1982, p. 214].) Thus, if second-sourcing is individually more profitable for firms than independent behavior, and if firms therefore opt for this form of limited cooperation, then each will unambiguously devote *greater* resources to the R&D race. The result of this increased R&D activity will be an earlier expected discovery date for the innovation with second-sourcing than in the Nash equilibrium.

An important question to ask is whether the increased pace of R&D activity with second-sourcing alleviates or aggravates the “common pool” or “fisheries” problem discussed in Section III. There it was noted that firms will invest more in R&D in the non-cooperative equilibrium than would a monopolist or social planner. This result depended critically upon the winning firm’s ability to appropriate fully the surplus created by its innovation. Such will be the case if research results can be kept private and if the winning firm can act as a perfectly-discriminating monopolist in its output market. The current model’s assumptions ensure that both of these requirements are satisfied in the non-cooperative and second-sourcing equilibria. This implies that second-sourcing will aggravate the common pool problem. The cost of this social inefficiency must be subtracted from any efficiency gains that second-sourcing creates by realigning firms’ capacity and output choices. By contrast, if the winning firm were unable to appropriate fully the social value of its patent, the Nash equilibrium could be characterized by *under-researching* relative to the social optimum. In this case, by promoting greater research effort, second-sourcing could move firms *closer* to the social optimum. Which of these outcomes is the more likely in any given industry could be established by empirical evidence on the ability of firms to keep secret their research discoveries, the cost to competitors of reverse-engineering or inventing around a patent, and the ability of patent holders to discriminate among customer groups.

Does there exist a superior means by which to reduce the real costs of firm-specific research risk? Research joint ventures offer one alternative. It is not difficult to show that if all R&D

activity in the upstream industry were coordinated, the central authority would choose a lower aggregate rate of investment with fewer independent research teams (projects) than would be forthcoming in the non-cooperative equilibrium (see Lee and Wilde [1980], theorems 2 and 3). Most importantly, the joint venture would select the socially-efficient level and distribution of research spending. However, once one departs from the situation of a monopoly supplier to a case where all firms are capable of serving downstream buyers, the incentive of each upstream firm to contribute to the joint R&D effort and to invest in plant capacity is reduced. The research joint venture expands competition at the production stage by eliminating the exclusive control previously enjoyed by the patent winner over the application of the input's production technology. This leads to a decline in aggregate R&D spending (relative to the monopoly solution), and a decrease in individual plant capacity (relative to the Nash equilibrium). This latter consequence may exacerbate the mismatching between available capacity and realized market demand in the industry, a point to which I shall return presently.

An alternative solution to the common pool problem is offered by Mortensen [1982]. Under his proposal, the winning firm receives the value of its innovation minus a compensation paid to each losing firm that equals the foregone value of continued competition. If combined with a reduction on entry at the R&D stage, this compensation scheme can fully internalize the externality that each firm imposes on its rivals in the non-cooperative equilibrium. While Mortensen's proposal could in theory provide a solution, its reliance on potentially sizable inter-firm transfers and erection of entry barriers would surely run afoul of current antitrust laws.

With the second-sourcing agreement, each firm's optimal capacity choice is now given by: <sup>24</sup>

$$(12) \quad k^* = \frac{B(r-c)(r-c-h) - (B-b)ng(r-c)}{n(r-c)^2 - h(n-1)(r-c)/2 - h^2} .$$

Total industry capacity is  $n$ -times this or:

$$(13) \quad K^* = \frac{Bn(r-c)(r-c-h) - (B-b)n^2g(r-c)}{n(r-c)^2 - h(n-1)(r-c)/2 - h^2} .$$

In order to identify and explain the source of the benefits to suppliers from second-sourcing,

it is necessary to compare firms' optimal capacities, industry aggregate capacity, and expected firm profitability in the two equilibria. The remainder of this section discusses these issues, and second-sourcing's benefits to purchasers are treated in Section V.

First, optimal firm-level capacity unambiguously decreases when firms agree to second-source. (See equations (A.1) and (A.2) in the Appendix.) The intuition is clear: second-sourcing raises the cost of acquiring capacity in the pre-production stage relative to the cost of acquiring it in the production stage. By assumption, capacity cannot be built after the second period and, as such, its *ex-post* marginal cost is infinite in the non-cooperative equilibrium. The marginal cost of capacity *ex-post* relative to *ex-ante* with non-cooperation is therefore  $(\infty/g)$ . In the second-sourcing equilibrium, this relative price falls to  $(\lambda/g)$ , where  $\lambda$  is the per unit capacity rental fee. Second-sourcing thereby creates an incentive for firms to wait to acquire capacity until *after* the R&D and demand uncertainty has been resolved, rather than committing themselves beforehand. This altered incentive unambiguously leads each firm to select a smaller plant capacity in the first period.

