VERTICAL INTEGRATION, SECRECY, AND HIGH-TECH INDUSTRIES

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ABSTRACT

In this paper we argue that an important, but mostly neglected, perspective on the vertical integration decision is that of keeping proprietary information secret. That is, especially in high-tech industries, firms will sometimes choose to vertically integrate in order to avoid sharing proprietary information with input suppliers because such sharing increases the probability the information will be learned by rival producers. We develop a model that illustrates the basic argument, and then extend the framework to show various ways this perspective can manifest itself in real world settings. These extensions include an analysis of high-tech industrial clusters that sheds light on differences between Silicon Valley and Route 128. Also, in addition to providing formal theoretical analyses, we compare the predictions of our formal analyses with relevant empirical evidence to show that our vertical integration and trade secrecy argument matches real world evidence quite well.

Keywords: vertical integration, secrecy, proprietary information, industrial clusters

JEL Classification: D21, L23

I. INTRODUCTION

Starting with the classic study of Coase (1937), a very large literature has developed that is focused on which transactions occur in the market and which occur inside firms. And this literature has investigated a large number of theoretical perspectives, including the well known transactions cost approach due to Williamson (1975,1978) and Klein, Crawford, and Alchian (1978), and the property rights approach due to Grossman and Hart (1986) and Hart and Moore (1988).[1] Despite the extensive prior literature on the subject, however, we believe there is an important perspective that has received limited attention. Specifically, we believe that, especially in the case of high-tech firms, an important perspective concerning which transactions are kept in-house is the desire by firms to keep proprietary information secret.

The basic argument is straightforward. Consider, for example, a firm that has an innovative but non-patented production process that gives the firm a competitive advantage in the market. The firm obviously has an incentive to keep the information secret since, if it is learned by the firm's rivals, then the firm's competitive advantage in the market will be eroded. Now suppose that there is an input used in the production process, where whoever produces the input needs detailed knowledge of this innovative production process to efficiently produce the input. One possibility is to purchase the input and require the supplier to sign a non-compete and non-disclosure agreement, but such contracts can be breached. An alternative, and in some cases more effective method because of the possibility of contractual breach, is for the firm to produce the input itself which avoids the need to share the proprietary information with outsiders.

In this paper, we argue that this perspective is important for understanding the vertical integration decision in high-tech industries. In particular, we present a model that captures the basic argument, and then develop a number of extensions that illustrate some of the various ways that this argument concerning vertical integration to enhance trade secrecy manifests itself in real world settings. In each case, in addition to providing a formal theoretical analysis, we compare

[1] See Gibbons (2005) for a survey that discusses the transactions cost and property rights approaches as well as a few well known alternatives.

the predictions of the formal theoretical analysis with the relevant empirical evidence to show that our trade secrecy argument matches real world evidence quite well.

We start with a model that captures the basic argument above. In this model, we focus on a firm that has a positive probability of an innovation that improves product quality, and there are two inputs in the production process – a standardized input and a customized input. Both inputs can either be produced in-house or purchased from an input supplier. Further, related to the above discussion, producing the customized input requires knowledge of the technology used to produce the good, but sharing that knowledge with an input supplier increases the probability that detailed knowledge of the firm's technology will be learned by a rival output producer. In equilibrium, the firm favors vertical integration for the customized input when contractual breach is a possibility, i.e., with a positive probability of a contractual breach the customized input will sometimes be produced in-house even when though is not the low cost way of producing the good. Further, the amount that the firm favors vertical integration for the customized input depends on various parameters of the model such as the size of the product improvement when innovation occurs and the probability of an innovation.

In our first extension, we add an R&D stage at the beginning of the game, and then focus on how equilibrium changes when there is a change in innovation investments due to a change in the effectiveness of R&D. We first show that extending the model in this way does not change the main finding of our basic framework that a firm sometimes chooses to vertically integrate even though this increases production costs. We then show that the model explains why vertical integration tends to be higher in high-tech firms and high-tech industries. That is, if the effectiveness of R&D investments varies within and across firms and industries, then there will be a positive correlation at the firm and industry level between investments in innovation and the likelihood of vertical integration. These results match quite well with empirical evidence concerning vertical integration and innovation as discussed, for example, in Lafontaine and Slade (2007).

In our second extension, we allow for multiple customized inputs in the production process. The basic idea explored in this analysis is that, if proprietary information is revealed to a rival as a result of the information being shared with an outside supplier of one customized input, then the return to producing a second customized input in-house is reduced. The result is that there is a complementarity in terms of the vertical integration decision, i.e., when a firm chooses to produce one customized input in-house the incentive to produce other customized inputs in-house increases. As discussed further below, this theoretical result is consistent with evidence concerning vertical integration found in the automobile industry.

Our last extension focuses on differences between Silicon Valley and Route 128. There are numerous differences between these two high-tech industrial clusters including that Silicon Valley is generally regarded as being more innovative, is associated with higher employee turnover, there is less secrecy concerning innovations, and there is less vertical integration (see, for example, Saxenian (1994), Kenney (2000), and Lee et al. (2000) for discussions). One difference between the two clusters is that in California firms are unable to enforce non-compete agreements with their employees due to a state level prohibition, while in Massachusetts such contracts are enforceable. We extend our basic framework to allow for high-tech employee turnover, and show that equilibrium then depends on whether employee non-compete agreements can be enforced. In particular, when they cannot, equilibrium is characterized by more rapid innovation, higher high-tech employee turnover, less secrecy, and less vertical integration which are important differences that have been observed between Silicon Valley and Route 128.

We are familiar with only two previous papers in the industrial organization literature that argue that vertical integration may sometimes be used as a way of protecting proprietary information. The first is an interesting, but not very well known paper, published by Kurt Lundgren in 1990. That paper is a descriptive piece in which, similar to part of the discussion above, Lundgren argues among other ideas that vertical integration used to enhance trade secrecy is an important but neglected perspective on the vertical integration decision. In addition to putting forth the basic argument, he provides discussions of various real world examples that fit the argument. More recently, Novak and Stern (2009) discuss the argument in an empirical paper on vertical integration decisions in automobile product development. Their main finding is that contracting choices in this setting exhibit complementarities, i.e., the returns to vertically integrating in the case of one input are higher the more other inputs the firm chooses to produce in-house. Novak and Stern argue that vertical integration used to enhance trade secrecy is one possible explanation for their findings, and our second extension formalizes their discussion. Note that neither of these previous papers focuses on formal game theoretic models of the vertical integration and trade secrecy argument which is the focus of our paper.[2]

Our paper is also related to Aghion and Tirole (1994). Like our paper, that paper considers the role of vertical integration in terms of innovation and intellectual property rights. The approach in that paper, however, is quite different. Their approach is along the lines of the property rights perspective of Grossman and Hart (1986) and Hart and Moore (1988) in which, because of incomplete contracting, the vertical integration decision affects investment incentives, and so firms are organized to optimize such incentives. In our approach, in contrast, the main focus is not innovation incentives, although that is a factor in one of the extensions. But rather our focus is how vertical integration can affect the value of an innovation by reducing the probability the innovation is learned by rival producers in the output market.

Another related idea can be found in the literature on foreign direct investment. An important topic in that literature is that, when a multi-national firm decides to invest in a foreign country, it must decide whether to license its technology to a foreign firm, or instead purchase overseas factors of production which allows the firm to produce internally. As pointed out in various early papers such as Rugman (1986) and Ethier (1986), an important perspective on this decision is that licensing potentially results in information about the initial firm's technology being learned by rival producers, which can erode the value of the technology to the original

[2] Novak and Stern (2009) do provide a theoretical model of the vertical integration decision with multiple inputs and secrecy. But they do not take a game theoretic approach in which the rivalry between output producers is formally modeled. They also do not explore the various extensions that we explore.

owner. So, in cases where this type of information leakage would be very costly to the original owner, the firm may choose to own the foreign factors of production and in this way reduce the probability that rivals learn the information. In a sense, our argument is that this basic insight extends beyond the topic of foreign direct investment, and applies whenever there is an input in which outsourcing can result in leakage of valuable proprietary information.

As a final introductory point, the perspective we take in this paper is similar to that taken by Harold Demsetz in his classic 1969 paper titled "Information and Efficiency: Another Viewpoint." The extent to which the originator of new knowledge benefits from its discovery depends on the degree to which the originator can appropriate the value of that discovery. And the degree of appropriation itself is not solely an issue of government regulation and policy. Rather, the originator can take actions to increase the degree of appropriability, which, in turn, can limit the role of government intervention. Our argument is that one such action is that of vertical integration of customized inputs, and that this idea potentially has important implications for the classic question, which inputs does a firm make and which does it buy?

The outline for the paper is as follows. Section II presents various factors pointing to the idea that vertical integration used to keep proprietary information secret is an important real world phenomenon. Section III presents a basic model that shows how vertical integration can arise due to a firm's incentive to keep proprietary information secret. Section IV presents our first extension which shows how the desire to keep proprietary information secret can lead to a higher frequency of vertical integration in high-tech industries. Section V presents our second extension which concerns the vertical integration decision when there are multiple inputs in the production process. Section VI presents our last extension which connects the vertical integration decision in high-tech industrial clusters to whether or not employee non-compete agreements are enforceable. Section VII presents a general discussion of how our theoretical approach is related to the empirical literature. Section VIII provides concluding remarks.

II. WHY CONSIDER SECRECY?

As mentioned briefly in the Introduction, the idea that the decision concerning whether or not to vertically integrate is related to the desire for secrecy does appear in the prior literature in a few places. But, overall, the vast literature on the vertical integration decision places very little emphasis on secrecy being an important driver of vertical integration decisions. For example, in his well known survey on the main theories concerning vertical integration, Gibbons (2005) does not even mention the desire for secrecy as a possibility. Similarly, in their well known survey on the theory and empirical literatures concerning vertical integration, Lafontaine and Slade (2007) have a broader focus than the four theories that Gibbons focuses on, but again there is no discussion of the possible role of secrecy.

Despite this lack of attention to the idea in the mainstream theoretical and empirical literatures concerning the vertical integration decision, we feel there are many reasons to believe that the desire to maintain secrecy is an important driver of real world vertical integration decisions, especially in high-tech industries. In this section we discuss a few of these reasons.

One objection to the secrecy argument concerning vertical integration is that the patent system eliminates the need for secrecy, so at least in a country with strong intellectual property rights protection secrecy should not be an important driver of vertical integration decisions. But this argument is not consistent with the evidence. For example, Mansfield, Schwartz, and Wagner (1981) conducted a survey of R&D workers and found that 60 percent of successful patented innovations were imitated within four years. Similarly, Levin et al. (1987) also found using survey data that patenting was imperfect in terms of stopping rivals from imitating an innovation, and many firms in their survey reported that they heavily use secrecy as a way of slowing down the imitation process.[3]

Another reason to think that secrecy is important involves the literature on foreign direct investment discussed briefly in the Introduction. As indicated in that discussion, an important

[3] For more recent work on secrecy see, for example, Png (2017a,b).

theoretical argument made in that literature is that multinational firms will prefer to purchase foreign factors of production rather than license when it is important to keep proprietary information secret. This perspective makes a number of testable predictions. These include that multinationals will be more likely to own foreign factors of production when products are new and complex, and when intangible assets are important. And various studies such as Mansfield and Romeo (1980), Davidson and McFetridge (1984), and Blomstrom and Zejan (1991) find empirical results consistent with these predictions.

An example of a single firm's behavior that suggests secrecy is important is that of Apple. As discussed in Lashinsky (2012), a key aspect of Apple's corporate strategy is a focus on secrecy. That is, in addition to an obvious focus on the designs of its products, the structure of the firm is to a great extent centered on maintaining the secrecy of those designs. This includes, consistent with the model analyzed in Section VI, trying to limit the turnover of its high-tech workforce. In fact, Apple was one of the firms that settled an anti-poaching lawsuit in 2015 concerning an allegation that the firms illegally agreed to not poach each others' high-tech workers.

So secrecy is important. But what are the reasons to think that vertical integration is important in terms of achieving secrecy? Novak and Stern (2009), in motivating their argument that secrecy may be important for understanding their empirical findings, discuss a 2001 lawsuit between DaimlerChrysler and General Motors. The lawsuit involved an allegation of the type of risk associated with purchasing from an input supplier that is at the heart of our argument. DaimlerChrysler had outsourced the design and manufacturing of Chrysler Jeep grilles to AM General which received a trademark for the grille in 1996 when it was exclusively designing grilles for Chrysler Jeeps. Subsequently, General Motors contracted with AM General in 1999 to develop and build vehicles in General Motors' Hummer line. DaimlerChrysler's allegation was that AM General passed the design of the Chrysler Jeep grille to General Motors for its design of the GM Hummer H2 grille with subsequent harm to DaimlerChrysler's Jeep product line. This harm likely would have been avoided if DaimlerChrysler had designed and produced the grille in-house rather than contract with AM General to design and manufacture the grille.

Another reason to think that secrecy is important in vertical integration decisions concerns the difference between the high-tech industrial clusters in Silicon Valley and Route 128. The differences between these high-tech clusters has drawn much attention in the academic literature and popular press including the well known study of Saxenian (1994). These discussions make it clear that Apple is an outlier in terms of Silicon Valley firms. In general it is the Route 128 firms that are more secretive. Further, Saxenian and others describe the higher levels of secrecy at Route 128 firms as the result of a number of differences between the two high-tech clusters including much higher levels of vertical integration in Route 128 relative to Silicon Valley.[4]

Overall, we are not arguing that existing evidence definitively proves that secrecy is an important factor in real world vertical integration decisions. Rather, our argument is that there are a number of ideas and real world examples already in the literature sufficiently suggestive of the idea that further theoretical attention to the idea is warranted. Then one can look to see whether the testable predictions that come out of such a theoretical analysis are consistent with existing empirical evidence. That is what the rest of this paper is about.

III. A BASIC MODEL

In this section we construct and analyze a model that allows us to formalize the basic argument that the incentive to keep proprietary information secret can lead to vertical integration. We first present the model and then provide an analysis focused on the decision concerning whether to produce an input in-house or from an input supplier.

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[4] One question of interest, but beyond the scope of the current paper, is why is Apple so successful using a strategy of secrecy when Route 128 firms have not achieved similar levels of success? Our conjecture is that it is due to the superior design skills of Steve Jobs and others at Apple. That is, it is possible that high levels of secrecy is part of a successful strategy when the firm has superior design skills as in the case of Apple, but that firms that employ high levels of secrecy are dominated by less secretive firms in the absence of such superior design skills.

A) <u>The Model</u>

Consider a one-period model in which everyone is risk neutral. In the model there is a firm, call it firm A, that produces a product for which there are two inputs and the firm must decide whether to produce inputs in-house or instead purchase the inputs from input suppliers. As discussed in the timing of moves for this model below, this decision is made at the beginning of the game.

