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Optimal Licensing of Agricultural Patents: Fees versus Royalties

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We develop a theoretical model of optimal licensing schemes for quality-improving innovations. We consider an oligopolistic market where two downstream firms compete in price and the upstream innovator holds a technology that may create differentiation between the products. Our results show that non-exclusive licensing performs better than exclusive licensing under both fixed fees and royalties and that the preferred contract consists of fixed fees only. We also find that the innovator's license revenue depends on the magnitude of the innovation so there is a greater reward to the innovator's institution if the innovation is large.

Key words: agricultural innovation, horticulture, licensing, patents, price competition, royalties

Introduction

Universities are critically important for generating commercially relevant research. Lach and Schankerman (2008) report that universities conduct 53% of all basic research and that "the number of U.S. patents awarded to university inventors annually increased from 500 in 1982 to 3,255 in 2006." With the passage of the Bayh-Dole Act in 1980, universities gained the right to retain and license the intellectual property rights (IPRs) associated with patents funded through federal research funds. Licensing activities are generally conducted through university technology transfer offices (TTOs), which serve as liaisons between researchers and private-sector firms. TTOs, therefore, must design licensing strategies that maximize the return to university-generated research. The choice of whether to offer exclusive or non-exclusive contracts consisting of either fixed fees, royalties, or a combination of the two depends critically on the nature of competition among downstream producers—the firms that buy and use the new technology. While license design for cost-reducing innovations is relatively well understood (Sen and Tauman, 2007), there is relatively little research on demand-enhancing innovations. In this paper, we study the optimal design of a patent-license pricing scheme for a demand-side agricultural product innovation.

We focus on an example of patent licensing in the horticultural industry, specifically new apple varieties. Several universities have been particularly active in developing and licensing new varieties (e.g., Cornell University, the University of Minnesota, and Washington State University), but there is little evidence that TTOs have sought to optimize license revenue in any formal way. Licensing schemes for patented fruit varieties are generally determined through negotiations between TTOs and a management company or grower-based cooperative. These negotiations typically begin with a request for bids from potential licensees or groups acting as representatives of potential licensees. The TTO evaluates bids based on financial and management considerations with a focus on initial

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payments, annual payments, quality control issues, contracts with individual growers, and marketing plans. A successful bid for a new variety will often allow the licensee the first right of refusal on subsequent varietal introductions. In different instances, the licensee has been an individual grower-packer, a grower-owned cooperative, or a management company acting on behalf of a group of growers. Once a licensee has been selected, licensors use different models concerning how the varieties are made available to individual growers. In some cases the varieties are released to one grower or a relatively small set of selected growers, although this approach has caused much tension among growers that were not selected (and more familiar with publicly available varieties) and university administrators (see Lehnart 2010). In other cases the new varieties are made available to all growers in a specified region. In practice, the varieties are licensed to individual growers and the licensing mechanisms involve primarily up-front fees that are made to the breeding program via the firm or the cooperative or the management company. The up-front fees are typically charged per unit of land devoted to production or, in the case of perennial crops, may be added to the cost of the trees. In some instances the licensees have a choice about whether the up-front fee will be paid per unit of land or per tree, and this condition does not force growers to adopt undesired, or unfamiliar, planting density patterns. Clearly, there is considerable heterogeneity in how patents are licensed in practice.

Our formal understanding of the optimal mechanism for patent licensing has changed considerably in recent years. Kamien and Tauman (1984, 1986), Katz and Shapiro (1985), and Kamien, Oren, and Tauman (1992) find that licensing via a royalty system generates less revenue for an external innovator than if a fixed fee or auction were used. However, the empirical research in non-agricultural industries tends to find that royalties, or combinations of fees and royalties, are far more common (Sen and Tauman, 2007). The challenge facing researchers then became reconciling this stylized fact with economic theory. By including more realistic institutional attributes of industry such as product differentiation (Motta, 1993; Faulí-Oller and Sandonís, 2002), asymmetric information (Gallini and Wright, 1990; Sen, 2005), risk aversion (Bousquet et al., 1998), moral hazard (Choi, 2001), incumbency (Shapiro, 1985; Kamien and Tauman, 2002; Wang, 2002; Sen and Tauman, 2007) or strategic delegation (Saracho, 2002) researchers were able to explain observed licensing strategies. Faulí-Oller and Sandonís (2002), for example, show that regardless of the type of competition, the optimal contract always includes a positive royalty when products are differentiated. Our challenge, therefore, is to explain why fees tend to dominate in the context of horticultural innovations.

Most of the theoretical literature on licensing patented research concerns cost-reducing innovations. In agriculture in general, and in the fruit and vegetable sector more specifically, however, a significant number of innovations seek to improve eating quality, a demand-side innovation. Unlike a cost-reducing innovation, a quality-improving innovation directly affects consumers' preferences and their willingness to purchase a product. Among studies that consider demand-side or product innovations, Bousquet et al. (1998) find that a combination of fees and royalties is optimal if demand for the new product is uncertain. In their model, fees and royalties are a means by which a risk neutral innovator can provide insurance—and be compensated for it—to a risk-averse licensee. Sen (2005) generates a similar combination of tools under asymmetric information. If the licensee has private information regarding its cost of producing the new product, then the licensor will benefit from using a combination of fees and royalties. Li and Wang (2010) consider a Cournot duopoly scenario in which the external innovator sells a quality improving innovation and find that exclusive licensing is preferred under fixed fees while non-exclusive licensing is preferred under royalties and two-part tariffs. Stamatopoulos and Tauman (2008) consider the strategic rationale for pricing a demand-side innovation into a downstream Bertrand duopoly market. Adopting a discrete choice modeling framework (Anderson, de Palma, and Thisse, 1992) to study the behavior of oligopolies under product differentiation, the innovator licenses its output using either a fixed fee, royalty, or combination of the two. When the market is covered (all consumers buy), they find that both firms purchase the innovation by paying a positive royalty and no fixed fee. If the value of the outside option is relatively high, then both firms will still license the innovation but pay a combination of fee and royalty. Although Stamatopoulos and Tauman (2008) show that quality-enhancing innovations are licensed using a contract that includes both fees and royalties, they do not treat the degree of innovation as a continuous variable. Therefore, it is not clear whether their result holds regardless of whether innovations are both minor and significant. This paper derives threshold values (for the degree of innovation) that define whether fees, royalties, or both are optimal.