Furthermore, it is a straightforward comparative statics problem to show that the absolute reduction in firm-level capacity from second-sourcing will be larger the more firms there are in the industry, the greater is the demand uncertainty faced by firms<sup>25</sup>, and the higher is the marginal capacity-building cost. Intuitively, each of these factors increases the incentive of firms to rely on second-sourced rather than internal capacity. Finally, the reduction in firm-level capacity will be greatest in cases of low markups over variable costs and relatively high capacity-use charges. Both factors lower the opportunity cost of having insufficient capacity in the production stage relative to the opportunity cost of having idle excess capacity.

Total industry capacity available for production may rise or fall under second-sourcing. Aggregate available capacity is given by equation (7) in the non-cooperative equilibrium and by equation (13) with second-sourcing. The ability of the winning firm to employ otherwise-idle capacity from its competitors tends to increase aggregate capacity available for production. The reduction in each firm's capacity investment, however, tends to offset this. Equations (A.3) and

(A.4) reveal that a necessary and sufficient condition for second-sourcing to increase aggregate installed capacity is that

$$(14) \quad 2h < (r-c).$$

Thus, aggregate capacity rises for relatively low marginal capacity-use fees and relatively high markups over variable costs. This result coincides with the earlier observation that these conditions will be associated with only a modest reduction in firm-level capacity investment. It can also readily be shown with comparative statics that if aggregate capacity does rise under second-sourcing, the increase will be largest when there are relatively few firms in the industry, when the marginal capacity-building cost is relatively low, and when there is relatively little demand uncertainty.

Recall the earlier discussion of research joint ventures. There it was noted that R&D cooperation would lead to a reduction in firm-level capacity from the expansion of competition in the product market. Just as in the case of second-sourcing, however, industry-wide capacity would still rise under the research joint venture if the reduction in each firm's plant size were on an order of magnitude less than  $n$ , the number of firms. However, a crucial difference remains between the joint venture and second-sourcing equilibria: the control over capacity-utilization or output-allocation decisions. Given the specification of firms' costs, if a single firm decides which plants should be active and which should remain idle (as under the second-sourcing agreement), the average cost of producing the input will be lower than if such decisions were made independently by each firm.<sup>26</sup> Fewer plants will be active in the second-sourcing equilibrium for any given rate of demand, economizing on set-up costs. Thus, while a research joint venture can lead to a more efficient allocation of resources in the development stage than will a second-sourcing agreement, this must be balanced against the more efficient allocation of resources at the production stage under the latter form of cooperation. The joint venture best aligns private and social interests at the research stage; second-sourcing best aligns these interests in the production stage.

The third and final variable of interest is firms' expected profits in the two equilibria. These may be compared by considering equations (6) and (10), evaluated at the optimal firm and industry-level capacities.<sup>27</sup> Several important insights and testable implications can be drawn. First, in the special case in which firms face no capacity-use charge for production, expected profits rise unambiguously with second-sourcing. When avoidable costs are zero, there is no minimum efficient scale of operations. Hence, there is no 'penalty' for operating many small plants instead of a smaller number of large plants. Moreover, in this situation, it can be shown that under second-sourcing firms will scale back their internal capacities at a rate that leaves *aggregate* capacity available for production exactly the same in the two equilibria. The source of the increase in firms' expected profits in this case therefore lies entirely in savings on capacity-building costs. In order to have access to the same stock of capacity in the two equilibria, firms individually need only invest  $(1/n)^{\text{th}}$  as much when second-sourcing is permitted. An identical argument applies to situations in which the marginal capacity-use charge is small relative to the product's markup over variable costs and the marginal cost of building capacity. The theory predicts that second-sourcing will be relatively attractive to firms in industries with low avoidable costs or, equivalently, with small minimum efficient scales of operation.

Second and more generally, firms' expected profits will increase under second-sourcing in those cases where aggregate available capacity rises. The argument is similar to that provided above. Industry-wide capacity will increase when there is less than a  $n\%$  decline in firm-level capacity. The benefit to firms from second-sourcing in this case lies not in savings on plant investment (holding constant total industry capacity), but rather from the increase in aggregate capacity that allows firms to satisfy a wider range of possible demands should they advance to the production stage. Increases in firms' expected profits under second-sourcing will thus be positively correlated with increases in available industry capacity. The conditions under which this latter result will occur were noted earlier in equation (14): a high markup over variable costs relative to the marginal capacity-use charge. Furthermore, as also noted earlier, if aggregate capacity does rise, the magnitude of that increase (and hence in firms' expected profits) will be

largest when there are few firms in the industry, when the marginal capacity-building cost is relatively low, and when there is relatively little demand uncertainty.

It is important to underscore that while unstable demand and large capacity commitment costs are necessary conditions for firms to have an incentive to second-source, the relationship is non-linear. At one extreme, if there is very little demand uncertainty and if commitment costs are negligible, there is clearly little to be gained from cooperation. At the other extreme, if demand is highly variable and if commitment costs are very high, the dampening firm-level effect on capacity will be so acute as to virtually eliminate the second-sourcing incentive. Moderate values for these variables are conducive to second-sourcing.