The firm faces a rival producer, call it firm B. At the beginning of the game the two firms have access to the same technology. This technology allows a firm to produce a unit of output of quality Q^L by combining one unit of a standardized input, one unit of a customized input, and l_l units of standard or low-tech labor.

There is a probability z_A, $0<z_A<1$, that firm A directly gains access to a superior technology and a similar probability z_B, $0<z_B<1$, that firm B directly gains access to this technology, where the realizations concerning whether or not a firm directly gains access to this second technology are independent events. This second technology allows a firm to produce a unit of quality Q^H, $Q^H>Q^L$, by combining one unit of the standardized input, one unit of the customized input, and l_l units of low-tech labor.

There is a competitive industry of input suppliers, where a firm in this industry can produce a unit of the standardized input at marginal cost c and no fixed cost. This means the competitive price for a unit of the standardized input is also c. Firm B can also produce a unit of the standardized input at marginal cost c and no fixed cost. But firm A has a marginal cost c of producing a unit of the standardized input and fixed cost Δ, where Δ is a random draw from a probability density function, $h(\Delta)$, which is strictly positive for all $0<\Delta<\infty$. The higher cost for firm A for producing the standardized input is due to unmodeled economies of scale and scope. The market for low-tech labor is also competitive and the unit price for low-tech labor is w_l.

A unit of the customized input can also be produced by a firm in the competitive input industry at constant marginal cost equal to c and no fixed cost, but doing so requires the output firm to share information about its technology with the input supplier. If this information concerns the superior technology and the information is shared with an input supplier, then the supplier can sell the information to the rival output producer which would allow the rival to produce units of quality Q^H even if the rival did not directly gain access to the superior technology. It is assumed that firm A can produce the customized input in-house at a per unit cost of c and fixed cost Δ, while firm B can produce the customized input in-house at constant marginal cost equal to c and zero fixed cost. Assuming that firm B can produce both standardized and customized units of the input in-house at the same cost as an input supplier simplifies the analysis because it means firm B receives no benefit from outsourcing.

In contracting with an input supplier, firm A can include in the contract a prohibition on the input supplier selling information concerning firm A's proprietary technology to the rival, where the courts allow a maximum penalty associated with a contractual breach equal to M^+ while M denotes the penalty specified in the contract. If the courts rule that a breach occurred, then the input supplier pays firm A the penalty specified in the contract.

Suppose that an input supplier has contracted with firm A to produce the customized input and has agreed to a prohibition concerning selling information about the firm's technology to the rival output producer. Further suppose that despite the prohibition the firm decides to sell the information anyway. Then there is a probability d that the courts will find evidence that the information was sold and the input supplier will be required to pay the contractually specified penalty, where d equals 0 with probability r and equals D, $0<D\leq 1$, with probability (1-r). It is also assumed that the input supplier privately observes whether d equals 0 or D prior to deciding whether to sell the information to the rival output producer.

There is a continuum of N consumers distributed uniformly along a Hotelling line of unit length. Firm A's product is located at one end of the line and firm B's product is located at the other end. Let consumer i be located at distance x_i from A's product which, in turn, means it is located distance $(1-x_i)$ from B's product. Further, let Q_j, j=A,B, be the quality of the product sold by firm j and let P_j be the price firm j charges for its product. Consumer i purchases either 0 or 1 total units of output, where the net utility the consumer derives from purchasing a unit from firm A (B) is Q_A-γx_i-P_A (Q_B-$\gamma(1-x_i)$-P_B).[5] We assume that the parameters of the model are such that in equilibrium the market is fully covered, i.e., all consumers purchase a unit of output from either firm A or firm B. Note that γ captures the extent of product differentiation in the model if product space is interpreted as differences in product design (if product space is interpreted as physical location then γ captures the importance of transportation costs).[6]

The timing of events in our one-period model is as follows. At the beginning of the game the value for Δ is realized and publicly observed, and then for each input firm A makes an irreversible decision concerning whether to produce the input in-house or contract with an input supplier (as discussed earlier, because firm B and the input suppliers are equally efficient at producing each input, there would be no benefit associated with firm B choosing to contract with an input supplier if given a choice).[7] Also, we assume that both the realized value for Δ and firm A's choice of whether to produce inputs in-house or contract with input suppliers are publicly observed. However, results would be unchanged if these realizations were not publicly observed.

In the next stage of the game there is a realization for each of firms A and B concerning whether or not the firm directly gains access to the superior technology, where each realization is privately revealed to the respective firm. If firm A earlier chose in-house production for both inputs, then the game ends with the following set of choices. First, firms hire labor. Second, firms simultaneously choose qualities to produce, where a firm is constrained to choose from the

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[5] To be precise, if a set of consumer of mass equal to n all purchase from firm A (B), then the total number of units purchased from A (B) is n.

[6] We also impose an additional parameter restriction. Specifically, we assume parameters are such that the increase in aggregate profits for firms A and B when only one firm produces high quality rather than both is higher than the increase in an output producer's profit from increasing quality from Q^L to Q^H when the other firm produces Q^H. It is easy to show that, holding all other parameters fixed, this condition will be satisfied if Q^H is sufficiently large.

[7] One way to justify the assumption that the decision to produce an input in-house or purchase it from an input supplier is made prior to other decisions and is irreversible is to assume that in-house production requires a prior investment in capital goods. Specifically, if the required capital good investment was sufficiently high and there was a lag between ordering the capital good and delivery, then equilibrium would be consistent with the decision concerning whether or not to vertically integrate being made prior to other decisions and the decision being irreversible. In order to simplify the model we do not formally model the choice of investing in capital goods and instead just assume that vertical integration decisions are made first and are irreversible.

technologies it has available and these choices are publicly observable. Third, firms simultaneously choose prices. Fourth, consumers make purchase decisions.

Suppose instead that at the earlier stage firm A chose to purchase one or both inputs from input suppliers. Then at the next stage, for each input it chose to purchase, it makes a take-it or leave-it contract offer to a randomly chosen input supplier, where the contract terms are the private information of the two parties (see footnote 9 for a related discussion). If it is the standard input or A does not have access to the superior technology, then the contract terms consist simply of a fixed fee and per unit price that A will pay the input supplier for units of the input. If it is the customized input and A has access to the superior technology, then the contract includes a fixed fee, a per unit price, and a penalty associated with the input supplier selling the information to firm B (setting the penalty at zero is equivalent to no prohibition on the input supplier selling the information). The input supplier then decides whether to accept the contract offer. If it chooses not to accept, then A does not produce and the game ends with B acting like a monopolist in the output market. If the input supplier accepts the offer and the offer was for units of the standardized input, then the game again ends with the four stages described above. Similarly, if the input supplier accepts the offer and the offer was for units of the customized input, but A does not have access to the superior technology, then the game again ends with the four stages described above.

Now consider the case in which the input supplier accepts the offer, the contract was for units of the customized input, and A has access to the superior technology, i.e., the input supplier acquires information concerning the superior technology. Then in the next stage of the game the value for d is realized and privately observed by the input supplier. Then the input supplier makes a take-it or leave-it offer to firm B concerning selling the information (a prohibitively high offer is equivalent to not offering to sell the information) and firm B then decides whether or not to accept the offer. After this decision, the four stages described above take place. Finally, in the case in which the input supplier sells the information, then with probability d the input supplier pays the contractually specified penalty to firm A. Our focus is Perfect Bayesian Equilibrium.[8]

B) Preliminary Results

As indicated, our main focus is the vertical integration decisions for firm A. Before providing results concerning these decisions, however, we provide some preliminary results concerning equilibrium output prices and consumer purchase decisions as functions of product qualities and firm A's earlier decisions whether or not to vertically integrate. Formal proofs are provided in the Appendix.

Let $P_j(Q_j,Q_k,v_S,v_C)$ denote firm j's price, j=A,B, as a function of firm j's product quality, firm k's product quality, $k\neq j$, v_S which denotes firm A's vertical integration decision concerning the standardized input, and v_C which denotes firm A's vertical integration decision concerning the customized input, where $v_S(v_C)=0$ means the standardized (customized) input is purchased from an input supplier and $v_S(v_C)=1$ means the standardized (customized) input is produced in-house. Also, let $x^*(Q_A,Q_B,v_S,v_C)$ denote the indifferent consumer as a function of Q_A, Q_B, v_S, and v_C, i.e., if $x_i<x^*(Q_A,Q_B,v_S,v_C)$ the consumer purchases A's product and $x_i>x^*(Q_A,Q_B,v_S,v_C)$ means the consumer purchases B's product. Note that the indifferent consumer is determined by product qualities and prices, but since prices are themselves functions of qualities and A's vertical integration decisions, we can express the location of the indifferent consumer as a function solely of qualities and A's vertical integration decisions.

The first result is that, because the vertical integration decisions do not affect firm A's marginal cost of production, prices and the location of the marginal consumer are independent of these choices. Specifically, $P_j(Q_j,Q_k,1,1)=P_j(Q_j,Q_k,1,0)=P_j(Q_j,Q_k,0,1)=P_j(Q_j,Q_k,0,0)$ for all Q_j, Q_k, and j triplets and $x^*(Q_A,Q_B,1,1)=x^*(Q_A,Q_B,1,0)=x^*(Q_A,Q_B,0,1)=x^*(Q_A,Q_B,0,0)$ for all Q_A,

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[8] We assume that if firm A has access to the superior technology and purchases the customized input from an input supplier, it shares the information concerning the superior technology with the input supplier even if its plan is to later producer Q^L units of output (this action is, in fact, off the equilibrium path). This assumption is not crucial but rather simplifies some of the proofs.

Q_B pairs. The logic is that efficient contracting between firm A and an input supplier requires the per unit price that firm A pays for a unit of an input to always equal c. As a result, firm A's marginal cost of production is independent of whether it chooses vertical integration or outsourcing for the two inputs. Given this, in the rest of the paper we suppress the vertical integration decisions in the notation capturing pricing and the location of the indifferent consumer. That is, $P_j(Q_j,Q_k)=P_j(Q_j,Q_k,1,1)=P_j(Q_j,Q_k,1,0)=P_j(Q_j,Q_k,0,1)=P_j(Q_j,Q_k,0,0)$ for all Q_j, Q_k, j triplets, and $x^*(Q_A,Q_B)=x^*(Q_A,Q_B,1,1)=x^*(Q_A,Q_B,1,0)=x^*(Q_A,Q_B,0,1)=x^*(Q_A,Q_B,0,0)$ for all Q_A, Q_B pairs.

Suppose both firms produce high quality. Then the two firms choose the same price and the indifferent consumer is located half way between the two firms on the Hotelling line, i.e., $P_A(Q^H,Q^H)=P_B(Q^H,Q^H)$ and $x^*(Q^H,Q^H)=1/2$. Similarly, $P_A(Q^L,Q^L)=P_B(Q^L,Q^L)$ and $x^*(Q^L,Q^L)=1/2$. In the Appendix we also show that the single price when the qualities are the same is independent of whether quality is high or low, i.e., $P_A(Q^H,Q^H)=P_A(Q^L,Q^L)$.

The two firms choose the same price when qualities are the same because of the symmetry of the situation. To be more precise, because as already indicated, the contractually specified per unit price in the case of outsourcing that A pays for a unit of an input is c, the two firms have the same marginal cost of production whether or not firm A vertically integrates or outsources.[9] Given qualities are the same and marginal costs are the same, the symmetry of the situation yields that A and B charge the same price and the indifferent consumer is located half way between the two firms.

The remaining set of cases concern what happens when the firms produce different quality products. Consider first the cases in which firm A produces high quality and firm B low quality. The higher quality means firm A will choose a higher price and also achieve a higher market share, i.e., $P_A(Q^H,Q^L)>P_B(Q^L,Q^H)$ and $x^*(Q^H,Q^L)>1/2$. Now suppose firm B produces

[9] This result depends on our assumption that contractual terms are not publicly observed. If contract terms were observable, then in the case of outsourcing firm A would have an incentive to have the per unit price in the two-part pricing contract be below the input supplier's marginal cost of production. This would give firm A an advantage in the pricing game with B. See, for example, Fershtman and Judd (1987) for a related analysis.

high quality and firm B low quality. Given the symmetry of the problem, pricing outcomes and the location of the marginal consumer are reversed. That is, $P_B(Q^H,Q^L)=P_A(Q^H,Q^L)$ and $x^*(Q^L,Q^H) =1-x^*(Q^H,Q^L)$.

C) Main Analysis

Firma A's vertical integration decision for the standardized input is straightforward. Firm A has a constant marginal cost c and a fixed cost Δ, $\Delta>0$, for producing units of the standardized input, while an input producer has a constant marginal cost c and no fixed costs. Further, firm A does not need to share information concerning its technology with the input producer if it chooses to purchase the input from an input supplier. The result is that, in order to minimize the cost of producing the standardized input, in equilibrium it always chooses to purchase the standardized input from an input supplier.

We now consider firm A's vertical integration decision for the customized input. Suppose that an input supplier did not have the option of selling information to the rival or alternatively that a contractual breach was not possible. Then firm A's decision concerning whether or not to produce or purchase the customized input would be the same as for the standardized input. That is, in the absence of the selling of information by an input supplier being a concern, our specification in which an input supplier has a lower total cost of production means firm A would receive no benefit from producing the input in-house and would thus choose to purchase the customized input.

But if the selling of information is a concern, then production efficiency is no longer the sole determinant of whether firm A chooses to produce or purchase the customized input. To see this, consider a state of the world in which firm A has access to the superior technology and firm B does not – this state of the world arises with probability $z_A(1-z_B)$. If firm A produces the customized input in-house, then B does not gain access to the superior technology which is beneficial from A's standpoint because it makes B a less effective competitor.[10] Suppose instead that firm A purchases the customized input from an input supplier. Information about the superior technology will be valuable to firm B and so the input supplier will face a positive price for selling the information to B. If the contract is not able to eliminate this incentive, then firm A may be better off producing the customized input in-house even though from a production efficiency standpoint this is not optimal. This is the main logic that drives results below concerning the vertical integration decision for the customized input.

We start by identifying parameterizations for which contracting fully avoids the information leakage problem with the result that firm A never chooses to vertically integrate.

Lemma 1: Holding all other parameters fixed, there exists a lowest value, denoted M*, such that the following is satisfied. If r=0 and M^+ is sufficiently large, i.e., $M^+ \geq M^*$, then firm A purchases both inputs from input suppliers with probability one.[11]

Suppose firm A has access to the superior technology, contracts with an input supplier for the production of the customized input, and includes in the contract both a prohibition on the input supplier selling information about the superior technology to firm B and a penalty associated with such selling. The condition r=0 means that the probability the input supplier would be required to pay the penalty if it sells information to firm B is D, D>0. If M^+ which is the maximum penalty allowed by the courts is sufficiently high, then firm A can stop the input supplier from selling information to firm B by setting the penalty in the contract high enough. As a result, given the cost advantage of input suppliers in producing the input, when r=0 and M^+

[10] We do not allow an output producer to sell information concerning the superior technology directly to its rival. But introducing this possibility would not change the equilibrium in a substantial way because in our model an output producer never has an incentive to make such a sale.