This article offers a theoretical model of optimal licensing schemes for quality-improving agricultural innovations. We consider an oligopolistic market where two downstream firms compete in price and the upstream innovator holds a quality-improving technology that may create differentiation between the products.[1] Since we are interested in university-based research specific to (but not limited to) the horticultural industry, the innovator is an outsider by default. We consider both exclusive and non-exclusive licensing. Under exclusive licensing, only one downstream firm gets the innovation, and in non-exclusive licensing, more than one firm is allowed to produce and sell the new product. This framework provides a realistic yet tractable description of the market for demand-side agricultural innovations.

We find that the innovator maximizes licensing revenue under a non-exclusive fixed-fee regime. In general, our results show that non-exclusive licensing performs better than exclusive licensing under both fixed fees and royalties and that a two-part tariff scheme will not be used because neither downstream firm can improve upon their pre-license profit level. With a fixed fee, the innovator is able to extract the licensing firms' increased profits but is not able to control industry output. Licensing through a royalty, the innovator is able to manipulate the cost structure of the licensing firms, which provides a measure of control over the final output. Two-part tariffs have the potential to generate the most revenue, but we find that licenses will never be purchased this way. When the innovator has control over the market, it is in her best interest to intensify competition between the downstream firms by licensing to one firm and then extracting rents generated by the market power conferred on the higher-quality producer. When the innovator does not have control over the final output, it is in her best interest to license to both firms and collect as much additional profit as possible from the innovation through a fixed fee. Further, licensing through either a fixed fee or a two-part tariff moderates competition between two downstream firms and results in a market that produces only high-quality products.

The Model

We consider a final market with two firms and two differentiated products: high-quality products and low-quality products, where high-quality products are produced with the innovation and low-quality products are produced using existing technology. Under exclusive licensing, we assume that each firm produces only one type of product. Competition in the final market results from the firms selling differentiated products. The innovation is patent-protected. Three types of licensing contract are considered in this paper: (i) a fixed-fee-based license, in which the licensee pays F to the patent holder regardless of the quantity he will sell in the final market, (ii) a royalty-based license, in which the licensee pays r to the patent holder for each unit he will sell, and (iii) a combination of both payment schemes where the licensee pays both a fixed up-front fee, F, and a per unit royalty, r, for the quantity sold.

We assume an oligopoly that consists of two firms, each producing a differentiated good. There is a continuum of consumers of the same type with a utility function separable and linear in each good. With this framework, we can perform partial equilibrium analysis. We assume that a representative consumer maximizes a quadratic, strictly concave utility function, which gives rise to

[1] Price competition is not necessary for firms that sell differentiated products, but given that most produce is sold through retail stores, price competition is a more natural choice.

a linear demand structure. Consumers are willing to pay more for higher quality products, where the maximum willingness to pay is given by $c(s_i)$. Differentiation comes from two sources: the degree of substitutability, b, and the quality, s_i. Therefore, inverse demand for each product on the downstream market is[2]

$$p_i = c(s_i) - q_i - (b/s_i)q_j, \tag{1}$$

where p_i is the price set by firm i, $i = 1,2$, and q_i represents the quantity sold by firm i. Without loss of generality, we assume that firm 1 produces low-quality products and firm 2 produces high-quality products under exclusive licensing and that both firms produce high-quality products under non-exclusive licensing. The variable s_i measures quality, with s_1 indicating low quality and s_2 high quality. The highest propensity to pay for quality, s_i, is denoted by $c_i = c(s_i)$. Following Li and Wang (2010), we first normalize s_1 to be 1 and then assume a relationship between low quality and high quality in which $s_1 = \lambda s_2 (\lambda \in (0,1))$, where λ captures the degree of product innovation. A larger λ implies a smaller quality improvement and a smaller λ indicates a greater quality improvement.[3]

We assume that λ is exogenous, which reflects the fact that TTOs are charged with marketing innovations that are presented to them from their faculty innovators. The degree of substitutability between the products is indicated by b ($b \in (0,1)$). When $b = 1$ and $\lambda = 1$ the two products are perfect substitutes. Including both is necessary to isolate the quality-enhancing nature of innovations. Namely, the parameter b captures the fact that the products are horizontally differentiated or that there is at least part of the market that would prefer each product even if the prices were the same. On the other hand, λ introduces a vertical component in that the willingness-to-pay for high-quality goods rises in $1/\lambda$ for the entire market. In the absence of the b parameter, the Singh and Vives (1984) model has no way of separating an innovation that is truly better from one that is merely different. By introducing both parameters, we separate the two effects and base our licensing model on a more general demand framework. Further, we assume a quadratic structure for the highest propensity to pay ($c(s_i) = s_i^2$) in order to ensure an interior solution (Sen and Tauman, 2007).[4] As we demonstrate below, the degree of innovation is a critical parameter in determining the optimal license structure for the innovator.