The model's predictions are consistent with the sharp (ten-fold) increase in second-sourcing activity in the semiconductor industry between 1974 and 1985. This activity is summarized in Tables I and II. First, the period 1975 to 1980 was characterized by significant merger and acquisition activity in the U.S. semiconductor industry, and the rate of new entry declined substantially.<sup>28</sup> Both factors contributed to a sharp fall in the number of major integrated circuit producers, which the model predicts should make second-sourcing more attractive to firms. The largest increase in second-sourcing activity in fact took place during the period 1975-1980.

Second, the model also indicates that firms will find second-sourcing to be more profitable when there is a large markup over variable costs. During the period 1974-1985, the gross markup rate (the value of industry shipments minus material costs and total employee compensation) rose roughly monotonically in the semiconductor industry, from 30% to 38%.<sup>29</sup> Again, this coincided with the significant increase in second-sourcing activity.

Third, if one breaks down the data in Tables III and IV more finely, one finds that 8-bit and 16-bit microprocessors have been second-sourced much more frequently and extensively than were the earlier 4-bit chips.<sup>30</sup> The 4-bit generation catered primarily to a small number of original equipment manufacturers (OEMs), whereas the 8 and 16-bit varieties were sold to a much larger number of OEMs in smaller quantities. Holding all else equal, a larger number of smaller buyers will reduce the variability of aggregate demand, which the model predicts will

tend to increase the expected profitability of second-sourcing. Again, this change in the composition of demand coincided with the increase in second-sourcing activity. The evidence for at least this industry appears to be strongly consistent with the model's predictions.

### INSERT TABLES I AND II ABOUT HERE

Finally, because firms continue to act as Cournot-Nash competitors in selecting their optimal R&D budgets and plant capacities, these choices are necessarily self-enforcing. Two other forms of cheating, however, could threaten the second-sourcing agreement's stability. First, if second-sourced output were sold under the patent-holder's brand name, a principal-agent problem of quality assurance could arise. A second-sourced firm could debase the patent holder's reputation capital by producing inferior quality output, either deliberately or unintentionally.<sup>31</sup> Second, firms on either side could act opportunistically at the production stage by forcing renegotiation of the capacity rental fee  $\lambda$ .

If third-party monitoring and enforcement are prohibitively expensive or infeasible, firms must be able to devise a self-enforcing agreement to overcome both potential problems. Telser [1987, ch. 6] derives sufficient conditions for a self-enforcing agreement. Intuitively, he shows that chiseling can be prevented if the one-period gain from cheating is small relative to the present value of gains from continued cooperation, and if firms expect to be producing in the industry over a sufficiently long horizon. Recalling the results of Section IV(ii), the first condition will be met when there are not too many firms in the industry, when there is moderate demand uncertainty, when there is a large markup on the input, and when capacity-building and capacity-use costs are moderate. The data on the first two requirements for the semiconductor industry are conducive to self-enforcement. The second condition implies that we should observe stable, on-going second-sourcing agreements in industries where the same firms compete continually over different product cycles. Notably, the identity of major semiconductor producers has, in fact, remained extremely stable over the last fifteen years.<sup>32</sup>

**TABLE I**  
**MICROPROCESSOR PRODUCERS' PRODUCTION STRATEGIES**

<u>Strategy</u>	<u>1974</u>	<u>1975</u>	<u>1976</u>	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>1980</u>	<u>1981</u>	<u>1982</u>	<u>1983</u>	<u>1984</u>	<u>1985</u>
Own Design Only	10	11	14	10	10	8	6	7	6	4	4	5
Second-Source Only	3	5	13	14	15	16	18	22	25	27	26	32
Some Own Design	10	16	18	20	21	18	19	17	18	14	14	14
Some Second-Source	3	10	17	24	26	26	31	32	37	37	36	41

Source: Swann [1987], Table 3.

**TABLE II**  
**MICROPROCESSOR PRODUCTS' SOURCES OF PRODUCTION**

<u>Source</u>	<u>1974</u>	<u>1975</u>	<u>1976</u>	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>1980</u>	<u>1981</u>	<u>1982</u>	<u>1983</u>	<u>1984</u>	<u>1985</u>
Original Design	12	21	32	39	43	43	44	43	47	43	40	40
Designs with a Second-Source	3	7	11	17	22	31	29	33	35	34	31	30
Second-Sources	3	11	20	41	51	69	83	103	117	111	107	109
Second-Sources Per Design	1	1.6	1.8	2.4	2.3	2.2	2.9	3.1	3.3	3.3	3.4	3.6

Source: Adapted from Swann [1987], Table 4.