[11] Throughout the paper we assume that an input supplier does not sell information about the superior technology to firm B when it is indifferent between selling and not selling the information. We also assume that, when firm A is indifferent between in-house production and purchasing the input from an input supplier, that it chooses to purchase the input.

is sufficiently high, the result is that firm A chooses to purchase the customized input given all possible realizations for Δ.

We now consider the vertical integration decision when the conditions identified in Lemma 1 do not hold.

Lemma 2: Holding all other parameters fixed, if r>0 and/or M^+ is sufficiently small, i.e., $M^+<M^*$, then there exists a value Δ^*, $0<\Delta^*<\infty$, such that firm A produces the customized input in-house when $\Delta<\Delta^*$ and purchases the input from an input supplier when $\Delta\geq\Delta^*$. In contrast, firm A purchases the standardized input from an input supplier for all realizations of Δ.

Lemma 2 tells us that there are two ways that the model can result in firm A having a positive probability of choosing vertical integration for the customized input. First, there is a strictly positive probability of vertical integration when r>0. In particular, the firm chooses to vertically integrate in this case when the extra production cost associated with producing inputs in-house is sufficiently small, i.e., $\Delta<\Delta^*$. The basic logic builds on the discussion above. The condition r>0 means that there is a strictly positive probability that the input supplier can sell the information to the rival with no probability of incurring a penalty. Firm A is unable to stop an input supplier it contracts with from selling information about the superior technology to firm B when there is a zero probability that the input supplier will pay a penalty. Since the selling of this information is costly to firm A, the firm will produce the customized input in-house if the production inefficiency associated with vertical integration is sufficiently small.

Second, even if r=0, the same basic logic holds if M^+ is not high enough. In this case, firm A could stop an input supplier from ever selling information to firm B if it could set the penalty associated with the selling of information high enough. But because the courts will not enforce a contractual penalty of that magnitude, firm A is unable to stop an input supplier from selling information to B. The result is again that, if the additional production cost of producing an input in-house is sufficiently small, then firm A chooses to produce the customized input in-house.

We now describe in more detail the nature of equilibrium behavior.

Proposition 1: There exist values Δ^* and M^* such that equilibrium is described by i) through vi). Further, $\Delta^*=0$ if $r=0$ and $M^+\geq M^*$, while $\Delta^*>0$ if $r>0$ and/or $M^+<M^*$.

i) Firm A purchases the standardized input from an input supplier for all realization of Δ.

ii) If $\Delta<\Delta^*$, then firm A produces the customized input in-house and each of firms A and B sells high (low) quality output if the firm directly gains (does not directly gain) access to the superior technology.

iii) If $\Delta\geq\Delta^*$, then firm A purchases the customized input from an input supplier.

iv) If $\Delta\geq\Delta^*$ and firm A does not directly gain access to the superior technology, then firm A sells low quality output and firm B sells high (low) quality output if firm B directly gains (does not directly gain) access to the superior technology.

v) If $\Delta\geq\Delta^*$, firm A directly gains access to the superior technology, $d=D$, and $M^+\geq M^*$, then firm A sells high quality output and firm B sells high (low) quality output if firm B directly gains (does not directly gain) access to the superior technology.

vi) If $\Delta\geq\Delta^*$, firm A directly gains access to the superior technology, and $d=0$ and/or $M^+<M^*$, then the input supplier sells information about the superior technology to firm B when firm B does not directly gain access and both firms A and B sell high quality output.

The first result to note in Proposition 1 is that, if $\Delta<\Delta^*$ which means that firm A chooses to produce the customized input in-house, then each of firms A and B produce high quality if the firm directly gains access to the superior technology and produces low quality otherwise. But this is not the full story concerning how product qualities are chosen when $\Delta\geq\Delta^*$. If $\Delta\geq\Delta^*$, then firm A chooses to purchase the customized input from an input supplier and, if it directly gains access to the superior technology, it shares the information concerning the superior technology with the input supplier. If d=D and $M^+ \geq M^*$, it is still the case that firm B produces high quality if it directly gains access to the superior technology and low quality otherwise. But if d=0 and/or $M^+ < M^*$, then the input supplier sells the information to firm B if firm B did not directly gain access and firm B then produces high quality rather than low quality output. From the preliminary results we know this sharing hurts firm A's profitability which is the detailed logic for why firm A chooses in-house production for the customized input in this case when Δ is sufficiently small since vertical integration stops this from occurring (see footnote 13 for a related discussion).

In the next step of the analysis we conduct a comparative statics analysis on Δ^*.

Corollary 1 to Proposition 1: Holding all other parameters fixed, if r>0 and/or $M^+ < M^*$, then Δ^* increases with increases in Q^H and z_A, while Δ^* decreases with increases in Q^L and z_B.[12]

The expected cost of producing the customized input in-house is higher production costs and this higher cost rises with Δ. The expected benefit is that when A directly gains access to the superior technology there is a higher probability that B will sell low quality rather than high quality output.[13] The probability the customized input is produced in-house is determined by Δ^*, where Δ^* is the value such that the expected cost of vertical integration exactly equals the expected benefit. To understand the results in Corollary 1 we simply need to understand how this expected benefit varies with changes in the various parameters in the model. For example, suppose there is an increase in Q^H. Then the benefit of being the sole firm selling the high

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[12] If the Corollary was not restricted to parameterizations that satisfy r>0 and/or $M^+ < M^*$, then the correct statement would be that Δ^* weakly increases with increases in Q^H and z_A, while Δ^* weakly decreases with increases in Q^L and z_B.

[13] To be precise, the expected benefit is not the full increase in firm A's expected profit in selling to consumers due to the higher probability that B produces low rather than high quality output. The reason is that, when A contracts with an input supplier for production of the customized input, A's payment to the input supplier reflects expected payments B will make to the input supplier for information concerning the superior technology. There is also the expected penalty A receives if the input supplier is caught selling information. So the expected benefit to A of producing the customized input in-house is in fact somewhat lower than the full increase in firm A's expected profit in selling to consumers due to the higher probability that B produces low rather than high quality output. See the Appendix for details.

quality product is larger, so Δ^* rises. Similarly, an increase in z_A increases the expected benefit of producing the customized input in-house because it increases the probability that in the absence of vertical integration the input supplier sells information to firm B and thus lowers firm A's profits. And again, an increase in the expected benefit of producing the customized input in-house results in an increase in Δ^*.

Before ending this section, it is interesting to note that a testable prediction of our model is that customized relative to standardized inputs should have a higher frequency of in-house production. The logic captured by our model is straightforward. An output producer does not need to share information concerning its production technology with an input supplier if the input is standardized, but such sharing can be important when the input is customized, especially when that customization is related to the production technology. So the incentive to vertically integrate to keep proprietary information secret should only arise with customized inputs which, in turn, implies a higher frequency of in-house production with customized inputs.

There is an extensive empirical literature concerning this prediction because this prediction is also made by the transactions cost theory of the firm. In that theory, producing customized inputs introduces the possibility of hold-up, i.e., the input supplier refuses to deliver the input without additional payments not agreed upon initially, with the result that output producers have an incentive to vertically integrate in order to avoid hold-up costs. The prediction that vertical integration is more frequent when the hold-up problem is more important has been tested in a large number of papers, and many of these papers are basically tests of whether vertical integration is more frequent when the input is customized. For example, many of the tests focus on whether physical and/or human capital specificity is high which is consistent with the production of customized inputs. The standard finding in this literature is that, consistent with our theory, but also with the transactions cost theory of the firm, vertical integration is more likely when the input has features consistent with it being customized rather than standardized. Some of the classic papers in this literature are Monteverde and Teece

(1982), Masten (1984), and Lieberman (1991) (see Lafontaine and Slade (2007) for a survey). We come back to a discussion of this literature in Section VII.

In summary, in this section we have formalized our basic argument that a firm may choose to vertically integrate in order to keep secret proprietary information concerning its production technology. In our model, production requires both a standardized input and a customized input. Also, one of the output producers chooses whether to produce inputs in-house or purchase them from input suppliers, where production costs for inputs are lower when they are purchased. If this output producer directly gains access to the superior technology, then purchasing the customized input from an input supplier requires sharing the information with the input supplier and the supplier has the option of then selling the information to a rival producer of the output. The result is that, if the setting is such that contractual penalties cannot completely prohibit such a sale, then the output producer chooses to purchase the standardized input if the extra cost of in-house production is large, but produces the customized input in-house if this extra cost is small. We further show how the probability of in-house production for the customized input varies with various parameters in the model, and also point out that a basic testable prediction of our argument is consistent with the empirical evidence.

IV. EXTENSION I: INNOVATION

In this section we extend the model to allow for an R&D decision at the beginning of the game. As discussed at the end of the section, a number of empirical papers on the vertical integration decision have found a positive correlation between investments in innovation and the extent of vertical integration. The main point of this section is to show that one possible explanation for this finding is that higher investments in innovation increase the incentive for a firm to keep proprietary information secret, and vertical integration of customized inputs is one way that firms can achieve this type of secrecy.

We make two related changes to Section III's model. We assume that z_A, i.e., the probability that firm A directly gains access to the superior technology, is a choice variable for firm A rather than a parameter of the model. To be precise, we assume that at the same time that firm A chooses whether to vertically integrate, it also chooses an investment in R&D that determines the probability the firm directly gains access to the superior technology. Let R_A be firm A's choice of an R&D investment. We assume that $\alpha z_A(R_A)$ is the probability that firm A directly gains access to the superior technology, where $z_A(0)=0$, $z_A'(0)=\infty$, and $z_A'(R_A)>0$ and $z_A''(R_A)<0$ for all $R_A>0$. That is, the probability the R&D investment is successful increases with the R&D investment but at a decreasing rate. Below we refer to R_A' as the equilibrium investment level.

The second change is that we assume that the effectiveness of investing in R&D which is determined by α is stochastic. In particular, α is a random draw from a probability density function, g(α), which is strictly positive for all $0<\alpha^L\leq\alpha\leq\alpha^H$ and $\alpha^H>\alpha^L$. A higher value for α means that increasing the investment in R&D has a larger effect on the probability the firm directly gains access to the superior technology. We also assume that $\alpha^H z(\infty)<1$, i.e., the probability the R&D investment is successful is always less than one, and that α is realized at the very beginning of the game and this realization is publicly observed.

We start with a preliminary set of results.

Proposition 2: For each realization of α firm A chooses an R&D investment R_A', $R_A'>0$, with the result that all the findings in Lemma 1, Lemma 2, Proposition 1, and Corollary 1 hold except that z_A is replaced by $\alpha z_A(R_A')$.

Proposition 2 states that, for each realization of α, all the earlier results of the previous section hold except that z_A is now the outcome of an R&D choice rather than being given exogenously. This is not at all surprising given the limited manner in which we have changed the model. Given this, our focus is now how equilibrium in this model changes with changes in α. In particular, our focus is how innovation investments and the probability of vertical integration for the customized input change with changes in the effectiveness of investments in R&D.

Proposition 3: Holding all other parameters fixed, an increase in α increases R_A', $\alpha z_A(R_A')$, and, if r>0 and/or $M^+<M^*$, Δ^* also increases.[14]

Proposition 3 states that an increase in the effectiveness of R&D investments increases the investment in R&D, the probability that firm A directly gains access to the superior technology, and, if r>0 and/or $M^+<M^*$, increases the probability that firm A chooses to produce the customized input in-house. The logic for these results builds on the logic found in the discussion following Corollary 1 to Proposition 1 in the previous section. An increase in α means that R&D investments are more valuable. The result is that firm A increases its investment in R&D which, in turn, increases the probability the investment is successful. Further, following the earlier discussion, given a higher value for α translates into a higher value for $\alpha z_A(R_A')$, there will also be a higher value for Δ^* given r>0 and/or $M^+<M^*$. That is, the higher value for $\alpha z_A(R_A')$ means there is a higher expected benefit associated with keeping the information concerning the superior technology secret. If the initial value for Δ^* is strictly positive, then Δ^* rises because the incremental production cost for producing the customized input in-house that equates the expected cost of vertical integration with the expected benefit must be higher.

Notice that this result serves as an explanation for why both within firms and industries and across firms and industries higher innovation investments are correlated with a higher frequency of vertical integration. For example, consider a firm which produces multiple products and each product is associated with a single input for which information concerning producing the product must be shared if the input is purchased from an input supplier. If α varies

[14] Without the restriction that parameterizations must satisfy r>0 and/or $M^+<M^*$, then the correct statement is that an increase in α weakly increases Δ^*.

across these various products, then the firm will invest more in innovation for products where α is high and those will also be the products with a higher probability of vertical integration. That is, within this firm there will be a positive correlation between innovation investments and vertical integration.

To see how the argument works across industries, suppose there are a number of firms like firm A spread across industries where the value for α varies across firms but is the same (or close to the same) for firms in the same industry. For those industries where α is high there will be faster innovation and more vertical integration than for those industries where α is low. In other words, in a cross-sectional analysis there will also be a positive correlation between innovation investments and the degree of vertical integration.

A number of empirical papers find results consistent with our predictions that within an industry the likelihood of vertical integration should be positively related to the magnitude of innovation investments, and that this relationship should also hold across industries. Monteverde and Teece (1982), for example, is a single industry study that finds results consistent with the first of these predictions. They study the vertical integration decision in the automobile parts industry and find that vertical integration is more likely when engineering design efforts are higher. More recently, Acemoglu et al. (2010) study the vertical integration decision across industries focusing on how the extent of vertical integration varies with the magnitude of innovation investments. And one of their main findings is consistent with our second prediction, i.e., across industries vertical integration is more likely when the output industry has higher investments in innovation.

It is interesting to note that Acemoglu et al. (2010) also find a second result concerning the importance of innovation investments for the vertical integration decision. In particular, although the magnitude of innovation investments in the output industry is positively related to the extent of vertical integration in their dataset, they also find that the magnitude of innovation investments in the input industry is negatively related to the extent of vertical integration. They argue that both findings are consistent with predictions they develop using a framework consistent with the property rights theory of the firm. And this second finding is not predicted by the model considered earlier in this section which predicts a positive effect on vertical integration for innovation investments in the output industry, but says nothing about innovation investments in the input industry. However, a further extension would capture this result.