Under non-exclusive licensing, both firms face similar demand functions and produce either low- or high-quality products exclusively in the final market. Under exclusive licensing, the demand functions facing low- and high-quality firms are, respectively:

$$q_1 = \left(\frac{1}{1 - b^2\lambda}\right)\left(-p_1 + bp_2 - \frac{b}{\lambda^2} + 1\right) \tag{2}$$

$$q_2 = \left(\frac{1}{1 - b^2\lambda}\right)\left(b\lambda p_1 - p_2 + \frac{1}{\lambda^2} - b\lambda\right), \tag{3}$$

[2] This demand function can be derived from the utility function of a representative consumer defined as follows: $U(q_1, q_2) = c(s_1)q_1 + c(s_2)q_2 - \frac{1}{2}(q_1^2 + 2\frac{b}{s_i}q_1q_2 + q_2^2)$
See Singh and Vives (1984) for a detailed analysis of the duopoly equilibrium with such a demand function. A detailed derivation is provided in Appendix A.

[3] In theory, λ is bound on (0,1), but our subsequent model solution shows that if λ is such that $q_2 < 1$, then suppliers will not be maximizing profits, so we need not consider this case. Therefore, even though λ is bound by (0,1) in theory, for purposes of the model solution it is effectively bound to a region around 0 that is consistent with suppliers making positive profits from the innovation.

[4] This demand specification implies that the inverse demand for high-quality goods depends on the difference in quality between low- and high-quality goods, but not vice versa. This is appropriate because we implicitly assume that demand for the low-quality good represents the core of the market that is familiar with the attributes of the incumbent product, and will not switch no matter the attribute set of the new product. For example, when Honeycrisp apples, widely regarded as possessing superior eating attributes to existing apples, were introduced on a widespread basis in the fall of 2009, there was no statistically significant effect on the price of Pink Lady apples, even through Pink Lady apples were positioned as superior alternatives to other varieties available at the time (econometric results available from the authors). For a non-agricultural example, consider cars. Consumers' willingness to pay for high-end luxury vehicles such as BMW, Lexus, or Cadillac is driven largely by the fact that they are not Fords, Toyotas, or Kias, while demand for the latter represents the core value of transportation at minimum cost subject to safety and functionality constraints.

where the own-price response for low-quality products is $-\frac{1}{1-b^2\lambda}$ and the cross-price response for low-quality products is $\frac{b}{1-b^2\lambda}$. The own-price response for high-quality products is$-\frac{1}{1-b^2\lambda}$ and the cross price response for high-quality products is $\frac{b\lambda}{1-b^2\lambda}$. Both intrinsic characteristics (b) and quality (λ) play roles in differentiating low- and high-quality products.[5] In this paper, we focus on the impact of quality on price differentiation.

Optimal Licensing Strategies

In this section, we study optimal licensing strategies for the innovator.[6] To do so, we first consider the profitability of each downstream firm and analyze their incentive to license the innovation. When the patent is licensed exclusively to one firm we refer to the licensee as firm 2. Throughout this paper, p_k^{ij}, q_k^{ij}, and π_k^{ij} denote firm k's price, quantity, and profit by means of contract i, where $k=1$ is firm 1 (low quality), ,$k=2$ is firm 2 (high quality), and $k=3$ is the innovator; $j=E$ indicates an exclusive contract; $j=N$ is a non-exclusive contract; and $i=NL,FE,FN,RE,RN,TE,TN$, which represent, respectively, no licensing, exclusive fixed-fee licensing, non-exclusive fixed-fee licensing, exclusive royalty licensing, non-exclusive royalty licensing, exclusive two-part tariff licensing, and non-exclusive two-part tariff licensing. For example, p^{FN} is the market price when the innovation is licensed to both firms through fixed fee. The innovator's profit is the sum of any royalty or fee less the cost of innovation. We assume the cost of innovation is convex in the extent of the quality improvement and assumes the same form as the propensity to pay, or $c(s_i)=s_i^2$.

The game consists of three stages. In the first stage, the innovator simultaneously offers either non-exclusive contracts or an exclusive contract consisting of either royalties, fees, or a combination of the two. In the second stage, the downstream firms either accept or reject the license contracts. In the third stage, the firms compete in the downstream market.

We first consider the case where no license is purchased in order to calculate the benchmark profit for both firms under an exclusive licensing scenario. When licensing is non-exclusive, we first solve for the optimal solution to the subgame played between downstream firms in order to establish the benchmark profit. The benchmark profit becomes the profit of the licensing firm under exclusive licensing. Then we consider the other licensing strategies in the following order: fixed-fee licensing, royalty licensing, and two-part tariff licensing. We compare profits under each licensing strategy with the benchmark profit and suggest the optimal licensing strategy for the patent holder.

Consistent with others in this literature (Li and Wang, 2010), we find that the degree of innovation (λ) is a critical parameter influencing the downstream firms' decisions to license and, hence, the innovator's profitability. Therefore, we provide comparative static results for the innovator's profit with respect to λ. In many cases, we show that there may indeed be no incentive to innovate at all if the new product is not sufficiently better than previous products.

No Licensing

We establish benchmark profits where no innovation is introduced. In this case, firms produce only low-quality products. Following Motta (1993), we assume constant marginal costs and normalize

[5] More generally, for values of λ between the extremes of 0 and 1, when there are both high- and low-quality goods in the market, the own-price response is the same for both high- and low-quality firms. The cross-price response, however, is higher for the low-quality firm than for the high-quality firm. That is, by introducing quality into the demand functions, the high-quality firm is less sensitive to the price of her rival's low-quality goods. While this is an implicit assumption in our demand function, we believe it is both reasonable and descriptive of the types of market we have in mind.