## V . THE BENEFITS TO PURCHASERS FROM SECOND-SOURCING

Purchasers of the input may also benefit from second-sourcing agreements. First, second-sourcing can reduce the risk of a “stock-out” for downstream firms’ essential input. Second, it can lower the average cost of production and in turn the market price of the input. These two benefits contrast sharply with the existing literature’s focus on preclusion of post-contractual opportunistic behavior by a monopoly seller.

The results in Section III established that in the non-cooperative equilibrium, each firm will select a capacity level smaller than the maximum possible rate of demand. Each potential input supplier selects its optimal capacity by weighing the cost of idle capacity in low demand states against the cost of foregone sales revenue in high demand states. As long as there are positive capacity-building and capacity-use charges ( $g > 0$  and  $h > 0$ ), or provided that the firm faces some R&D uncertainty ( $p_i < 1$ ), however, it will choose to run the risk of stocking-out in high demand states. This risk is also borne by downstream buyers to the extent that the input is essential to their own production process. If they are unable to purchase all of their input needs, downstream firms will incur the costs associated with being unable to fully satisfy demand for the final good.

Second-sourcing provides a means by which to reduce the risk of stock-out situations for inputs and thereby remove uncertainty from downstream firms’ own production schedules. As indicated in Section IV(ii), second-sourcing can reduce the fraction of potentially-unsatisfied demand by promoting a more efficient utilization of industry capacity. Plant capacity of firms that “lose” the R&D race, which would have remained idle, can instead be used to satisfy demand in excess of the winner’s internal capacity. The conditions under which second-sourcing leads to an increase in total industry capacity, and thereby reduces the risk of stock-outs, were given in Section IV(ii).

Second-sourcing can provide additional efficiency benefits in the form of lower costs of production that may be shared between upstream and downstream firms. In the non-cooperative equilibrium, the input supplier’s average cost of production is:

$$(15) \quad AC_{nce} = \frac{F + cq + h\hat{k}}{q} = c + \frac{f + (g + h)\hat{k}}{q} \quad \text{for } q \leq \hat{k}.$$

Thus, (industry) average costs are decreasing up to the firm's capacity constraint. In the second-sourcing equilibrium, the firm's average cost of production is:

$$(16) \quad AC_{sse} = \frac{F + cq + h(1 + [q/k^*])k^*}{q} = c + \frac{f + (g + h(1 + [q/k^*]))k^*}{q} \quad \text{for } q \leq K^* = nk^*.$$

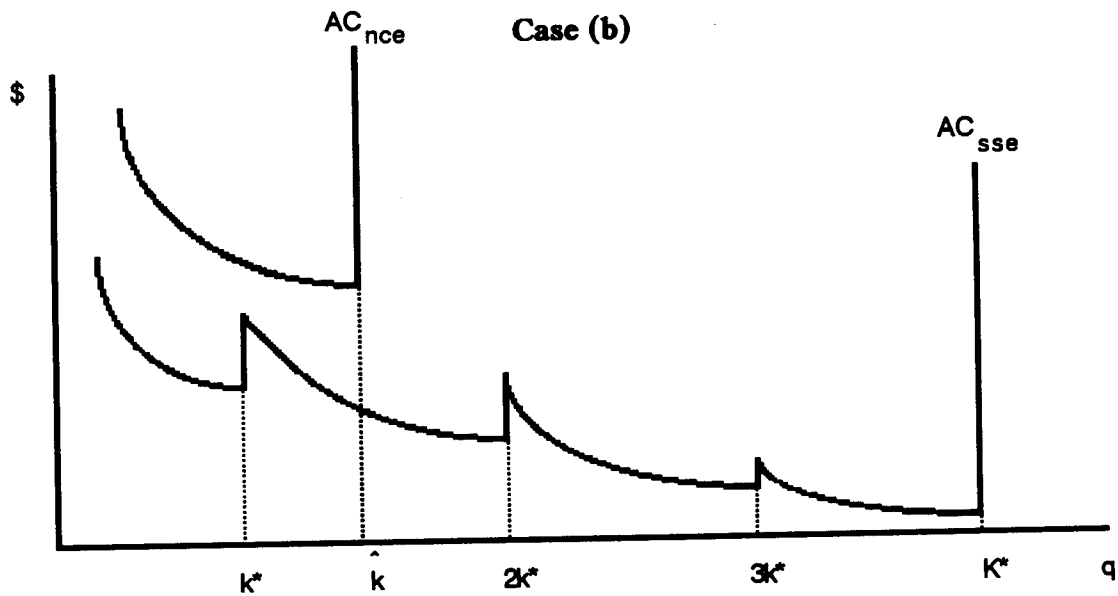
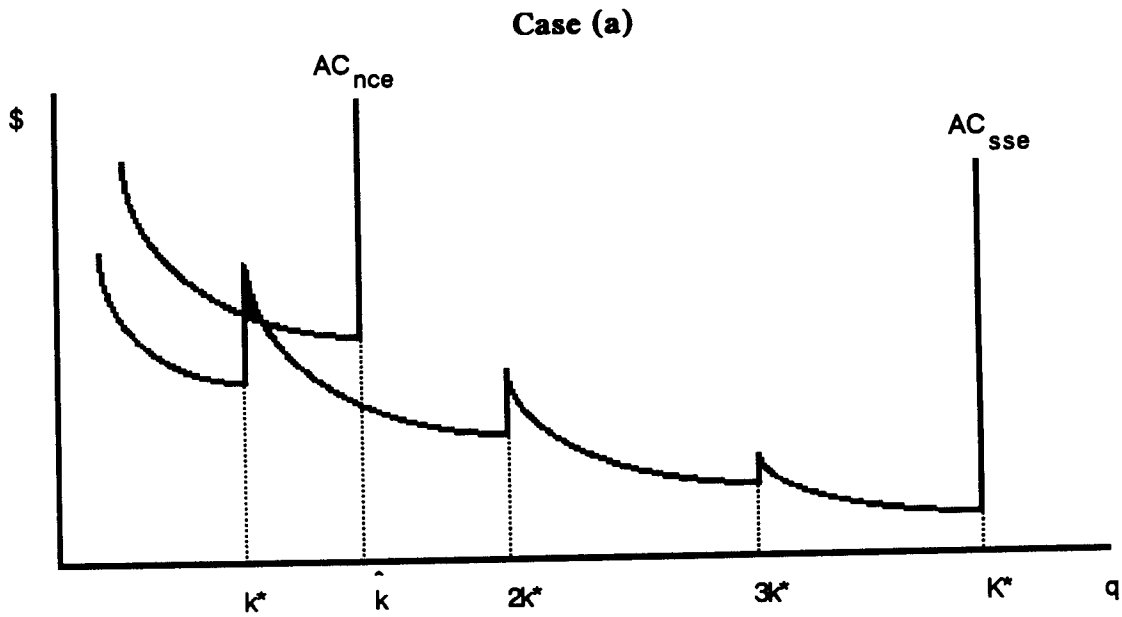
As such, the winning firm will operate each active plant at full capacity before bringing on-line the next plant. At each multiple of  $k^*$  in demand, therefore, (industry) average costs jump by  $hk^*/q$  dollars because of the avoidable or setup cost that is incurred.<sup>33</sup>