In the basic model and extensions we consider in this paper the cost disadvantage that the output firm, i.e., firm A, has in producing inputs in-house is stochastic, but the distribution itself is fixed. But consider two similar output firms both facing the type of environment considered in our formal model in Section IV except that in one case producing inputs requires higher investments in R&D than in the other. It would not be surprising if the output producer's cost disadvantage in producing inputs in-house was larger in the case where investments in R&D in the input industry were higher. In other words, not being at the knowledge frontier is probably more important for the production of goods where innovation investments are higher. If we were to incorporate this idea into the model by having the distribution function for Δ depend on the level of innovation investments in the input industry, then the model would yield a prediction consistent with the second finding in the Acemoglu et al. (2010) paper. That is, in settings characterized by higher innovation investments in the input industry the extent of vertical integration should be less.

V. EXTENSION 2: MULTIPLE CUSTOMIZED INPUTS

In this section we extend the basic model of Section III by having two customized inputs in the production process. The main point of this analysis is to show that with multiple customized inputs the decision concerning whether or not to produce one customized input in-house is affected by the decision concerning the other customized input. In particular, we find that there is a type of complementarity concerning vertical integration decisions when there are multiple customized inputs which is consistent with the empirical findings in Novak and Stern (2009). Note that it would be easy to extend the analysis to more than two customized inputs, and show that the same type of complementarity we find for two customized inputs holds when there are more than two. We focus on the two customized input case because that makes the basic logic of the analysis easier to follow.

We make the following changes to Section III's model. The main change is that producing a unit of output now requires one unit of each of two distinct customized inputs, where we refer to these two distinct inputs as inputs 1 and 2. The specification for costs of production for each customized input is the same as in Section III. That is, for each customized input there is a competitive industry of input suppliers (a different industry for each customized input). An input supplier for input j, j=1,2, can produce a unit of the input at constant marginal cost c and no fixed cost, while firm B can also produce a unit of input j at constant marginal cost c and no fixed cost. Firm A, however, has constant marginal cost c and fixed cost Δ_j for producing a unit of input j, where Δ_j is a random draw from a probability density function, $h(\Delta)$, which is strictly positive for all $0<\Delta<\infty$. We also assume that the realizations for Δ_1 and Δ_2 are independent draws from $h(\Delta)$. Note that assuming that Δ_1 and Δ_2 are drawn from the same distribution is not at all crucial for the results but rather serves to simplify the notation.[15]

There are again probabilities z_A and z_B that firms A and B directly gain access to the superior technology. Suppose firm A does directly gain access to the superior technology and has chosen to purchase one or both customized inputs from input suppliers. If it has chosen to purchase only one customized input, then the model works the same as before. There will be an incentive for the input supplier to sell information about the superior technology to firm B and firm A will have an incentive to stop this from occurring through a contractual penalty. Suppose instead that firm A chooses to purchase both customized inputs. Then each input supplier will have an incentive to sell information about the superior technology to firm B and, if the state of the world is such that firm B did not directly gain access to the superior technology, firm B will be able to sell high quality output if just one of the input suppliers sells the information. In other

[15] We assume that firm A can produce units of the standardized input at constant marginal cost c and fixed cost Δ_1, although results would be the same if we instead assumed that firm A's fixed cost for producing the standardized input was Δ_2 or some convex combination of Δ_1 and Δ_2.

words, in terms of selling the information about the superior technology, the two input suppliers are rivals selling perfect substitutes because firm B only needs information from one of the two sources to produce the high quality output. We also assume that in the case $r>0$ and firm A purchases both customized inputs from inputs suppliers, the realization for d is the same for the two input suppliers.

In terms of the timing of the game, the only new assumption concerns the stage in which an input supplier offers to sell information concerning the superior technology to firm B. The change is that, if firm A gains access to the superior technology and firm A purchases both customized inputs from input suppliers, then the two input suppliers simultaneously make take-it or leave-it offers to firm B concerning selling the information.

We now proceed to the analysis. We start with a preliminary result similar to the one found in Lemma 1.

Lemma 3: Holding all other parameters fixed, there exists a lowest value, denoted M^*, such that the following is satisfied. If $r=0$ and M^+ is sufficiently large, i.e., $M^+ \geq M^*$, then firm A purchases all three inputs from input suppliers with probability one.

Similar to the basic model in Section III, if there is always a positive probability that an input supplier that sells information to firm B will be penalized and the government will enforce large penalties, then firm A purchases both customized inputs. The reason is that firm A can stop input suppliers from selling information to firm B using a contractual penalty, so there is no benefit in terms of keeping information secret by choosing to vertically integrate.

We now present a result similar to the one found in Lemma 2 of the basic model.

Lemma 4: Holding all other parameters fixed and also holding fixed firm A's decision concerning whether or not to produce or purchase input k, if $r>0$ and/or M^+ is sufficiently small, i.e., $M^+<M^*$, then there exists a value Δ_j^*, $0 \leq \Delta_j^* < \infty$, such that firm A produces input j, j=1,2 and

$j \neq k$, when $\Delta_j < \Delta_j^*$ and purchases the input from an input supplier when $\Delta_j \geq \Delta_j^*$. In contrast, firm A purchases the standardized input from an input supplier for all realizations of Δ.

The results captured in Lemma 4 are also a generalization of what happens in the basic model. Specifically, if the parameterization is such that firm A cannot completely stop an input supplier from selling information to firm B through a contractual penalty, then there is a return to vertical integration for the customized input, and the firm chooses to produce a customized input in-house if its cost disadvantage in producing the input is sufficiently small. The main difference between Lemmas 2 and 4 is that in Lemma 4 this basic logic applies to two inputs rather than one.

We now generalize Proposition 1 to the case with two customized inputs.

Proposition 4: There exist values Δ^*, Δ^{**}, Δ^{***}, $0 \leq \Delta^* \leq \Delta^{**} \leq \Delta^{***}$, and M^*, such that equilibrium is described by i) through x). Further, $\Delta^* = \Delta^{**} = \Delta^{***} = 0$ if $r=0$ and $M^+ \geq M^*$, while $0 < \Delta^* \leq \Delta^{**} \leq \Delta^{***}$ (and $\Delta^* < \Delta^{***}$) if $r>0$ and/or $M^+ < M^*$.

i) Firm A purchases the standardized input from an input supplier for all values of Δ.

ii) If $\Delta_j < \Delta^*$ and $\Delta_k < \Delta^{***}$, $j \neq k$, then firm A produces both customized inputs in-house and each of firms A and B sells high (low) quality output if the firm directly gains (does not directly gain) access to the superior technology.

iii) If $\Delta_j \geq \Delta^*$ and $\Delta_k \geq \Delta^{***}$, $j \neq k$, then firm A purchases both customized inputs from input suppliers.

iv) If $\Delta_j < \Delta^*$ and $\Delta_k \geq \Delta^{***}$, $j \neq k$, then firm A produces input j in-house and purchases input k from an input supplier.

v) If $\Delta^* \leq \Delta_j < \Delta^{***}$ and $\Delta^* \leq \Delta_k < \Delta^{***}$, then firm A produces both customized inputs in-house if $(\Delta_j + \Delta_k)/2 < \Delta^{**}$ and purchases both customized inputs from input suppliers if $(\Delta_j + \Delta_k)/2 \geq \Delta^{**}$.

vi) If firm A purchases one or both customized inputs but does not directly gain access to the superior technology, then firm A sells low quality output and firm B sells high (low) quality if the firm directly gains (does not directly gain) access to the superior technology.

vii) If firm A purchases only one customized input from an input supplier, directly gains access to the superior technology, d=D, and $M^+ \geq M^*$, then firm A sells high quality output and firm B sells high (low) quality if firm B directly gains (does not directly gain) access to the superior technology.

viii) If firm A purchases only one customized input from an input supplier, directly gains access to the superior technology, d=0 and/or $M^+ < M^*$, then the input supplier sells information about the superior technology to firm B when firm B does not directly gain access and both firms A and B sell high quality output.

ix) If firm A purchases both customized inputs from input suppliers, directly gains access to the superior technology, d=D, and $M^+ \geq M^*$, then firm A sells high quality output and firm B sells high (low) quality if firm B directly gains (does not directly gain) access to the superior technology.

x) If firm A purchases both customized inputs from input suppliers, directly gains access to the superior technology, d=0 and/or $M^+ < M^*$, then one of the input suppliers sells information about the superior technology to firm B when firm B does not directly gain access and both firms A and B sell high quality output.

Proposition 4 tells us that in a number of ways the nature of equilibrium when there are two customized inputs is quite similar to the nature of equilibrium given a single customized input. In each case firm A chooses to produce a customized input in-house when a contractual penalty cannot fully stop an input supplier from selling information about the superior technology and firm A's cost disadvantage is sufficiently small. Further, the reason it chooses in-house production is that this reduces the probability that firm B learns information about the superior technology from an input supplier.

The result that is of particular interest is $\Delta^* < \Delta^{***}$ given $r>0$ and/or $M^+ < M^*$. Consider firm A's decision concerning whether or not to produce input j in-house in this case. If the firm chooses to produce input k in house, $k \neq j$, then the proposition tells us that it chooses to produce input j in-house if and only if $\Delta_j < \Delta^{***}$. But if the firm chooses to purchase input k from an input supplier, then the firm produces input j in-house if and only if $\Delta_j < \Delta^*$. In other words, producing one input in-house increases the probability the firm produces the other input in-house, i.e., there is a complementarity in the vertical integration decision concerning the two customized inputs.

The logic for this result can be understood by focusing on the expected benefit to vertical integration for a customized input in this model. As discussed, this expected benefit is that vertical integration eliminates the possibility that firm B acquires information about the superior technology from the input supplier and sells high quality output as a result. Note that this benefit only arises in states of the world in which firm B would produce low quality output if it did not acquire information about the superior technology from the input supplier.

Given this, consider firm A's decision concerning whether or not to choose vertical integration for input j. If input k is produced in-house, then the probability that B produces low quality in the absence of information about the superior technology from a supplier of input j is $(1-z_B)$. But if input k is purchased from an input supplier, then this probability can be lower than $(1-z_B)$ because of a positive probability firm B acquires the information from the supplier of input k. This means the benefit to firm A of eliminating the possibility that firm B acquires information about the superior technology from a supplier of input j can be smaller when firm A purchases input k. The result is that the value for Δ which makes firm A indifferent between producing a customized input in-house and purchasing it from an input supplier can be smaller when the other customized input is purchased.

Interestingly, Novak and Stern (2009) provide an empirical test of the main prediction of this extension. In particular, they consider vertical integration decisions in automobile product development and find that there is complementarity in the choice of vertical integration decisions. As our model predicts, a firm is more likely to produce one customized input in-house when a second customized input is produced in-house.[16]

VI. EXTENSION 3: LABOR TURNOVER OF HIGH-TECH WORKERS

In this section we extend Section III's model by introducing high-tech workers and allowing for labor turnover. The main point here is to show that labor turnover, i.e., turnover of high-tech workers, reduces the incentive for vertical integration. The basic idea is that, if proprietary information can be learned by rival producers through the turnover of high-tech workers, then the incentive for a firm to choose vertical integration to reduce the possibility of such learning is reduced. At the end of the section we discuss how these results are related to discussions in, for example, Saxenian (1994), Kenney (2000), and Lee et al. (2000) concerning lower levels of vertical integration in Silicon Valley relative to Route 128.

Note that the idea that high-tech labor mobility is a way that proprietary information can be learned by rival producers was first put forth by Arrow (1962). And later studies such as Almeida and Kogut (1999), Maliranta et al. (2009), and Singh and Agrawal (2011) provide empirical support for the idea. In this section we build on this research and argue that outsourcing and labor turnover are substitute avenues through which this type of information leakage can take place and, therefore, the incentive to vertically integrate in order to reduce the probability of such leakage is higher when the alternative avenue of high-tech worker turnover is not present.

In this section we introduce three related changes to Section III's model. First, we introduce high-tech workers who are important in the innovation process. In particular, we

[16] They further find that the effect is stronger for systems in the automobile that are "tightly coupled" which is consistent with our secrecy argument. The logic is that when the inputs are part of a system that is "tightly coupled" it is more likely that producing the various inputs requires knowledge of the same proprietary information that is valuable to the firm's rivals. Also, as mentioned in the Introduction, Novak and Stern (2009) do discuss keeping proprietary information secret as one possible explanation for their findings. They also discuss the possibility that their results can be explained by the need to coordinate designs across systems that are tightly coupled within an automobile. They do not provide tests that distinguish between these two distinct theoretical mechanisms for why vertical integration decisions may exhibit complementarity. We come back to a discussion of this issue in the Conclusion.

assume that in order to have probabilities z_A and z_B of directly gaining access to the superior technology, each of firms A and B must hire l_h high-tech workers at the beginning of the game from a competitive market for high-tech workers. We further assume that a high-tech worker can earn a wage w_h by working elsewhere in the economy, i.e., w_h is the reservation wage of a high-tech worker, and that Q^H is high enough that hiring high-tech workers at the beginning of the game is profitable for both firms.[17]

The second change is that, just after the firms choose the qualities to produce and these choices are publicly observed, each output supplier has the option of poaching the high-tech workers of the rival output producer. This poaching stage works as follows. Each output producer has the option of making a wage offer to the rival's high-tech workers. The rival observes the offer and makes a counter-offer. Each worker then decides whether the worker is willing to leave and, if one or more workers offers to leave, the rival decides which workers to hire. Note that, if a high-tech worker stays after receiving a wage offer from the rival, the worker's compensation is the wage counter-offer. And if the worker leaves, then the worker receives nothing from the initial employer and instead receives the wage offered by the firm she moves to. Also, if, for example, firm A poaches one of firm B's high-tech workers after firm B announced it would produce high quality output, then A can switch to high quality production even if it had previously announced that it would produce low quality output.[18]

The third change is that we consider the model under two distinct assumptions concerning the regulatory environment. One setting we consider is that employee non-compete agreements are not enforceable which is the case in California. Under this assumption, the model works exactly as described above. The other setting is that employee non-compete agreements are enforceable which is the case in Massachusetts. In this case, an output firm can

[17] We also assume that Q^H is high enough that poaching is profitable when it allows a firm to produce high rather than low quality output. See the proof of Proposition 5 in the Appendix for details.
[18] We further assume that a firm that employs l_h high-tech workers at the beginning of the game and loses a worker to poaching must replace the worker with a high-tech worker employed elsewhere in the economy.

stipulate that a high-tech worker who agrees to work at the firm is not able to accept a wage offer made by the rival at the poaching stage. In other words, if all the high-tech workers of firm A are subject to employee non-compete agreements, then firm B cannot gain access to the superior technology by hiring one of the firm's high-tech workers.

We begin by considering how the model works when employee non-compete agreements are enforceable.