[6] Optimality is defined, as in the literature, as the difference between license revenues and the cost of innovation. Although our analysis concerns university research activities, and universities are expected to conduct basic research in the public interest, our profit-maximization assumption reflects the observed activities of university TTO offices. Namely, as Bulut and Moschini (2009) note, "Quite clearly, when it comes to patenting and licensing, universities are likely to behave based on their self-interest rather than the public interest" (p. 124). Resolving the debate as to whether universities should maximize the returns to their research investment is left for either political or legal discussion.

them to be 0. Therefore, the duopoly profits when no license is purchased are

$$\pi_1^{NL} = \max_{p_1} p_1 q_1 = p_1 \left[\frac{1}{1-b^2} (-p_1 + bp_2 - b + 1) \right] \tag{4}$$

$$\pi_2^{NL} = \max_{p_2} p_2 q_2 = p_2 \left[\frac{1}{1-b^2} (-p_2 + bp_1 - b + 1) \right] \tag{5}$$

Solving the first-order conditions of this problem results in the optimal prices:

$$p^{NL} = p_1^{NL} = p_2^{NL} = -\frac{1-b}{-2+b} \tag{6}$$

In this expression, $p^{NL} > 0$ because $1-b$ must be positive and $-2+b$ must be negative as b is between 0 and 1. Price competition under no licensing results in positive market prices. Profit is symmetric and depends solely on the degree of substitutability between the products. The expression for the profit earned by both firms becomes

$$\pi^{NL} = \pi_1^{NL} = \pi_2^{NL} = \frac{1-b}{(-2+b)^2(1+b)} \tag{7}$$

This is also positive because b is between 0 and 1. Both firms make positive profits under the no licensing scenario and when they both produce the low-quality products. We refer to such a profit as the benchmark profit. When the innovation is introduced into the market through licensing, the demands for high- and low-quality products will change and so will firms' profits. Firms compare their potential profits with the benchmark profit and decide whether it is in their best interests to license the innovation.

Fixed-Fee Licensing

When licensing using fixed fees, the patent holder extracts the entire profit due to the innovation by setting the fixed fee equal to the difference between the licensee's profit with the innovation and the benchmark profit. If the fee were any larger, the licensees would be better off without the patent as the new profit will be smaller than the benchmark profit. If the fixed fee is smaller than the incremental profit, the innovator will not extract all the profit and can always benefit more by increasing the fixed fee until it is exactly equal to the difference.

PROPOSITION 1. *Under exclusive fixed-fee licensing, the innovator makes a positive profit when λ is smaller than 0.40.*

Proof. Under exclusive fixed-fee licensing, only one firm purchases the patent. We assume that firm 2 purchases the innovation and produces high-quality products. The profit is given by

$$\pi_2^{FE} = \max_{p_2} p_2 \left[\frac{1}{1-b^2\lambda} \left(b\lambda p_1 - p_2 + \frac{1}{\lambda^2} - b\lambda \right) \right] - F^{FE}. \tag{8}$$

Since firm 1 doesn't purchase the patent, it does not yield any revenue directly to the innovator, but its optimal price conditions the profit from firm 2, the firm purchasing the patent. In this case, firm 1 produces low-quality products with a profit of

$$\pi_1^{FE} = \max_{p_1} p_1 \left[\frac{1}{1-b^2\lambda} \left(-p_1 + bp_2 - \frac{b}{\lambda^2} + 1 \right) \right]. \tag{9}$$

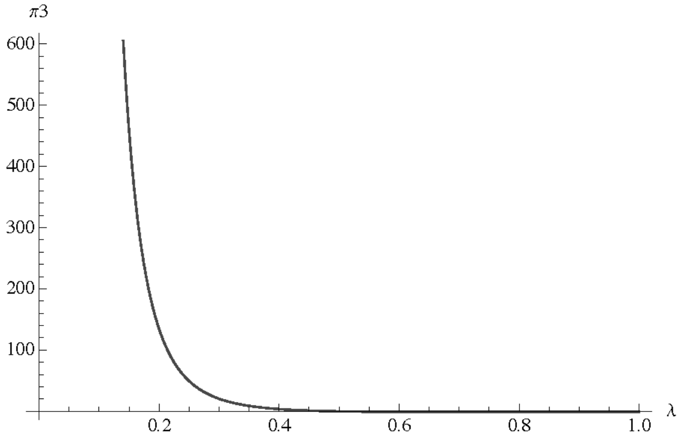

Figure 1. Innovator Profit under Exclusive Fixed-Fee Licensing

Solving for the optimal fee and subtracting the benchmark profit leaves a fixed fee of

$$F^{FE} = \frac{-1+b}{(-2+b)^2(1+b)} - \frac{\left(-2+b^2\lambda+b\lambda^3\right)^2}{\lambda^4\left(-4+b^2\lambda\right)^2\left(-1+b^2\lambda\right)}, \tag{10}$$

so profit for the innovator becomes

$$\pi_3^{FE} = F^{FE} - c_2 = \frac{-1+b}{(-2+b)^2(1+b)} - \frac{\left(-2+b^2\lambda+b\lambda^3\right)^2}{\lambda^4\left(-4+b^2\lambda\right)^2\left(-1+b^2\lambda\right)} - \frac{1}{\lambda^2} > 0, \tag{11}$$

where $c_2 = c(s_2) = 1/\lambda^2$ is the cost of innovation. This expression is only positive when $\lambda < 0.40$ (at $b = 0.50$), so the innovator makes a positive profit under exclusive fixed-fee licensing when the innovation is substantial (see figure 1) at a moderate level of substitutability. By using the fixed-fee strategy, the innovator is able to extract all the profit above benchmark profit, leaving the profit of licensee exactly equal to the benchmark profit.