Comparing industry average production cost in the two equilibria, there are two general possibilities as illustrated in Figure 2.<sup>34</sup> In panel (a), there exists a (shaded) region where the industry average cost of production is higher with second-sourcing than without. Scenario (a) can occur if the marginal cost of building capacity is very low,  $\hat{k}$  is very close to an integer multiple of  $k^*$ , and the firm's avoidable or setup cost is relatively high. If these three conditions are met, there can exist a region (or multiple regions) of low demand where average cost is higher with cooperation. In such cases, the minimum cost production plan calls for one large plant to be active, rather than several of the smaller plants available to the winning firm in the second-sourcing equilibrium. With low rates of demand, firms are unable to economize on the plants' avoidable costs, resulting in a higher average cost of production.

#### INSERT FIGURE 2 ABOUT HERE

In the alternative scenario, depicted in panel (b), the industry average cost of production is lower for all rates of demand under second-sourcing. This is a direct result of the increased flexibility in meeting demand that second-sourcing provides to upstream firms. The second-sourcing agreement essentially turns the winning firm into a multi-plant monopolist with a large number of relatively small plants at its disposal (recall that  $k^* < \hat{k}$  for all parameter values). The ability of the eventual upstream supplier to match more closely on-stream capacity with realized demand is the source of the efficiency gain. A larger number of small plants, in lieu of one large plant, are able to meet the range of possible demands with a lower average level of excess

**FIGURE 2**  
**INDUSTRY AVERAGE COST**



**Legend:** AC = average cost  
nce = non-cooperative equilibrium  
sse = second-sourcing equilibrium

capacity, a lower average level of excess demand and, in turn, a lower average cost of production. The cost of this improved matching of utilized capacity and demand is given by the fixed capacity–building cost,  $F$ . Firms’ optimal capacity choices under the second–sourcing agreement balances the marginal costs and benefits of increased allocative flexibility for production decisions.

Given the convenient simplifying assumption that buyers have completely inelastic demand schedules at reservation price  $r$  for one unit of the good and completely inelastic schedules beyond that point, all of the benefits from this lower average cost would accrue to the upstream producer. None of the model’s earlier qualitative results, however, is dependent upon this particular specification of downstream demand.<sup>35</sup> Relaxing this assumption to permit an arbitrary negatively–sloped inverse demand function subject to random fluctuations would result in a sharing of the gains from the more efficient allocation of industry demand across plants between upstream and downstream firms. In these cases, then, purchasers will benefit directly from their supplier’s agreement to second–source production.