Proposition 5: Suppose employee non-compete agreements are enforceable. Holding all other parameters fixed, if l_h is sufficiently large, then every high-tech worker hired by each of firms A and B at the beginning of the game agrees to an employee non-compete agreement. The result is that there is no high-tech worker turnover at the poaching stage and all the findings in Lemma 1, Lemma 2, Proposition 1, and Corollary 1 to Proposition 1 hold.

When enforceable, there is no cost to an output producer to include employee non-compete agreements in its hiring offers to high-tech workers at the beginning of the game. But there is a return since a worker subject to such an agreement cannot leave, and this eliminates the possibility that, for example, firm B will gain access to the superior technology by poaching one of firm A's high-tech workers. So when they are enforceable, both firm A and firm B include employee non-compete agreements in their hiring offers to high-tech workers, and then the model works basically the same way as in Section III's analysis. Note that the role of l_h being sufficiently large in the statement of the proposition is discussed in footnote 19.

We now consider how the model works when employee non-compete agreements are not enforceable. The difference is that, if they are not enforceable, then when an output producer directly gains access to the superior technology the rival can learn about the superior technology by poaching one of the initial firm's high-tech workers. As shown below, this can result in a significantly reduced incentive for firm A to choose vertical integration. Note, below our focus is parameterizations where the number of high-tech workers per firm is large which results in poaching being an important aspect of equilibrium behavior.

Proposition 6: Suppose employee non-compete agreements are not enforceable. Holding all other parameters fixed, if l_h is sufficiently large, then firm A purchases both inputs from input suppliers. Also, i) through iv) characterize equilibrium behavior.

i) If firm A directly gains access to the superior technology and firm B does not, then firm B acquires information concerning the superior technology either by poaching one of firm A's high-tech workers or by purchasing the information from firm A's input supplier for the customized input.

ii) If firm B directly gains access to the superior technology and firm A does not, then firm A poaches one of firm B's high-tech workers.

iii) If firm A and/or firm B directly gains access to the superior technology, then both firms sell high quality output.

iv) If neither firm A nor firm B directly gains access to the superior technology, then both firms sell low quality output.

To understand Proposition 6 it is best to start with what happens when firm B directly gains access to the superior technology and firm A does not. In that case, firm A has an incentive to poach one of firm B's high-tech workers, but firm B has an incentive to make counter-offers to stop any high-tech workers from leaving. Basically, what happens is that as the number of high-tech workers gets large, the cost to firm B of stopping every one of its high-tech workers from leaving by making a high counteroffer becomes prohibitively expensive. The result is that firm A poaches one of firm B's high-tech workers and then both firms sell high quality output.[19]

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[19] The reason that the results in Proposition 5 only hold when l_h is sufficiently large is related to this discussion. If l_h is sufficiently small (note that such a range for l_h is not guaranteed to exist), then each output producer can stop

Now consider what happens when firm A directly gains access to the superior technology and firm B does not. Whether firm A produces or purchases the customized input, the poaching argument above tells us that firm B will gain access to the superior technology. In turn, since B gains access to the superior technology whether or not A produces the customized input and since A has a cost disadvantage in producing the input, A chooses to purchase the customized input from an input supplier.

In other words, in this model acquiring information about the superior technology by purchasing it from an input supplier and acquiring it by poaching a rival's high-tech worker are substitute ways of acquiring the information. When employee non-compete agreements are enforceable, firm A can stop information acquisition via poaching by employing these agreements. The result is that, in that case, there is a return to producing the customized input in-house because choosing vertical integration means that firm B cannot acquire the information through either avenue. But stopping one way that firm B can acquire the information without stopping the other is of no value to firm A. So when employee non-compete agreements are not enforceable and counter-offers also do not stop poaching, then firm B can acquire the information through poaching and producing the customized input in-house to stop firm B from acquiring the information by purchasing it from an input supplier is of no value to firm A.

One of the interesting aspects of the results captured in Propositions 5 and 6 is how well those propositions capture differences between Silicon Valley and Route 128. Discussions such as found in Saxenian (1994), Kenney (2000), and Lee et al. (2000) describe these two sets of industrial clusters as being quite different. Silicon Valley, relative to Route 128, has more employee turnover, less vertical integration, less secrecy concerning innovative ideas, and higher rates of innovation.[20] Our model suggests that the underlying cause of these differences is the

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poaching by making a high counteroffer. Since an output producer will not receive a benefit from attempting to poach a rival's high-tech worker when the poaching offer is guaranteed to be unsuccessful, when l_h is in this range there will be equilibria in which output producers employ non-compete agreements in hiring high-tech workers, but there will also be equilibria in which they do not.

[20] Fallick, Fleischman, and Rebitzer (2006) use data from the Current Population Survey to show that high-tech industrial clusters in California, including Silicon Valley, do indeed have higher turnover rates of high-skilled workers than do high-tech industrial clusters located outside of California.

different legal environments in California and Massachusetts. In Massachusetts employee non-compete agreements are enforceable. This is the case analyzed in Proposition 5. Consistent with descriptions of Route 128, that case is characterized by no turnover of high-tech workers, substantial vertical integration even though vertical integration drives up production costs, and high levels of secrecy concerning innovative ideas. In contrast, Proposition 6 considers what happens when employee non-compete agreements are not enforceable as is the case in California. Consistent with descriptions of Silicon Valley, that proposition is characterized by substantial turnover of high-tech workers, less vertical integration, and little secrecy concerning innovative ideas.[21]

A number of previous authors have argued that differences between Silicon Valley and Route 128 stem from the different legal environments in California and Massachusetts concerning the enforceability of employee non-compete agreements (see, for example, Gilson (1999) and Hyde (2003)). We both extend the argument to differences between the two high-tech clusters concerning the frequency of vertical integration, and also provide a theoretical framework which allows for a clearer understanding of how the various differences are related.[22]

VII. DISCUSSION

As discussed in Section II, there are a number of real world examples that suggest that keeping proprietary information secret is sometimes an important motivation behind why firms choose to vertically integrate. But in the prior economics literature concerning vertical integration this motivation has received little attention and, in particular, there has been almost no formal theoretical analyses of the issue. In this paper, we explore this idea using a formal

[21] The current model captures differences in speed of innovation between Silicon Valley and Route 128 in a limited way. That is, when non-compete agreements are not enforceable, a larger proportion of the output sold is high quality when only one of the output producers gains direct access to the superior technology. But there is no difference between the two regimes concerning the probability that some high quality units are sold. We conjecture, however, that extending the framework to more periods would allow us to also capture a richer difference between these regimes concerning speed of innovation.

[22] Ghosh and Shankar (2017) also present a formal theoretical framework concerning how the different legal rules in the two states can lead to observed differences between Silicon Valley and route 128, but they do not consider the vertical integration decision.

game theoretic approach, where our main focus has been on whether testable predictions from this perspective on the vertical integration decision are consistent with findings in the vast empirical literature on the subject. And the clear answer that comes out of our analysis is yes!

In our theoretical analysis, we started by constructing a duopoly model in which the two firms are located at opposite ends of a Hotelling line. Further, one of the firms chooses whether to produce a customized input in-house which keeps proprietary information secret, or purchase the input from an input supplier in which case the information may be learned by the rival output producer. We also consider extensions concerning innovation, multiple customized inputs, and labor turnover. These analyses yield four distinct testable predictions: i) vertical integration should be more common with customized rather than standardized inputs; ii) vertical integration should be more frequent in settings in which investments in innovation are high; iii) there should be complementarity in vertical integration decisions for inputs that are closely related in the design of the product; and iv) vertical integration should be less common in settings with high labor turnover of high-tech workers.

What is particularly interesting about these four predictions is that all four are consistent with empirical evidence already in the literature. On the other hand, in all but one of the cases there are plausible alternative explanations. For example, there is substantial evidence that vertical integration is indeed more likely for customized rather than standardized inputs. But, as is well known, the prediction that customized inputs are more likely to be produced in-house is one of the main predictions of the transactions cost theory of the firm. Similarly, Acemoglu et al. (2010) find that vertical integration is more common when investments in innovation in the output industry are high. But they also show theoretically that this finding is consistent with the property rights theory of the firm.

The one prediction that is distinctive is the main prediction of the last extension which is that vertical integration should be less common in settings where there is high labor turnover of high-tech workers. The logic of the prediction is that, if proprietary information is already being learned by rivals through the turnover of high-tech workers, a firm will have a reduced incentive to vertically integrate to stop a rival from acquiring the information from an input supplier. As discussed in Section VI, this prediction is consistent with descriptions concerning differences between the high-tech industrial clusters in Silicon Valley and Route 128. And, at least in terms of existing statements of the main alternative theories of vertical integration, this prediction is not made by any of the main alternative theories such as the property rights and transaction cost theories of the firm.

Overall, the fact that the testable predictions that come out of our theoretical analysis match existing empirical evidence so well is clearly suggestive of the idea that the secrecy perspective is important in real world vertical integration decisions. But this is also tempered by the fact that most of the predictions we focus on are also consistent with one or more well known alternative theories such as the transactions cost theory of the firm and the property rights theory of the firm. We feel, therefore, that before concluding that this perspective is indeed important in real world vertical integration decisions, it is essential to explore further the extent to which the evidence is consistent with predictions from this perspective, such as the prediction concerning high-tech labor turnover, which are not also predictions associated with alternative theories.

VIII. CONCLUSION

Why do firms produce some inputs in-house while other inputs are purchased on the market? This is a classic question in economics which goes back to the seminal paper of Coase (1937), and which has been the focus of theorizing by a number of leading scholars in the modern theory of industrial organization such as Oliver Williamson, Oliver Hart, and Sanford Grossman. Despite the more than substantial attention to theoretical perspectives on this decision, there is one quite plausible perspective for why a firm might choose to produce an input in-house which has received very little attention in the mainstream economics literature on the topic. This is the idea that by producing an input in-house a firm avoids sharing proprietary information concerning the design of its product with input suppliers, and thus reduces the likelihood that important design elements are learned by rival output producers.

Our paper is focused on exploring this idea from a theoretical perspective and then investigating whether the testable implications that come out of our theoretical analysis are consistent with existing empirical evidence. We start by constructing a one-period duopoly model in which there are two output producers located at opposite ends of a Hotelling line. One of the firms must decide whether to produce inputs in-house or purchase them from input suppliers, where one of the inputs is a standardized input and the other is a customized input. There is also a probability that this firm directly gains access to a superior technology which allows the firm to produce higher quality output. If the firm chooses to produce the customized input in-house, the rival output producer only gains access to the superior technology if it discovers the technology independently. But if the firm purchases the customized input from an input supplier, then there is the possibility that the input supplier will sell the information to the rival output producer.

Our analysis of this model yields that the incentive to keep proprietary information secret results in the firm sometimes choosing to produce the customized input in-house even though production costs would be lower if the input was purchased from an input supplier. The reason for this result is the expected increase in market power due to the increase in the probability that the rival producer does not gain access to the superior technology. We then extend the model in three ways. First, we introduce an R&D stage at the beginning of the game and show that this perspective on the vertical integration decision predicts a positive correlation between investments in innovation and frequency that a firm chooses to vertically integrate. Second, we extend the model to allow for two customized inputs in the production process and show that this yields complementarity in the vertical integration decision, i.e., the decision to produce one customized input in-house increases the probability the other customized input will also be produced in-house. Third, we extend the model by incorporating the possibility of high-tech worker turnover. In this extension, we show that vertical integration is more likely in settings in which worker non-compete clauses are allowed.

Our analysis yields a large number of testable implications. For example, our main analysis predicts that vertical integration should be more common for customized rather than standardized inputs as has been found in various studies such as Monteverde and Teece (1982), Masten (1984), and Lieberman (1991). Further, the extensions, as just indicated, yield additional predictions including: i) investments in innovation should be positively related to the frequency of vertical integration as found in Monteverde and Teece (1982) and Acemoglu et al. (2010); ii) vertical integration decisions when there are multiple customized inputs should be complementary as found in Novak and Stern (2009); and iii) vertical integration should be more common in high-tech labor markets when employee non-compete clauses are allowed which is consistent with discussions in Saxenian (1994) and others concerning differences between Silicon Valley and Route 128.

As discussed in Section VII, although the predictions of the model and extensions match existing empirical evidence quite well, it is also the case that most of the predictions have alternative explanations. With this in mind, we believe there are two related directions worth pursuing. First, we think it would be interesting to develop more testable predictions that are distinctive, i.e., develop predictions that are consistent with our secrecy perspective concerning the vertical integration decision, but that are not easily explained by the main alternative theories. Second, we think it would be useful to conduct empirical tests of these types of more distinctive tests, and also conduct further tests of the predictions in the current paper for which existing empirical testing is limited, such as the prediction concerning complementarity of vertical integration decisions.

APPENDIX

We start with proofs of the preliminary results found in Subsection III.B and then provide proofs of the lemmas, propositions, and corollaries.

Proof of the Preliminary Results: When a consumer located at x buys a unit from A her utility is given by Q_A-γx-P_A, while her utility when she buys a unit from B is Q_B-γ(1-x)-P_B. Let $x^*(Q_A,Q_B,P_A,P_B)$ denote the indifferent consumer as a function of qualities and prices. We immediately have (A1) (remember that we restrict the analysis to parameterizations such that the market is covered).

(A1) $$x^*(Q_A,Q_B,P_A,P_B) = 1/2 + [Q_A-Q_B-(P_A-P_B)]/2\gamma$$

We now consider the pricing game as a function of qualities and firm A's vertical integration decisions. We start with cases in which firm A chooses to produce both inputs in-house, i.e., $v_S=v_C=1$. Let $\pi_A(Q_A,Q_B,P_A,P_B,v_S,v_C,R_1)$ denote firm A's profit as a function of qualities, prices, the vertical integration decisions, and any change in cost, denoted R_1, associated with purchasing one or both input from input suppliers when the firm does not choose vertical integration for both inputs (note that R_1=0 if the firm chooses vertical integration for both inputs). Given (A1), we have (A2).

(A2) $$\pi_A(Q_A,Q_B,P_A,P_B,1,1,0) = (P_A-2c-l_lw_l)[1/2+[(Q_A-Q_B-(P_A-P_B))/2\gamma] - 2\Delta$$

Firm B's profit as a function of qualities, prices, and any payment for information, denoted R_2, that B makes to an input supplier, denoted $\pi_B(Q_A,Q_B,P_A,P_B,R_2)$, is given by (A3).

(A3) $$\pi_B(Q_A,Q_B,P_A,P_B,,R_2) = (P_B-2c-l_lw_l)[1/2+[(Q_B-Q_A-(P_B-P_A))/2\gamma] - R_2$$

In a Nash equilibrium in this game each firm will choose a price taking qualities and the price of the other firm as given. Let $P_A(Q_A,Q_B,P_B,v_S,v_C,R_1)$ be firm A's price as a function of Q_A, Q_B, P_B, the vertical integration decisions, and the value for R_1. Taking the first order condition for P_A with respect to the expression in (A2) yields (A4).