PROPOSITION 2. *Under a non-exclusive fixed-fee strategy, the innovator makes a positive profit when $\lambda < 0.50$.*

Proof. Under non-exclusive licensing, both firms purchase the patent and produce high-quality products. In this case, however, the benchmark profit for both firms is the profit of the low-quality firm under exclusive licensing, which is the same as the profit under no licensing. Since the innovator licenses through a fixed fee to both, she is able to extract the extra profit of both firms and leave them with benchmark profits. The profits for both firms are written as

$$\pi_1^{FN} = \max_{p_1} p_1^{FN} q_1^{FN} - F^{FN} = p_1^{FN}\left[\frac{1}{1-b^2\lambda^2}\left(b\lambda p_2 - p_1 + \frac{1}{\lambda^2} - \frac{b}{\lambda}\right)\right] - F^{FN} \tag{12}$$

for firm 1 and

$$\pi_2^{FN} = \max_{p_2} p_2^{FN} q_2^{FN} - F^{FN} = p_2^{FN}\left[\frac{1}{1-b^2\lambda^2}\left(b\lambda p_1 - p_2 + \frac{1}{\lambda^2} - \frac{b}{\lambda}\right)\right] - F^{FN} \tag{13}$$

for firm 2. Solving both maximization problems results in a fixed fee of

$$F^{FN} = \frac{4-4\lambda^4+4b\lambda(\lambda^3-1)+3b^2(\lambda^6-1)-b^3(\lambda^7+3\lambda^6-3\lambda-1)}{(b-2)^2(b+1)\lambda^4(b\lambda-2)^2(b\lambda+1)}, \tag{14}$$

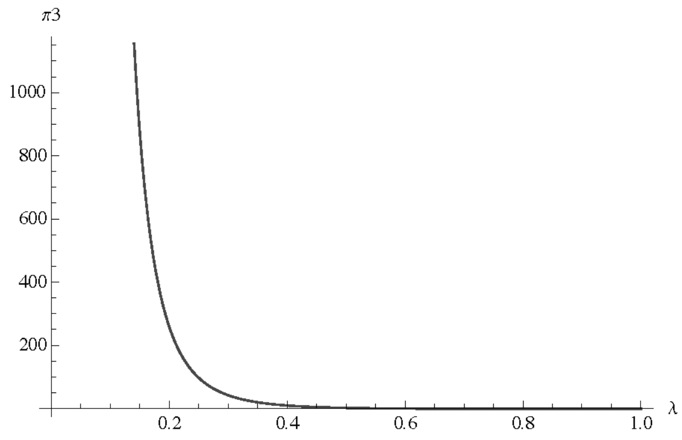

Figure 2. Innovator Profit under Non-Exclusive Fixed-Fee Licensing

so the level of profit for the innovator becomes

$$\pi_3^{FN} = 2F^{FN} - c_2$$

$$(15) \quad = -\frac{1}{\lambda^2} + \frac{2(4 - 4\lambda^4 + 4b\lambda(\lambda^3 - 1) + (3b^2 + b^4\lambda)(\lambda^6 - 1) - b^3(\lambda^7 + 3\lambda^6 - 3\lambda - 1)}{(b-2)^2(b+1)\lambda^4(b\lambda - 2)^2(b\lambda + 1)}.$$

Because innovation is costly, however, we again observe a threshold level of quality above which innovation will not make sense from the upstream firm's perspective. Again, fixing the level of $b = 0.5$ for comparison purposes, we calculate profit under a range of λ values as shown in figure 2.

Under non-exclusive fixed-fee licensing, both firms produce high-quality products. After extracting the increased profits from both firms and compensating for the cost incurred by investing in the innovation, the innovator only makes a positive profit when $\lambda < 0.5$. Since there are incentives to license the patent under both exclusive and non-exclusive licensing, a comparison of the innovator's profits under both scenarios will yield a better understanding of the optimal licensing under a fixed-fee strategy.

PROPOSITION 3. *Under a fixed-fee strategy, the patent-holding firm prefers non-exclusive licensing.*

Proof. To understand which licensing strategy is better under a fixed fee, we take the difference between profits under non-exclusive and exclusive licensing arrangements:

$$(16) \quad \pi_3^{FN} - \pi_3^{FE} = \frac{-1+b}{(b-2)^2(b+1)} + \frac{\left(b^2\lambda + b\lambda^3 - 2\right)^2}{\lambda^4\left(b^2\lambda - 4\right)^2\left(b^2\lambda - 1\right)} - \frac{2(4 - 4\lambda^4 + 4b\lambda(\lambda^3 - 1) + 3b^2(\lambda^6 - 1)}{(b-2)^2(b+1)\lambda^4(b\lambda - 2)^2(b\lambda + 1)} + \frac{b^4\lambda(\lambda^6 - 1) - b^3(\lambda^7 + 3\lambda^6 - 3\lambda - 1)}{(b-2)^2(b+1)\lambda^4(b\lambda - 2)^2(b\lambda + 1)} > 0.$$

This result indicates that non-exclusive licensing yields larger profits for the innovator. Under fixed-fee licensing the patent-holding firm is willing to license her patent to both firms instead of just one. The intuition behind this proposition is straightforward. The innovator is able to extract all of the extra profit from the innovation by charging a fixed fee to both firms, leaving the profits of the licensees exactly equal to the benchmark profit. This finding is contrary to Li and Wang (2010) who find that the patent holder is willing to sell its patent to a single firm under a fixed-fee contract. Li and Wang (2010) considered a Cournot duopoly framework in which firms compete in quantities. In their model, a non-exclusive licensing strategy was not preferred because licensing to both firms generates the same quality improvement without affecting competition. We consider instead a Bertrand duopoly framework in which firms compete in prices. When firms sell differentiated products and compete in prices, the innovation generates higher demand at a higher price level. The innovator is better off licensing her patent to both firms, thus clearing low-quality products out of the market.