Preventing opportunistic behavior by suppliers is the most frequently–cited explanation in the existing literature on second–sourcing. How important is it relative to the efficiency explanation offered in this paper? Consider again the evidence from the semiconductor industry, where second–sourcing has been extensively used. Semiconductor products typically have multiple second–sources. Table II reveals that most microprocessors have had three or more second–sourced producers. In particular, Intel’s 8086 and Zilog’s Z8000 microprocessors each had five licensed second–sources, while Motorola’s 68000 chip had six alternative licensed suppliers.<sup>36</sup> Moreover, the average number of second–sources per design has risen steadily over time.

If the primary motive for buyers to require second–sourcing is to assure contractual performance or discipline developers’ behavior, the existence of many alternative suppliers would appear to be redundant, particularly given the fact that contracting with second–sources is not costless. Moreover, as discussed in Section I, the existing literature stresses multiple competitors at the bidding stage, rather than in the production era, as being essential for a

second-sourcing agreement to prevent opportunism. In particular, Shepard [1987, p. 367]'s model of second-sourcing as a commitment against opportunism predicts that innovating firms will license only a single rival. Contrary to her assertion, this prediction is not consistent with the evidence for the industry that she considers, semiconductor production. The fact that many semiconductor products have relied upon a large number of second-sourced suppliers suggests that stock-out and cost-reduction motives may be empirically more important than preclusion of opportunism, at least in this industry.

Finally, as others have noted, there are a variety of solutions to the opportunism problem. Klein, Crawford and Alchian [1978] note that vertical integration can eliminate the threat of opportunism simply by internalizing its potential source. Telser [1987] shows how self-enforcing agreements in repeat-purchase settings can discipline contracting parties. Klein and Leffler [1981] stress reputational capital as a disciplining device. Second-sourcing is thus only one of several possible solutions to the opportunism problem. Similarly, to rely solely upon an opportunism explanation for second-sourcing, as the previous literature has done, would not seem appropriate.

## VI. CONCLUSIONS

This paper has presented an explanation of how second-sourcing can benefit both suppliers and purchasers in a market characterized by R&D and demand uncertainty. By analyzing second-sourcing in a market setting rather than within the standard principal-agent framework, it has reached results that differ significantly from the existing literature. Second-sourcing allows producers to diversify-away firm-specific risk and to increase their flexibility in responding to industry-wide risk. The direct result is a better matching between firms' productive capacity and realized industry demand. This increased efficiency in turn benefits buyers by reducing the probability of stock-outs and lowering the average cost of inputs in most circumstances. This benefit must be weighed against the possibility that second-sourcing may exacerbate the common pool problem in firms' R&D investment decisions.

A very different explanation than that presented here for second-sourcing is that firms may be constrained from adopting preferred market arrangements, and will therefore select second-sourcing as a second-best alternative. Two obvious alternatives to second-sourcing are horizontal merger and technology licensing agreements. Firms may prefer either of these forms of cooperation to second-sourcing, yet be constrained by their legal or regulatory environment so as effectively to preclude these options. Horizontal mergers are subject to antitrust scrutiny by the Department of Justice, and patent cross-licensing agreements have been challenged as facilitating collusion.<sup>37</sup> Mergers and acquisitions involving foreign firms are now subject to a heightened antitrust standard, and additional political uncertainty, under the *Exon-Florio Amendment*.<sup>38</sup> By contrast, the current legal attitude towards second-sourcing is fairly liberal.<sup>39</sup> Legal obstacles and the generally sour atmosphere of trade relations between the United States and Japan may thus at least partially explain the large, and increasing, number of American-Japanese second-sourcing agreements in the semiconductor industry. In many cases, second-sourcing may simply be the next best alternative for firms seeking to reap the benefits of more formal methods of cooperation such as merger.

## APPENDIX

• Firm-level Capacity in the Non-Cooperative and Second-Sourcing Equilibria:

With non-cooperation, each firm's capacity is given by (7). Under second-sourcing, it is given by (12). Subtracting yields:

$$(A.1) \quad k^* - \hat{k} = \left( \frac{B(r-c)(r-c-h) - (B-b)ng(r-c)}{n(r-c)^2 - h(n-1)(r-c)/2 - h^2} \right) - \left( \frac{B(r-c)(r-c-h) - (B-b)ng(r-c)}{(r-c-h)(r-c+h)} \right).$$

Rewriting the denominators of each expression gives:

$$(A.2) \quad k^* - \hat{k} = \left( \frac{B(r-c)(r-c-h) - (B-b)ng(r-c)}{n(r^2 + c^2 - 2cr) - h^2 + h(n-1)(r-c)/2} \right) - \left( \frac{B(r-c)(r-c-h) - (B-b)ng(r-c)}{(r^2 + c^2 - 2cr) - nh^2} \right)$$

The numerators in the two terms in (A.2) are identical. For all  $n > 1$  and  $h > 0$ , the first term's denominator exceeds that of the second term. It therefore follows that  $k^* < \hat{k}$  unambiguously.