(A4) $$P_A(Q_A,Q_B,P_B,1,1,0) = [Q_A-Q_B+P_B+\gamma+2c+l_lw_l]/2$$

Let $P_B(Q_A,Q_B,P_A,R_2)$ be firm B's price as a function of Q_A, Q_B, P_A, and R_2. Taking the first order condition for P_B with respect to the expression in (A3) yields (A5).

(A5) $$P_B(Q_A,Q_B,P_A,0) = [Q_B-Q_A+P_A+\gamma+2c+l_lw_l]/2$$

We can combine (A4) and (A5) to find an expression for the price of each firm that does not depend directly on the price of the other firm. Let $P_A(Q_A,Q_B)$ be firm A's price as a function of Q_A and Q_B in the case of in-house production of both inputs. Combining (A4) and (A5) yields (A6).

(A6) $$P_A(Q_A,Q_B) = [Q_A-Q_B+3(\gamma+2c+l_lw_l)]/3$$

Let $P_B(Q_A,Q_B)$ be firm B's price as a function of Q_A and Q_B when firm A produces both inputs in-house. Combining (A4) and (A5) yields (A7).

(A7) $$P_B(Q_A,Q_B) = [Q_B-Q_A+3(\gamma+2c+l_lw_l)]/3$$

Now consider cases in which firm A chooses to purchase one or both inputs from input suppliers, i.e., $v_S=0$ and/or $v_C=0$. Given contract terms and any payment from B to an input supplier for information are not publicly observed, standard arguments yield that an equilibrium contract between firm A and the input supplier will have a per unit payment equal to c and any payment from B to an input supplier will be a lump sum amount. So arguments like those above yield that (A6) also describes firm A's price in cases in which A purchases one or both inputs, while (A7) describes firm B's price in such cases.

It is useful for later proofs to have profit expressions in which profits are solely functions of qualities, the vertical integration decisions, R_1, and R_2. Let $\pi_A(Q_A,Q_B,v_S,v_C,R_1)$ be firm A's profit as a function of qualities, the vertical integration decisions, and R_1. From above we have (A8).

(A8) $$\pi_A(Q_A,Q_B,v_S,v_C,R_1) = [(Q_A-Q_B+3\gamma)^2/18\gamma] - (v_S+v_C)\Delta - R_1$$

Similarly, firm B's profit as a function of qualities and R_2, denoted $\pi_B(Q_A,Q_B,R_2)$, is given by (A9).

(A9) $$\pi_B(Q_A,Q_B,R_2) = [(Q_B-Q_A+3\gamma)^2/18\gamma] - R_2$$

We now consider the claims made in Subsection III.B. The first claim is that $P_j(Q_j,Q_k,1,1)=P_j(Q_j,Q_k,1.0)=P_j(Q_j,Q_k,0,1)=P_j(Q_j,Q_k,0.0)$ for all Q_j, Q_k, and j triplets. This has already been shown. The second claim is that $x^*(Q_A,Q_B,1)=x^*(Q_A,Q_B,0)$ for all Q_A, Q_B pairs. This follows given (A1) and the result above that, given qualities, prices are independent of the vertical integration decisions. The third claim is that $P_A(Q^L,Q^L)=P_B(Q^L,Q^L)$. This follows from (A6) and (A7). The fifth claim is $x^*(Q^H,Q^H)=1/2$. This follows from (A1) in combination with (A6) and (A7). The sixth claim is $x^*(Q^L,Q^L)=1/2$. This also follows from (A1) in combination with (A6) and (A7). The seventh claim is $P_A(Q^H,Q^H)=P_A(Q^L,Q^L)$. This follows from (A6). The eighth claim is $P_A(Q^H,Q^L) > P_B(Q^L,Q^H)$. This follows from (A6) and (A7). The ninth claim is $x^*(Q^H,Q^L)>1/2$. This follows from (A1) in combination with (A6) and (A7). The tenth claim is $P_B(Q^H,Q^L)=P_A(Q^H,Q^L)$. This follows from (A6) and (A7). The eleventh claim is $P_A(Q^L,Q^H)=P_B(Q^L,Q^H)$. This also follows from (A6) and (A7). The twelfth claim is $x^*(Q^L,Q^H)=1-x^*(Q^H,Q^L)$. This follows from (A1) in combination with (A6) and (A7).

It is also useful for later proofs to provide expressions for firm A's and firm B's expected profit as a function of the vertical integration decisions. Before taking this step, the first point to note is that (A8) and (A9) tell us that, if A chooses vertical integration for the customized input, then each of firms A and B produce the highest quality product it has the ability to produce independent of firm A's vertical integration decision for the standardized input. This is also the case, given (A9), for firm B even when A chooses to purchase the customized input. Suppose A chooses to purchase the customized input and directly gains access to the superior technology. (A8) tells us that firm A will choose to produce high quality output. So, in all cases, each of firms A and B produce the highest quality product it has the ability to produce.

We now consider expected profit for each of firms A and B at the beginning of the game as a function of firm A's vertical integration decision concerning the customized input. Let π_A^{VI} be firm A's expected profit if it chooses vertical integration for the customized input but not the standardized input, and π_B^{VI} be firm B's expected profit given A chooses vertical integration for the customized input but not the standardized input. From above we know each firm produces the highest quality product it has the ability to produce. We also know, given the zero expected profit constraint due to competition among input suppliers, that the equilibrium per unit price for the standardized input is c and the fixed fee is zero. This means π_A^{VI} is given by (A10) and π_B^{VI} is given by (A11).

(A10) $$\pi_A^{VI} = z_A z_B(\gamma/2) + (1-z_A)(1-z_B)(\gamma/2) + [z_A(1-z_B)(Q^H-Q^L+3\gamma)^2/18\gamma] + [(1-z_A)z_B(Q^L-Q^H+3\gamma)^2/18\gamma] - \Delta$$

(A11) $$\pi_B^{VI} = \pi_A^{VI} + \Delta$$

Now suppose firm A does not produce either input in-house. There are two subcases. The first is that the parameterization is such that firm B never purchases information concerning the superior technology from an input supplier. Call firm A's expected profit in this case π_A^{NVI1} and firm B's expected profit in this case $\pi_B^{NVI1.}$ Because competition means that input suppliers earn zero expected profits, we have $\pi_A^{NVI1}=\pi_A^{VI}+\Delta$. Also, in this case firm A's vertical integration decision concerning the customized input does not affect firm B's profit in any state of the world so $\pi_B^{NVI1}=\pi_B^{VI}$.

The second subcase is that firm B has a positive probability of purchasing information concerning the superior technology when A directly acquires that information and B does not. Call firm A's expected profit in this case π_A^{NVI2} and firm B's expected profit in this case π_B^{NVI2}. Because the input supplier makes a take-it or leave-it offer to B when the input supplier has information concerning the superior technology, none of the surplus from the sale of this information goes to B. This means $\pi_B^{NVI2}=\pi_B^{VI}$. Further, because firm A makes a take-it or leave-it offer to the input supplier, the expected surplus from the sale of information to B is in fact captured by firm A. But from (A8) and (A9) we know that joint profits are higher when one firm has access to the superior technology in contrast to the value for joint profits when both firms have access to the superior technology. Thus, it must be the case that $\pi_A^{NVI2}<\pi_A^{NVI1}$. Let $\lambda=\pi_A^{NVI1}-\pi_A^{NVI2}$.

Proof of Lemma 1: We know that input suppliers can produce the standardized input at lower cost, there is competition among input suppliers, and firm A does not need to share information about its technology when it purchases the standardized input. Together, these three aspects of the model tell us that firm A purchases the standardized input. Also, given the zero expected profit constraint associated with competition, the per unit price equals c and the fixed fee equals zero.

If firm A chooses to produce the customized input in-house its expected profit is π_A^{VI}. So the firm will choose to purchase the customized input if the best contract it can offer an input supplier results in expected profits greater than or equal to π_A^{VI}, and will choose to produce the customized input in-house if the best contract results in expected profits less than π_A^{VI} (see footnote 11).

Suppose firm A directly gains access to the superior technology, firm B does not, and r=0. (A9) tells us that, absent any payment to an input supplier for information concerning the superior technology, firm B's profit will be higher if it acquires that information and produces high rather than low quality. Let φ be firm B's increase in profit in this case absent any payment for information. This is firm B's maximum willingness to pay for information concerning the superior technology. (A9) tells us that φ is given by (A12).

(A12) $$\varphi = (\gamma/2) - [(Q^L - Q^H + 3\gamma)^2/18\gamma]$$

For the rest of the proof we assume r=0 as in the lemma. Let $M^* = \varphi/D$. Suppose $M^+ \geq M^*$. If firm A chooses to purchase the customized input and the contract specifies a value for $M \geq M^*$, then from above we know the input supplier will not sell information to firm B and from the proof of the preliminary results we have that firm A's expected profit is $\pi_A^{VI} + \Delta$. Thus, the best contract results in expected profit greater than π_A^{VI} which means firm A purchases the customized input from an input supplier with probability one.

Suppose $M^+ < M^*$ and firm A chooses to purchase the customized input. By definition the value for M specified in the contract must satisfy $M < M^*$ which from above means the input supplier will sell information concerning the superior technology to firm B when A directly acquires that information and B does not. From the proof of the preliminary results we now have that expected profit for A in this case equals $\pi_A^{NVI2} < \pi_A^{NVI1}$. Given (A10), this means expected profit is less than π_A^{VI} for Δ sufficiently small. In turn, this means firm A will choose to purchase the customized input from an input supplier with probability less than one. So M^* is the lowest value such that firm A purchases the input with probability one whenever $M^+ \geq M^*$.

<u>Proof of Lemma 2</u>: The same argument as in the proof of Lemma 1 yields that firm A purchases the standardized input from an input supplier, where the per unit price equals c and the fixed fee equals zero.

If firm A chooses to produce the customized input in-house, its expected profit is π_A^{VI}. Consider first the case r=0 and $M^+ < M^*$. As argued in the proof of Lemma 1, expected profit for A in this case equals $\pi_A^{NVI2} = \pi_A^{NVI1} - \lambda$. Let $\Delta^* = \lambda$. We now have that firm A produces the customized input in-house when $\Delta < \Delta^*$ and purchases the customized input from an input supplier when $\Delta \geq \Delta^*$ (see footnote 11).

The next case we consider is r>0 and $M^+ < M^*$. In this case, if firm A chooses to purchase the customized input from an input supplier, then when A directly gains access to the superior technology and B does not there are two subcases. With probability r there is a zero probability of the input supplier being detected if it sells information to B and a probability (1-r) that the probability is D. Using arguments like in the proof of Lemma 1 yields that the input supplier will sell information to firm B when A has direct access to the information, B does not, and d=D. This is also clearly the case when d=0. From the proof of the preliminary results we now have that A's expected profit is again $\pi_A^{NVI2}=\pi_A^{NVI1}-\lambda$. Again, let $\Delta^*=\lambda$. We now have that firm A produces the customized input in-house when $\Delta<\Delta^*$ and purchases the customized input from an input supplier when $\Delta\geq\Delta^*$ (see footnote 11).

The last case is r>0 and $M^+\geq M^*$. In this case, if firm A chooses to purchase the customized input from an input supplier, then when A directly gains access to the superior technology and B does not there are again two subcases. With probability r there is a zero probability of the input supplier being detected if it sells information to B and a probability (1-r) that the probability is D. Clearly, the input supplier will sell information to B when d=0. Using arguments like in the proof of Lemma 1 yields that the input supplier will not sell information to B when d=D (see footnote 11). From the proof of the preliminary results we now have that A's expected profit is again $\pi_A^{NVI2}=\pi_A^{NVI1}-\lambda$. Again, let $\Delta^*=\lambda$. We now have that firm A produces the input in-house when $\Delta<\Delta^*$ and purchases the input from an input supplier when $\Delta\geq\Delta^*$ (see footnote 11).

<u>Proof of Proposition 1</u>: i) follows immediately from arguments in the proof of Lemma 1.

Lemma 1 tells us that $\Delta^*=0$ for parameterizations characterized by r=0 and $M^+\geq M^*$. Given this, ii) does not apply to these parameterizations. Suppose r>0 and/or $M^+<M^*$. Then Lemma 2 tells us that firm A produces the customized input in-house when $\Delta<\Delta^*$. Further, the proof of the preliminary results showed that a firm always produces the highest quality product it has the ability to produce. In combination these results prove ii).

Lemma 1 tells us that, if r=0 and $M^+\geq M^*$, then firm A purchases the input from an input supplier when $\Delta\geq\Delta^*$. Lemma 2 tells us that, if r>0 and/or $M^+<M^*$, then firm A purchases the customized input from an input supplier when $\Delta\geq\Delta^*$. In combination these results prove iii).

Suppose $\Delta\geq\Delta^*$ and firm A does not directly gain access to the superior technology. Then an input supplier cannot sell information concerning the superior technology to firm B. Thus, firm B has the ability to produce high quality output only if the firm directly gains access to that technology. In the proof of the preliminary results we showed that each of firms A and B always produces the highest quality output it has the ability to produce. In combination these results prove iv).

Suppose $\Delta\geq\Delta^*$, firm A directly gains access to the superior technology, d=D, and $M^+\geq M^*$. In the proofs of Lemmas 1 and 2 we showed that in this case the input supplier does not sell information concerning the superior technology to firm B. In the proof of the preliminary results we showed that each of firms A and B always produces the highest quality output it has the ability to produce. In combination these results prove v).

Suppose $\Delta \geq \Delta^*$, firm A directly gains access to the superior technology, d=0, and/or $M^+ < M^*$. In the proof of Lemmas 1 and 2 we showed that in these cases the input supplier sells information concerning the superior technology to firm B. In the proof of the preliminary results we showed that each of firms A and B always produces the highest quality output it has the ability to produce. In combination these results prove vi).

We can now characterize π_A^{NVI2} more fully. Proposition 1 tells us that π_A^{NVI2} is lower than π_A^{NVI1} because when A directly gains access to the superior technology and d=0 and/or $M^+ < M^*$, then the input supplier sells information about the superior technology to firm B when B does not directly gain access and both firm A and firm B sell high quality output. So to more fully characterize π_A^{NVI2} we need to more fully analyze this case.

Suppose firm A does not produce the customized input in-house, A directly gains access to the superior technology, B does not, and d=0 and/or $M^+ < M^*$. Since the input supplier makes a take-it or leave-it offer to firm B for the information concerning the superior technology, firm B's profit is the same as if it did not purchase the information. Similarly, because firm A makes a take-it or leave-it offer to the input supplier concerning purchasing the customized input, the input supplier earns zero expected profits. So the profit associated with selling the information is captured by firm A.