Royalty Licensing

Royalties are different from fixed fees in that the innovator cannot extract all of the downstream profit through a royalty scheme but can better preserve industry profit by changing downstream firms' output. Because the innovator's profit is positively related to output, it can generate greater license revenue by incentivizing higher industry output. We first consider exclusive licensing then non-exclusive licensing.

PROPOSITION 4. *Under exclusive royalty licensing, the innovator makes a positive profit when the level of innovation is high ($\lambda \leq 0.35$).*

Proof. Under exclusive royalty licensing, the innovator sells her patent to only one firm. Without loss of generality, we assume that firm 2 purchases the patent and produces high-quality products. The royalty becomes part of the marginal cost, denoted by r. The profit function for firm 2 is revenue after accounting for the royalty payment and is written as

$$\pi_2^{RE} = \max_{p_2}(p_2^{RE} - r^{RE})q_2^{RE} = (p_2 - r^{RE})\left[\frac{1}{1-b^2\lambda}\left(b\lambda p_1 - p_2 + \frac{1}{\lambda^2} - b\lambda\right)\right]. \tag{17}$$

Firm 1 then produces low-quality products. Because this firm does not purchase the patent, its profit is irrelevant to the income earned by the innovator, but its optimal price conditions the profit earned by firm 2. Firm 1's profit derives from selling only low-quality products, so its optimal choice of price is found as the solution to

$$\pi_1^{RE} = \max_{p_1} p_1^{RE} q_1^{RE} = p_1\left[\frac{1}{1-b^2\lambda}(-p_1 + bp_2 - \frac{b}{\lambda^2} + 1)\right]. \tag{18}$$

The innovator earns a per unit royalty for every unit sold by firm 2, so by deducting the cost of innovation from the revenue earned from firm 2, we obtain the innovator's profit as

$$\pi_3^{RE} = r^{RE} q_2^{RE} - \frac{1}{\lambda^2}. \tag{19}$$

Solving for the optimal royalty rate gives

$$r^{RE} = \frac{-2 + b^2\lambda + b\lambda^3}{4\lambda^2(-2+b^2\lambda)} > 0.$$

Substituting this expression back into the profit functions yields[7]

$$\pi_3^{RE} = \frac{-4b^6\lambda^5 + b^4\lambda^2\left(28\lambda^2 - 1\right) - 2b^3\lambda^4 - b^2\lambda\left(\lambda^5 + 56\lambda^2 - 4\right) + 4b\lambda^3 + 32\lambda^2 - 4}{4\lambda^4(b^2\lambda - 4)(b^2\lambda - 2)(b^2\lambda - 1)}. \tag{20}$$

To sign this expression, we again fix $b = 0.5$ and calculate the relationship between λ and innovator profit (see figure 3). The innovator thus earns a positive profit when degree of innovation is relatively

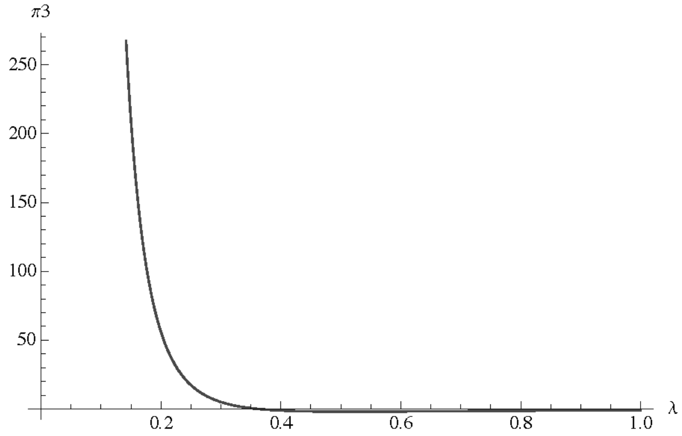

Figure 3. Innovator Profit under Exclusive Royalty Licensing

high ($0 < \lambda \leq 0.35$) and a negative profit when degree of innovation is relatively low ($0.35 < \lambda < 1$).

Our results with respect to royalty contracts are intuitive because only a significant innovation should generate positive returns to the innovator. To see this, consider that the introduction of royalties has two effects. First, the royalty becomes part of marginal cost, which increases the price of the high-quality product. Second, the royalty can influence output in the downstream market. Under exclusive licensing, the innovator's profit is closely related to the profit of the high-quality firm. The innovator wants to set a royalty that is low enough to induce higher output yet not too low as royalties are earned on a per unit basis. When the innovation is sufficiently large ($0 < \lambda \leq 0.35$), the innovator benefits due to higher output, but when the innovation is relatively small ($0.35 < \lambda < 1$), the innovator earns less because the loss of demand dominates the higher profit incurred by greater differentiation.

PROPOSITION 5. *Under non-exclusive royalty licensing, the innovator makes a positive profit when the level of innovation is high ($\lambda < 0.50$).*

Proof. Under non-exclusive licensing, the innovator sells the patent to both firms and controls the entire output through royalty licensing. The profit functions are given by

(21) $$\pi_2^{RN} = (p_2^{RN} - r^{RN})q_2^{RN} = (p_2 - r)\left[\frac{1}{1-b^2\lambda^2}\left(b\lambda p_1 - p_2 + \frac{1}{\lambda^2} - \frac{b}{\lambda}\right)\right],$$

for firm 2 and

(22) $$\pi_1^{RN} = (p_1^{RN} - r^{RN})q_1^{RN} = (p_1 - r)\left[\frac{1}{1-b^2\lambda^2}\left(b\lambda p_2 - p_1 + \frac{1}{\lambda^2} - \frac{b}{\lambda}\right)\right]$$

for firm 1. Profit to the innovator is given by

$$\pi_3^{RN} = r^{RN}(q_1^{RN} + q_2^{RN}) - \frac{1}{\lambda^2}.$$

Again, solving for the optimal royalty gives

(23) $$r^{RN} = \frac{1}{2\lambda^2} > 0.$$

[7] Detailed derivations are provided in Appendix A.