• Industry Capacity in the Non-Cooperative and Second-Sourcing Equilibria:

With non-cooperation, industry capacity is given by (7). Under second-sourcing, it is given by (13). Subtracting yields:

$$(A.3) \quad K^* - \hat{K} = \left( \frac{Bn(r-c)(r-c-h) - (B-b)n^2g(r-c)}{n(r-c)^2 - h(n-1)(r-c)/2 - h^2} \right) - \left( \frac{B(r-c)(r-c-h) - (B-b)ng(r-c)}{(r-c-h)(r-c+h)} \right).$$

Upon rearranging and collecting terms, a necessary and sufficient condition for industry capacity to rise with second-sourcing is that:

$$(A.4) \quad 2h < (r-c).$$

Aggregate capacity therefore rises for relatively low capacity-use charges and large markups over variable costs. The intuition is supplied in the text.

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- 1 Von Ungern Sternberg [1988] discusses how excess capacity can provide a similar commitment.
  - 2 For example, Intel's 8086 microprocessor and Zilog's Z8000 chip each had five licensed second-sources, while Motorola second-sourced production of its 68000 microprocessor to six other firms (Organization for Economic Cooperation and Development [1985, p. 54]). Other detailed accounts of second-sourcing agreements in the semiconductor industry may be found in Haklisch [1986].
  - 3 Shepard [1987]'s model implies a single second-sourced firm will be chosen by the monopolist. In Farrell and Gallini [1988], the monopoly supplier is indifferent about the number of second-sources because it can fully extract their profits through the licensing fee.
  - 4 The fact that specific integrated circuit designs can be very closely replicated by multiple producers makes second-sourcing technologically-viable in the semiconductor industry. For industries where a common fabrication technology is harder to ensure, second-sourcing will be less apt to occur.
  - 5 Vertical integration is discussed in Section V. I thus postpone its consideration.
  - 6 The paper shows that another frequently-mentioned motive for second-sourcing, the incomplete appropriability of R&D results creating a Hobson's choice for firms over licensing second-sources (Swann [1987]), is not an adequate explanation for the practice. In this model, research results are private yet the incentive to second-source often remains.
  - 7 For a general discussion of production commitments and flexibility under demand uncertainty, see Flacco and Kroetch [1986], Turnovsky [1973] and Leland [1972].
  - 8 I assume that only those firms undertaking R&D in the first period can provide capacity in the production era. Sufficiently strong economies of scope in R&D and capacity design would produce this result.

<sup>9</sup> None of the paper's central results is altered if one assumes instead that firms invest a lump-sum amount in R&D at the start of the race. See Loury [1979] for such a formulation. See also the excellent surveys in Reinganum [1989] and Kamien and Schwartz [1982].

<sup>10</sup> As specified, the R&D race is "memoryless." Thus, the probability of success at any point is independent of past R&D activity.

<sup>11</sup> More formally, the assumptions are (see Lee and Wilde [1980]):

(i)  $v(0) = 0 = \lim v'(x) \text{ as } x \rightarrow \infty,$

(ii)  $v''(x) > 0 \text{ or } < 0 \text{ as } x < x^0 \text{ or } > x^0, \text{ and}$

(iii)  $v(x)/x > 0 \text{ or } < 0 \text{ as } x > x^0 \text{ or } < x^0.$

<sup>12</sup> I assume a zero real interest rate throughout the paper to simplify the exposition.

<sup>13</sup> Specifically, one may substitute for (3) an arbitrary downward-sloping inverse demand function,  $p = \beta(x)$ , where  $x$  denotes the quantity offered and where uncertainty enters demand additively. Thus, actual demand is given by  $p = \beta(x-q)$ , where  $q$  continues to be distributed uniformly over the interval  $[b, B]$  with the restriction that  $\beta(0) = 0$ . The paper's qualitative results continue to be valid under this more general specification of demand industry conditions.

<sup>14</sup> If  $q < hk/(r-c)$ , then gross revenues are  $(r-c)q$  which is less than  $hk$ , the firm's avoidable cost, and therefore it will choose not to produce.

<sup>15</sup> If idle capacity has alternative uses — whether in a different industry, a different product line in the same industry, or in subsequent product cycles — the paper's conclusions remain valid, although in a slightly weakened form.

<sup>16</sup> I assume that  $hk_j/(r-c) \geq b$ . Second order conditions ensure that  $(r-c-h) > 0$ .

<sup>17</sup> The result agrees with that derived by Flacco and Kroetch [1986] who consider the firm's output choice when it faces uncertainty in its production process.