Let $\sum\pi(Q^H,Q^L)$ be aggregate profits when firm A sells high quality and firm B low quality, while $\sum\pi(Q^H,Q^H)$ is aggregate profits when both firms sell high quality (for these expressions it is assumed that firm A does not produce the customized input in-house and the input supplier earns zero expected profits). Let $\psi=\sum\pi(Q^H,Q^L)-\sum\pi(Q^H,Q^H)$, where from earlier we know that ψ is given by (A13).

(A13) $$\psi = [(Q^H-Q^L+3\gamma)^2/18\gamma] + [(Q^L-Q^H+3\gamma)^2/18\gamma] - \gamma$$

In terms of the difference between π_A^{NVI1} and π_A^{NVI2}, we now have that π_A^{NVI2} must be lower by ψ multiplied by the probability this case arises. If $M^+ < M^*$, then this probability equals $z_A(1-z_B)$. So in this case $\pi_A^{NVI2}=\pi_A^{NVI1}-z_A(1-z_B)\psi=\pi_A^{VI}+\Delta-z_A(1-z_B)\psi$. If r>0 and $M^+ \geq M^*$, then this probability equals $rz_A(1-z_B)$. So in this case $\pi_A^{NVI2}=\pi_A^{NVI1}-rz_A(1-z_B)\psi=\pi_A^{VI}+\Delta-rz_A(1-z_B)\psi$.

<u>Proof of Corollary 1 to Proposition 1</u>: Here we prove both Corollary 1 to Proposition 1 and the related statement in footnote 13. Suppose r=0 and $M^+>M^*$. Then $\Delta^*=0$ which means Δ^* weakly increases with increases in Q^H and z_A, while it weakly decreases with increases in Q^L and z_B.

Now suppose r>0 and/or $M^+<M^*$ which earlier results imply $\Delta^*>0$. π_A^{VI} is given by (A10). There are two subcases. Suppose $M^+<M^*$. In this subcase, we know from above that $\pi_A^{NVI2}=\pi_A^{VI}+\Delta-z_A(1-z_B)\psi$. Δ^* is the value for Δ that makes firm A indifferent between producing the customized input in-house and purchasing the input from an input supplier, i.e., $\Delta^*=z_A(1-z_B)\psi$. Inspection of (A13) now tells us that Δ^* increases with Q^H, increases with z_A, decreases with Q^L, and decreases with z_B. The same relationships hold for the second subcase, r>0 and $M^+\geq M^*$, using similar arguments.

Now suppose r=0 and $M^+=M^*$. Given $M^*=\varphi/D$, it is easy to show that M^* is independent of z_A and z_B, while it increases with Q^H and decreases with Q^L. We immediately have that Δ^* is weakly increasing with z_A and weakly decreasing with z_B since changes in either still mean $\Delta^*=0$. Suppose Q^L increases. Then M^* falls in which case $M^+>M^*$ and $\Delta^*=0$. So Δ^* is weakly decreasing with Q^L. Suppose Q^H increases. Then M^* rises in which case $M^+<M^*$ and $\Delta^*>0$. So Δ^* increases with Q^H.

<u>Proof of Proposition 2</u>: In the proof of Proposition 3 we show how R_A' is determined for each realization of α. Given this, in this proof we take as given that each realization of α translates into a choice of R_A'. For any realization of α, take the value for R_A' as given and the resulting value for $\alpha z_A(R_A')$ also as given. Then all the results in Lemma 1, Lemma 2, Proposition 1, and Corollary 1 to Proposition 1 must hold after replacing z_A with $\alpha z_A(R_A')$. This follows given the arguments in the proofs of the Preliminary Results, Lemma 1, Lemma 2, Proposition 1, and Corollary 1 to Proposition 1.

<u>Proof of Proposition 3</u>: Here we prove both Proposition 3 and the related statement in footnote 14. Suppose R_A' increases with an increase of α. By definition, there is a corresponding increase in $\alpha z_A(R_A')$ and, further, arguments like those in the proof of Corollary 1 to Proposition 1 yield that Δ^* also weakly increases (and strictly increases if r>0 and/or $M^+<M^*$). So proving the proposition and footnote only requires showing that an increase in α results in an increase in R_A'.

There are two cases, where earlier results tell us that which case is the relevant one for any parameterization is independent of the realization of α. The first case is that, if firm A chooses to purchase the customized input from an input supplier, firm B never purchases information concerning the superior technology from the input supplier. We know from earlier arguments that in this case firm A never produces the customized input in-house. Let firm A's expected profit in this case as a function of α and R_A be denoted $\pi_A^{NVI1}(\alpha,R_A)$. Generalizing results from the proof of the Preliminary Results we have (A14).

$$\text{(A14)} \qquad \pi_A^{NVI1}(\alpha,R_A) = \alpha z_A(R_A)z_B(\gamma/2) + (1-\alpha z_A(R_A))(1-z_B)(\gamma/2) + [\alpha z_A(R_A)(1-z_B)(Q^H-Q^L+3\gamma)^2/18\gamma] + [(1-\alpha z_A(R_A))z_B(Q^L-Q^H+3\gamma)^2/18\gamma] - R_A$$

Let $X_1=(Q^H-Q^L+3\gamma)^2/18\gamma$ and $X_2=(Q^L-Q^H+3\gamma)^2/18\gamma$. R_A' must satisfy the first order condition given in (A15).

$$\text{(A15)} \quad \alpha z_A'(R_A')z_B(\gamma/2) - \alpha z_A'(R_A')(1-z_B)(\gamma/2) + \alpha z_A'(R_A')(1-z_B)X_1 - \alpha z_A'(R_A')z_BX_2 - 1 = 0$$

Rearranging terms yields (A16).

$$\text{(A16)} \qquad \alpha z_A'(R_A')z_B[(\gamma/2)-X_2] + \alpha z_A'(R_A')(1-z_B)[X_1-(\gamma/2)] - 1 = 0$$

Note that $X_1>(\gamma/2)>X_2$. So (A16) tells us that an increase in α must result in an increase in R_A'.

The second case is that, if firm A chooses to purchase the customized input from an input supplier, firm B purchases information concerning the superior technology from an input supplier with a strictly positive probability. There are two subcases, where earlier results tell us that which subcase is the relevant one for any particular parameterization is independent of the realization for α. The first subcase is characterized by $M^+<M^*$. Let $\Delta^*(\alpha,R_A)$ be the cutoff value for Δ concerning the vertical integration decision as a function of α and R_A. Also, let $E\pi_A(\alpha,R_A)$ be the expected profit of firm A as a function of α and R_A. Generalizing earlier results yields (A17).

$$\text{(A17)} \quad E\pi_A(\alpha,R_A) = \pi_A^{NVI1}(\alpha,R_A) - \int_0^{\Delta^*(\alpha,R_A)} \Delta h(\Delta) - \alpha z_A(R_A)(1-z_B)\int_{\Delta^*(\alpha,R_A)}^{\infty} \psi h(\Delta) - R_A$$

Taking the first order condition with respect to R_A yields (A18).

$$\text{(A18)} \qquad \alpha z_A'(R_A')z_B(\gamma/2) - \alpha z_A'(R_A')(1-z_B)(\gamma/2) + \alpha z_A'(R_A')(1-z_B)X_1 - \alpha z_A'(R_A')z_BX_2 - \alpha z_A'(R_A')(1-z_B)\int_{\Delta^*(\alpha,R_A)}^{\infty} \psi h(\Delta) - 1 = 0$$

Rearranging terms yields (A19).

$$\text{(A19)} \quad \alpha z_A'(R_A')z_B(\gamma/2) - \alpha z_A'(R_A')(1-z_B)(\gamma/2) + \alpha z_A'(R_A')(1-z_B)[X_1-(\gamma/2)-\int_{\Delta^*(\alpha,R_A)}^{\infty} \psi h(\Delta)] - 1 = 0$$

Since $X_1-(\gamma/2)>\psi$, (A19) tells us that an increase in α must result in an increase in R_A'.

The second subcase is characterized by r>0 and $M^+ \geq M^*$. A similar argument yields that an increase in α also results in an increase in R_A' in this subcase.

Proof of Lemma 3: This proof is basically the same as the proof of Lemma 1 with some changes due to the existence of two customized inputs rather than one. We thus present a short version of the proof that leaves out some details.

If firm A chooses to produce both customized inputs in-house we denote its expected profit as π_A^{VI}, while π_A^{NVI1} is firm A's expected profit when it purchases both customized inputs and neither input producer ever sells information concerning the superior technology to firm B. Using arguments like in the proof of the Preliminary Results it can be shown that $\pi_A^{NVI1} = \pi_A^{VI} + \Delta_1 + \Delta_2$. Suppose firm A directly gains access to the superior technology, firm B does not, and r=0. As in the one customized input case, absent any payment to an input supplier for information concerning the superior technology, firm B's profit will be higher if it acquires that information and produces high rather than low quality. As before, let φ be firm B's increase in profit in this case absent any payment for information. This is firm B's maximum willingness to pay for information concerning the superior technology.

For the rest of the proof we assume r=0 as in the lemma. Let $M^* = \varphi/D$ as before. Suppose $M^+ \geq M^*$. If firm A chooses to purchase both customized inputs and the contracts specify values for $M \geq M^*$, then from above we know the input suppliers will not sell information to firm B and an argument like in the proof of the Preliminary Results for the one customized input case now yields that expected profit is $\pi_A^{VI} + \Delta_1 + \Delta_2$. This tells us that, if $M^+ \geq M^*$, then the firm will choose to purchase both customized inputs because it can do better by purchasing both inputs and specifying a value $M \geq M^*$ in each contract.

Suppose firm A chooses vertical integration for input j and chooses to purchase input k from the market. If the input contract specifies a value $M \geq M^*$, then an argument like in the proof of the Preliminary Results for the one customized input case now yields that expected profit is $\pi_A^{VI} + \Delta_k < \pi_A^{VI} + \Delta_j + \Delta_k$. Thus, if $M^+ \geq M^*$, firm A will not choose vertical integration for a single customized input in combination with $M \geq M^*$ for the contract with the input supplier for the other customized input because it can do better by purchasing both customized inputs and specifying a value $M \geq M^*$ in each input contract.

Suppose again firm A chooses vertical integration for input j and chooses to purchase input k from the market. Now suppose the input contract specifies a value for $M<M^*$. This means the input supplier will sell information concerning the superior technology to firm B when A directly acquires that information and B does not. An argument like one in the proof of the Preliminary Results for the one input case now yields that expected profit for A is below $\pi_A^{VI}+\Delta_k<\pi_A^{VI}+\Delta_j+\Delta_k$. Thus, if $M^+\geq M^*$, firm A will not choose vertical integration for a single customized input. Combining this result with the previous result yields that, if $M^+\geq M^*$, firm A chooses to purchase both customized inputs from input suppliers with probability one.

Suppose $M^+<M^*$ and firm A purchases both customized inputs from input suppliers. By definition the value for M specified in the contract must satisfy $M\leq M^+$ which means the expected value of the penalty in each contract is less than firm B's willingness to pay for information concerning the superior technology when it does not acquire the information directly. Given this, when firm A directly acquires information concerning the superior technology and B does not, one of the customized input suppliers will sell information concerning the superior technology to firm B. In turn, an argument like in the proof of the preliminary results yields that expected profit for firm A in this case is less than π_A^{NVI1} which, in turn, means that it is less than π_A^{VI} for Δ_1 and Δ_2 both sufficiently small. This means that firm A will choose to purchase both customized inputs from input suppliers with probability less than one. So M^* is the lowest value such that firm A purchases both customized inputs with probability one whenever $M^+\geq M^*$.

<u>Proof of Lemma 4</u>: Suppose the lemma is not true. Then there exist values Δ_a and Δ_b, $\Delta_b>\Delta_a$, such that firm A produces input j when $\Delta_j=\Delta_b$ and purchases input j when $\Delta_j=\Delta_a$. Suppose this is the case. Holding all other parameters including Δ_k fixed, let $\pi_A^{VI}(\Delta_j)$ be firm A's expected profit associated with producing the input as a function of $\Delta_{j,}$. Note, for this value we are also holding fixed firm A's decision concerning whether or not to produce or purchase input k at the equilibrium choice given $\Delta_j=\Delta_b$. Also, let $\pi_A^{NVI}(\Delta_j)$ be firm A's expected profit associated with purchasing the input as a function of Δ_j. For this value we are also holding fixed firm A's decision concerning whether or not to produce or purchase input k at the equilibrium choice given $\Delta_j=\Delta_a$.[23]

[23] It can be shown that the subgame starting with firm j's decision concerning whether or not to produce or purchase input j yields unique values for $\pi_A^{VI}(\Delta_j)$ and $\pi_A^{NVI}(\Delta_j)$ for each possible value for Δ_j.

Revealed preference yields (A20) and (A21).

(A20) $$\pi_A^{NVI}(\Delta_a) \geq \pi_A^{VI}(\Delta_a)$$

(A21) $$\pi_A^{NVI}(\Delta_b) \leq \pi_A^{VI}(\Delta_b)$$

Subtracting (A21) from (A20) yields (A22).

(A22) $$\pi_A^{NVI}(\Delta_a) - \pi_A^{NVI}(\Delta_b) \geq \pi_A^{VI}(\Delta_a) - \pi_A^{VI}(\Delta_b)$$

But given Δ_j is a fixed cost which means it has a limited effect on payoffs after the vertical integration decision (see also footnote 23), it must be the case that $\pi_A^{NVI}(\Delta_a)=\pi_A^{NVI}(\Delta_b)$ and $\pi_A^{VI}(\Delta_a)+\Delta_a=\pi_A^{VI}(\Delta_b)+\Delta_b$. These relationships yield $0=\pi_A^{NVI}(\Delta_A)-\pi_A^{NVI}(\Delta_b)<\pi_A^{VI}(\Delta_a)-\pi_A^{VI}(\Delta_b) =\Delta_b-\Delta_a$ which contradicts (A22). So there cannot exist values Δ_a and Δ_b, $\Delta_b>\Delta_a$, such that firm A produces input j when $\Delta_j=\Delta_b$ and purchases input j when $\Delta_j=\Delta_a$ which, in turn, means the lemma must be true.

<u>Proof of Proposition 4</u>: i) follows from arguments like those found in the proof of Lemma 1.

Let Δ^* be the cutoff value for the vertical integration decision for input j when input k is purchased from an input supplier, while Δ^{***} is the cutoff value for the vertical integration decision for input j when input k is produced in-house. That is, when input k is purchased from an input supplier, then input j is purchased from an input supplier when $\Delta_j \geq \Delta^*$ and produced in-house when $\Delta_j<\Delta^*$. Also, when input k is produced in-house, then input j is purchased from an input supplier when $\Delta_j \geq \Delta^{***}$ and produced in-house when $\Delta_j<\Delta^{***}$. Such values must exist given Lemma 4.