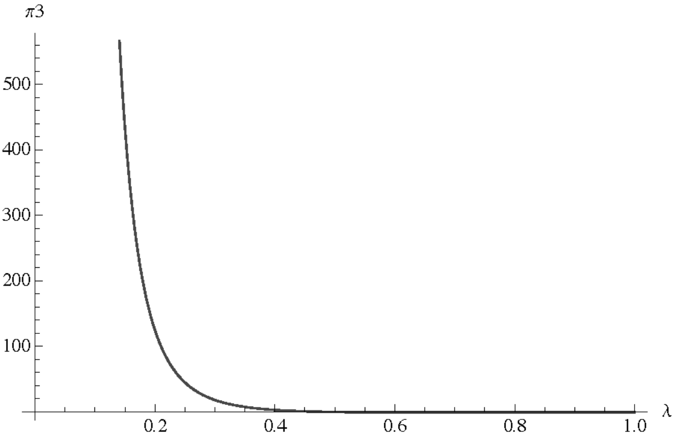

Figure 4. Innovator Profit under Non-Exclusive Royalty Licensing

Substituting the result back into the innovator's profit function and solving leaves

$$\pi_3^{RN} = \frac{1 - 4\lambda^2 - 2b\lambda^3 + 2b^2\lambda^4}{4\lambda^4 + 2b\lambda^5 - 2b^2\lambda^6}. \quad (24)$$

Signing this expression is again difficult analytically, so we calculate innovator profit at $b = 0.5$ and show how profit varies with λ (see figure 4). Figure 4 shows that the innovator has an incentive to license when $\lambda < 0.50$. Even though both firms produce the high-quality product and face similar demand functions, their profit differs from the benchmark profit (unlike in the case of non-exclusive fixed-fee licensing) because the royalty alters the structure of demand as it increases marginal cost. The overall profit from the high-quality market under non-exclusive licensing depends not only on inherent product differentiation (b) but also on the differentiation brought by innovation (λ). When the magnitude of the innovation is larger, the innovator's profit rises, and when the magnitude of innovation is smaller, the innovator's profit falls. In the next proposition, we compare the profits earned under both strategies to get a better understanding of how royalty alters the innovator's profit.

PROPOSITION 6. *Under a royalty contract, the patent holder favors non-exclusive licensing.*

Proof. The difference in profits between exclusive licensing and non-exclusive licensing is[8]

$$\pi_3^{RN} - \pi_3^{RE} > 0 \quad (25)$$

which is greater than 0. This result indicates that non-exclusive royalty licensing yields greater profit for the innovator relative to exclusive licensing. Compared with the situation of licensing to one firm, licensing to both firms generates higher aggregate output, which leads to higher licensing profit. As a consequence, the patent holder is willing to transfer its technology to both. This finding differs qualitatively from the outcome expected by Li and Wang (2010) under quantity competition, as they favor exclusive licensing. In their case, quality enhancement creates asymmetric demands between the two firms, softening market competition and generating higher incremental profit for the high-quality firm. With royalty licensing, the innovator's profit is directly related to that earned by the high-quality firm. Price competition, on the other hand, favors increasing output from both firms.

Two-Part Tariff Licensing

When comparing a fixed fee with a royalty, we see that with a fixed fee the innovator is able to extract a lump sum of profit above the benchmark profit without changing the nature of competition

[8] Detailed derivations are provided in Appendix A.

between the firms. By licensing to both firms with a fixed fee, the innovator can set the licensees' profits back to the benchmark level and they will still have an incentive to purchase the license. With a royalty, however, the structure of competition is changed because higher royalties raise marginal cost. Therefore, even when the innovator licenses to both firms, their profits differ from the benchmark level. In the following section, we show how a combination of both fixed fees and royalties affect the innovator's profit.

Licensing by a two-part tariff is more complicated because the patent holder must trade off two effects: On one hand, the patent holder has an incentive to lower the royalty in order to moderate competition between the downstream firms and preserve industry profit, then extract it with fixed fees. On the other hand, the patent holder has an incentive to keep the royalty higher in order to extract as much profit as possible from the licensees. The more profound the innovation, the lower the net profit of the licensee and the better off the licensor.

PROPOSITION 7. *Under exclusive two-part tariff licensing, firm 1 makes more profit than the benchmark level, while firm 2 makes less profit than the benchmark, so licensing will not occur.*

Proof. By using a two-part tariff, the innovator sets a royalty to control output in the final market and a fixed fee to extract any excess profits. Under exclusive licensing, we assume the innovator sells her patent to only firm 2, therefore firm 2 produces high-quality products and firm 1 produces low-quality products. Recall from the nature of the game that the innovator's optimal decision is conditional on the solution to the subgame played among the downstream firms. Profitable licensing depends on the willingness of at least one firm to purchase the license. To see why neither will, consider the profit earned by firm 2[9]

$$\pi_2^{TE} = (p_2^{TE} - r^{TE})q_2^{TE} - F^{TE} < \pi^{NL}, \tag{26}$$

and

$$\pi_1^{TE} = p_1^{TE} q_1^{TE} = -\frac{(b^2\lambda^4 + b^3\lambda - 6b^2\lambda^3 - 2b + 6\lambda^2)^2}{4\lambda^4(b^2\lambda - 6)^2(b^2\lambda - 2)^2(b^2\lambda - 1)} > \pi^{NL} \tag{27}$$

for firm 1. Solving for the optimal royalty gives a value of

$$r^{TE} = -\frac{b^2\lambda + b\lambda^3 - 2}{\lambda^2(b^2\lambda - 6)(b^2\lambda - 2)} > 0 \tag{28}$$