<sup>18</sup> Upon substitution of (8) into (5) and making use of the problem's symmetry, a necessary and sufficient condition for non-negative expected profits is that  $[(nv(\hat{x}_j) - v'(\hat{x}_j)\hat{x}_j) / (n-1)v'(\hat{x}_j) - \hat{x}_j] / nv(\hat{x}_j) > F$  which, upon simplification implies  $[v(\hat{x}_j) - v'(\hat{x}_j)\hat{x}_j] / v(\hat{x}_j)(n-1)v'(\hat{x}_j) > F$ . A

necessary condition for non-negative expected profits therefore is that  $v(\hat{x}_i)/\hat{x}_i > v'(\hat{x}_i)$ , implying that the firm is in a region of decreasing returns with respect to the R&D input.

<sup>19</sup> For a discussion and evaluation of recent proposals to relax antitrust restrictions on production joint ventures in the United States, see Shapiro and Willig [1990].

<sup>20</sup> For a formal solution to the problem of the optimal distribution of plant sizes for a multi-plant monopolist operating under demand uncertainty, see Sharkey [1977]. Stigler [1939] also provides an early recognition of these issues. That cooperation among firms may be necessary to yield a non-empty core in the presence of demand uncertainty and avoidable costs that depend on plant capacity is shown by Telser [1978].

<sup>21</sup> There remains uncertainty about the timing of an innovation's discovery, but this does not affect firms' optimal capacity choices in this model.

<sup>22</sup>  $[\cdot]$  denotes the greatest integer function, i.e.,  $[x] =$  the greatest integer less than or equal to  $x$ .

<sup>23</sup> To see this, let  $K^s$  be the aggregate second-sourced capacity. If a firm wins the R&D race, its total second-sourcing payments to the  $(n-1)$  losers are then  $\lambda K^s$ . In the symmetric equilibrium it makes this payment with probability  $1/n$ , so that its total expected payment is  $\lambda K^s/n$ . A losing firm receives  $1/(n-1)$ th of the second-sourcing payments, or  $\lambda K^s/(n-1)$  dollars. It receives this payment with probability  $(n-1)/n$ , yielding an expected receipt of  $[\lambda K^s/(n-1)]/[(n-1)/n]$  or  $\lambda K^s/n$  dollars. This is exactly equal to the firm's expected payout.

There are two restrictions on the values that  $\lambda$  may assume. First, to preserve the incentive to undertake R&D, net revenues must be higher when the firm wins the R&D game than when it loses. This requires that the value of the terms in the first pair of curly brackets exceed that in the second pair in equation (9), placing a finite upper bound on the value that  $\lambda$  may assume. Second, time-consistency requirements place a lower bound of zero on  $\lambda$ . For empirical evidence on the characteristics of second-sourcing contracts and fees, see Caves *et al.* [1983] and Haklisch [1986].

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- 24 Equation (12) is derived by approximating the greatest integer function by  $[x] \approx x - 1/2$ , and evaluating it at its mean value over the interval  $[k_i, \sum k_j]$ .
- 25 Increased demand uncertainty is interpreted as a mean-preserving spread in the underlying demand distribution function.
- 26 For an elaboration and treatment of optimal industry organization, see Sharkey [1977].
- 27 Upon substitution of the optimal values for firm and industry level capacity in the two equilibria into (6) and (10), the expected profit expressions are not conducive to comparative statics exercises. For this reason, the text confines itself to an intuitive discussion of firms' relative expected profits with and without second-sourcing. The actual expressions derived for expected profits will be supplied by the author upon request.
- 28 See generally Finan and LaMond [1985], pp. 160–61. See also Appendix A, Table 2 of Haklisch [1986] for a chronology of the major mergers and acquisitions in the industry since the mid-1970's.
- 29 Data are taken from U.S. Department of Commerce, Bureau of the Census, Annual Survey of Manufacturers, 1974 to 1986.
- 30 See Swann [1987], Tables 1 and 2.
- 31 This problem is particularly relevant for industries like semiconductors where output across firms appears identical, and imperfections (eg., higher access failure rates) can only be detected after purchase. Monitoring of second-sourced production facilities could resolve these quality control problems.
- 32 For evidence on this, see Lazlo [1985], Exhibits XVI – XVIII.
- 33 Accordingly, the jumps in the firm's average cost decline in the pattern  $h, h/2, h/3, h/4, \dots$ .
- 34 I consider only the case of  $K^* > \hat{K}$  which, as Section IV(ii) noted, is the most likely outcome if second-sourcing is adopted by firms. In Figure 2, I assume arbitrarily that  $k^* < \hat{k} < 2k^*$ . The conclusions in this section, however, are perfectly general.

<sup>35</sup> Again, see Sharkey [1977] for a treatment of the firm's investment behavior under more general forms of demand uncertainty.

<sup>36</sup> Organization for Economic Cooperation and Development [1985], Table V-1.

<sup>37</sup> For a theoretical treatment of the patent collusion argument, see Priest [1977].

<sup>38</sup> The recently-blocked merger proposal between semiconductor firms Fujitsu and Fairchild is a case in point.

<sup>39</sup> For a treatment of some of the issues, see Taylor [1984].