Lemma 3 immediately tells us that $\Delta^*=\Delta^{**}=\Delta^{***}=0$ if $r=0$ and $M^+ \geq M^*$. Suppose $r>0$ and/or $M^+<M^*$. As before, let ψ be the increase in aggregate profits when A sells high quality and B low quality relative to aggregate profits when both sell high quality, while φ is B's profit increase from selling high rather than low quality when A sells high quality and B makes no payment for information. There are two subcases.

First, suppose $r>0$ and $M^+ \geq M^*$. Consider the vertical integration decision concerning input j. Suppose first that input k is produced in-house. Employing arguments similar to arguments presented earlier, we can show that if input j is produced in-house then firm A's expected profit is given by the expression in (A23), while if it is purchased from an input supplier then A's expected profit is given by the expression in (A24).

(A23) $$z_A z_B(\gamma/2) + (1-z_A)(1-z_B)(\gamma/2) + [z_A(1-z_B)(Q^H-Q^L+3\gamma)^2/18\gamma]$$

$$+ [(1-z_A)z_B(Q^L-Q^H+3\gamma)^2/18\gamma] - \Delta_j - \Delta_k$$

(A24) $$z_A z_B(\gamma/2) + (1-z_A)(1-z_B)(\gamma/2) + [z_A(1-z_B)(Q^H-Q^L+3\gamma)^2/18\gamma] + [(1-z_A)z_B(Q^L-Q^H+3\gamma)^2/18\gamma] - \Delta_k - rz_A(1-z_B)\psi$$

Δ^{***} is the value for Δ_j which makes the two expressions equal which means $\Delta^{***}=rz_A(1-z_B)\psi$.

Now suppose input k is purchased from an input supplier. Employing arguments similar to arguments presented earlier, we can show that if input j is produced in-house then firm A's expected profit is given by the expression in (A25), while if it is purchased from an input supplier then A's expected profit is given by the expression in (A26). Note that the expression in (A26) is based on the price that B pays for information when d=0 for both inputs being equal to zero due to competition between the input suppliers.

(A25) $$z_A z_B(\gamma/2) + (1-z_A)(1-z_B)(\gamma/2) + [z_A(1-z_B)(Q^H-Q^L+3\gamma)^2/18\gamma] + [(1-z_A)z_B(Q^L-Q^H+3\gamma)^2/18\gamma] - \Delta_j - rz_A(1-z_B)\psi$$

(A26) $$z_A z_B(\gamma/2) + (1-z_A)(1-z_B)(\gamma/2) + [z_A(1-z_B)(Q^H-Q^L+3\gamma)^2/18\gamma] + [(1-z_A)z_B(Q^L-Q^H+3\gamma)^2/18\gamma] - rz_A(1-z_B)(\psi+\varphi)$$

Δ^* is the value for Δ_j which makes the two expressions equal. This means $\Delta^*=rz_A(1-z_B)\varphi$. Since $\psi>\varphi$ (see footnote 6), a comparison of the two expressions yields $\Delta^{***}>\Delta^*>0$.

Second, suppose $M^+<M^*$. Consider again the vertical integration decision concerning input j. Suppose first that input k is produced in-house. Employing arguments similar to arguments presented earlier, we can show that if input j is produced in-house then firm A's expected profit is given by the expression in (A23), while if it purchased from an input supplier then A's expected profit is given by the expression in (A27).

(A27) $$z_A z_B(\gamma/2) + (1-z_A)(1-z_B)(\gamma/2) + [z_A(1-z_B)(Q^H-Q^L+3\gamma)^2/18\gamma] + [(1-z_A)z_B(Q^L-Q^H+3\gamma)^2/18\gamma] - \Delta_k - z_A(1-z_B)\psi$$

Δ^{***} is the value for Δ_j which makes the two expressions equal which means $\Delta^{***}=z_A(1-z_B)\psi$.

Now suppose input k is purchased from an input supplier. Employing arguments similar to arguments presented earlier, we can show that if input j is produced in-house then firm A's expected profit is given by the expression in (A28), while if it is purchased from an input supplier then A's expected profit is given by the expression in (A29).

(A28) $$z_A z_B(\gamma/2) + (1-z_A)(1-z_B)(\gamma/2) + [z_A(1-z_B)(Q^H-Q^L+3\gamma)^2/18\gamma] + [(1-z_A)z_B(Q^L-Q^H+3\gamma)^2/18\gamma] - \Delta_j - z_A(1-z_B)\psi$$

(A29) $$z_A z_B(\gamma/2) + (1-z_A)(1-z_B)(\gamma/2) + [z_A(1-z_B)(Q^H-Q^L+3\gamma)^2/18\gamma]$$

$$+ [(1-z_A)z_B(Q^L-Q^H+3\gamma)^2/18\gamma] - z_A(1-z_B)(\psi+\varphi-(1-r)DM^+)$$

Δ^* is the value for Δ_j which makes the two expressions equal which means $\Delta^*=z_A(1-z_B)(\varphi-(1-r)DM^+)$. Since $\psi>\varphi$ (see footnote 6), we again have $\Delta^{***}>\Delta^*>0$.

Suppose $\Delta_j<\Delta^*$ and $\Delta_k<\Delta^{***}$, $j\neq k$. By the definition of Δ^*, we have that input j is produced in-house. Given this, the definition of Δ^{***} tells us that input k is also produced in-house. The proof of the preliminary results showed that a firm always produces the highest quality product it has the ability to produce. This proves ii).

Suppose $\Delta_j\geq\Delta^*$ and $\Delta_k\geq\Delta^{***}$, $j\neq k$. By the definition of Δ^{***}, we have that input k is purchased from an input supplier. Given this, the definition of Δ^* tells us that input j is also purchased from an input supplier. This proves iii).

Suppose $\Delta_j<\Delta^*$ and $\Delta_k\geq\Delta^{***}$, $j\neq k$. From the definition of Δ^* and Δ^{***}, we have that input j is produced in-house and input k is purchased from an input supplier. This proves iv).

Suppose $\Delta^*\leq\Delta_j\leq\Delta^{***}$ and $\Delta^*\leq\Delta_k\leq\Delta^{***}$. By the definition of Δ^* and Δ^{***}, it must be the case that either both inputs are produced in-house or both are purchased from input suppliers. Firm A's expected profit for the latter is independent of $\Delta_j+\Delta_k$, while expected profit for the former falls as $\Delta_j+\Delta_k$ rises. So there must be a critical value, Δ^{**}, $\Delta^*\leq\Delta^{**}\leq\Delta^{***}$, such that both customized inputs are produced in-house when $(\Delta_j+\Delta_k)/2<\Delta^{**}$ and both are purchased from input suppliers when $(\Delta_j+\Delta_k)/2\geq\Delta^{**}$. This proves v).

The statement in vi) follows immediately from the proof in the preliminary results that a firm always produces the highest quality output it has the ability to produce.

The statement in vii) follows from the proof in the preliminary results that a firm always produces the highest quality output it has the ability to produce in combination with an earlier argument that firm A will stop the input supplier from ever selling information concerning the superior technology to firm B when $M^+\geq M^*$ by choosing $M\geq M^*$.

The statement in viii) follows from the proof in the preliminary results that a firm always produces the highest quality output it has the ability to produce in combination with the earlier argument that an input supplier will sell information concerning the superior technology to firm B when it has the information, B does not, and d=0 and/or $M^+<M^*$.

The statement in ix) follows from a generalization of the proof of vii). The statement in x) follows from a generalization of the proof of viii).

<u>Proof of Proposition 5</u>: Suppose employee non-compete agreements are enforceable and firms A and B both include non-compete agreements in their compensation offers to high-tech workers at the beginning of the game. Then each of firms A and B cannot poach a high-tech worker of its rival at the poaching stage and arguments like those presented in earlier proofs yield that Lemma 1, Lemma 2, Proposition 1, and Corollary 1 to Proposition 1 must hold. Note further that, since there is no poaching, the wage each of firms A and B pay to high-tech workers is w_h which is the reservation wage for high-tech workers. Call firm A's expected profit associated with this outcome π_A^{NC}, while firm B's expected profit associated with this outcome is π_B^{NC}.

Suppose firm B includes employee non-compete agreements in its compensation offers to high-tech workers at the beginning of the game and consider firm A's choice concerning whether or not to include non-compete agreements in its own offers. If firm A chooses to include non-compete agreements in its compensation offers to high-tech workers, then the high-tech workers earn zero additional compensation from poaching as pointed out above and firm A pays each worker w_h. In turn, as argued above, Lemma 1, Lemma 2, Proposition 1, and Corollary 1 to Proposition 1 describe the outcome and firm A's expected profit is denoted π_A^{NC}.

Suppose firm A instead chooses not to include non-compete agreements in its compensation offers to high-tech workers. It is straightforward that behavior will be basically the same as when A does include non-compete agreements except possibly when A directly gains access to the superior technology and B does not. Suppose A offers an initial wage to high-tech workers, denoted w_h^{IA}, strictly above w_h. Clearly, expected profit for A would be below π_A^{NC} and A would have been better off including non-compete agreements.

Given this, suppose firm A's initial wage offer to high-tech workers satisfies $w_h^{IA} \leq w_h$. We start with the case in which the firm subsequently chooses vertical integration. Suppose firm B does not directly gain access to the superior technology and let ξ be the decrease in firm A's profit associated with B acquiring the ability to produce high quality output. If l_h is sufficiently large, firm B will offer a poaching wage to all l_h workers of firm A equal to $w_h^{IA}+\varepsilon$, where $l_h\varepsilon=\xi$ (a higher wage is not needed for B to successfully poach one of A's high-tech workers and any lower wage is too low for B to successfully poach one of A's high-tech workers). Then firm A will not have an incentive to offer a high enough counter-offer to stop its high-tech workers from offering to leave.[24] The result is that all of firm A's high-tech workers offer to leave and firm B hires one of them and pays the worker $w_h^{IA}+\varepsilon$.

Note that ε approaches zero as l_h gets large which means that the return to a worker who is poached approaches zero as l_h gets large. This is also true below for the case in which A does not choose to vertically integrate. But if the return to being poached approaches zero and the probability of leaving also approaches zero as l_h gets large, it must be the case that w_h^{IA} approaches w_h from below as l_h gets large since firm A must offer an initial wage to high-tech workers that guarantees an expected payment at least equal to w_h. In turn, if ε approaches zero as l_h gets large, then it must be the case that the poaching wage, $w_h^{IA}+\varepsilon$, approaches w_h as l_h gets large. So poaching will be profitable in this case if Q^H is sufficiently large (see footnote 17).

We now have that, if firm A chooses to produce the customized input in-house and does not include non-compete agreements in its compensation offers to high-tech workers, then as l_h gets large outcomes are basically the same from A's perspective as when A chooses to produce the customized input in-house and includes non-compete agreements except that firm B acquires information concerning the superior technology when A directly gains access to the superior technology and B does not. Based on arguments like those found in the proof of the preliminary results, this means that, assuming in-house production for the customized input, as l_h gets large firm A's expected profit is higher if it includes non-compete agreements in its offers to high-tech workers.

Now consider the same situation as above but firm A chooses to purchase the customized input from an input supplier. Suppose firm A has access to the superior technology and firm B does not. As l_h gets large, if the input supplier does not sell information concerning the superior technology to firm B, then B will acquire the information via poaching at a cost that approaches w_h. There are two subcases. The first subcase is that parameters are such that the input supplier would not sell the information even if poaching was not a possibility. Then arguments like above yield that A would be better off with non-compete agreements. The second subcase is that parameters are such that the input supplier would sell the information in the absence of poaching. In this case poaching limits how much of firm B's extra profits associated with producing high

[24] For this step of the proof we assume a worker offers to leave when the worker is indifferent between offering to leave and not offering to leave. This is not essential for the proposition to hold but somewhat simplifies the proof.

rather than low quality A can capture via the initial contract with the input supplier, so A is again better off with non-compete agreements.

Suppose firm A anticipates that B will include non-compete agreements in its initial contract offers to high-tech workers and firm A chooses not to include non-compete agreements in its initial offers to high-tech workers. Previous results yield that, if l_h is sufficiently large, firm A's expected profit would be higher if it chose to include non-compete agreements and made the same choices concerning vertical integration for the customized input as a function of the realization of Δ as when it did not include non-compete agreements. This means that, if A anticipates that B will include non-compete agreements in its initial contract offers to high-tech workers and l_h is sufficiently large, then firm A will also include non-compete agreements in its offers to high-tech workers.

Now suppose that firm A anticipates firm B will not choose to include non-compete agreements in its initial compensation offers to high-tech workers. This means that firm A will have the option of poaching firm B's high-tech workers when firm A does not directly gain access to the superior technology. But having this option does not significantly affect firm A's incentive to include non-compete agreements in its initial compensation offer to high-tech workers. As a result, arguments similar to those above yield that, if firm A anticipates that firm B will not include non-compete agreements in its initial compensation offers to high-tech workers and l_h is sufficiently large, then A will include non-compete agreements in its initial compensation offers to high-tech workers. In turn, combining this result with the result in the paragraph just above yields that, if l_h is sufficiently large, firm A will always include non-compete agreements in its initial compensation offers to high-tech workers.

Finally, similar arguments yield that firm B also chooses to include non-compete agreements in its initial compensation offers to high-tech workers if l_h is sufficiently high. The only difference in the arguments is that we do not need to consider the possibility that firm B chooses not to produce the customized input in-house which also means that firm A never has an option of acquiring information about the superior technology from an input supplier.

<u>Proof of Proposition 6</u>: Arguments found in the proof of Proposition 5 yield that, as l_h gets large, i) through iv) must hold. So to prove the proposition we only need to show that as l_h gets large firm A never chooses to produce the customized input in-house.

Suppose the firm chooses to produce the customized input in-house. From the proof of Proposition 5 we know that, as l_h gets large, the result is that when A directly gains access to the superior technology and B does not, then B poaches one of A's high-tech workers and A is unable to capture any of B's subsequent profit increase. Suppose instead A chooses not to vertically integrate. Two things occur that affect A's profitability. First, A's profit rises by Δ because the cost of producing the input falls by Δ and in equilibrium the input supplier earns zero expected profit. Second, B will still acquire the information concerning the superior technology when A directly gains access and B does not. But it may acquire the information via the input supplier which would allow firm A to capture some of B's increased profit through the contract between A and the input supplier. Both of these factors serve to increase A's profitability, so A never chooses to produce the customized input in-house as l_h gets large.

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