Combining royalty and fee, the maximum innovator profit becomes[10]

$$\pi_3^{TE} = r_2^{TE} q_2^{TE} + F^{TE}, \tag{29}$$

which we find to be positive when $\lambda < 0.4$ for a fixed value of $b = 0.5$ (see figure 5). Even though the innovator makes a positive profit when $\lambda < 0.4$, the profit will not be realized because firm 2 makes less profit than the benchmark and, therefore, will not purchase the patent.

PROPOSITION 8. *Under non-exclusive two-part tariff licensing, both firm 1 and firm 2 make less profit than the benchmark level, so licensing will not occur.*

Proof. Under non-exclusive licensing, the innovator sells the patent to both firms. Both firms produce high-quality products and low-quality products are cleared out of the market. The licensing firms benefit from producing high-quality products, but are required to pay a per unit royalty and an up-front fixed fee. The profit functions for the two firms are now written as

$$\pi_j^{TN} = (p_j^{TN} - r^{TN})q_j^{TN} - F^{TN} \tag{30}$$

[9] Detailed calculations are in Appendix B.
[10] Detailed calculations are in Appendix B.

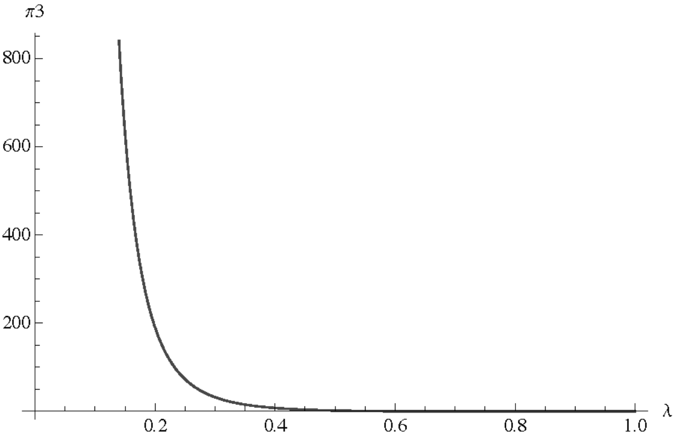

Figure 5. Innovator Profit under Exclusive Two-Part Tariff Licensing

for firm $j = 1, 2$. The fixed fee is set to equal the difference between new profit and the benchmark profit. Since both firms buy licenses and the returns are symmetrical, the fixed fee is the same for both firms:

$$F^{TN} = \pi_2^{TN} - \pi^{NL}. \tag{31}$$

Solving for the optimal royalty gives

$$r^{TN} = \frac{1}{6\lambda^2 - 2b\lambda^3} > 0. \tag{32}$$

Substituting the optimal royalty and fee expressions back into the symmetric profit functions, we find[11]

$$\pi_1^{TN} = \pi_2^{TN} < \pi^{NL}, \tag{33}$$

so neither firm is willing to purchase a license.

Hypothetically, the innovator thus earns equal up-front fixed fees from both firms and per unit royalty payments for every unit produced. Profit for the innovator is given by the solution to [12]

$$\pi_3^{TN} = 2F^{TN} + r^{TN}(q_1^{TN} + q_2^{TN}) - \frac{1}{\lambda^2}, \tag{34}$$

which would be positive if the downstream firms choose to purchase the patent in the second stage of the game. As in the case of non-exclusive royalty licensing, both firms produce high-quality products and face the same demand. Their profits differ from the benchmark level because the royalty alters the structure of demand. Total profit in the high-quality market under non-exclusive licensing depends not only on the fact that the products are differentiated from each other (b) but also the vertical differentiation due to the innovation (λ) (see figure 6). When λ is smaller (larger innovation), innovator profit is higher because the margins earned downstream by the purchasing firms are larger.

Comparing innovator profit between exclusive and non-exclusive contracting with a two-part tariff is therefore meaningless because licensing will not occur in either case.

[11] Detailed calculations are in Appendix B.
[12] Detailed calculations are provided in Appendix A.

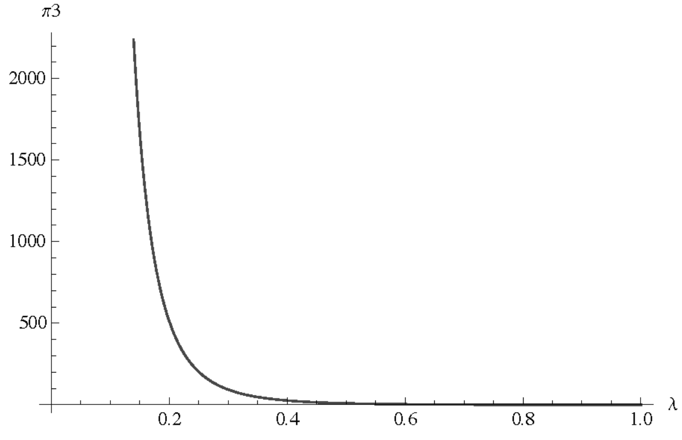

Figure 6. Innovator Profit under Non-Exclusive Two-Part Tariff Licensing

Discussion

Downstream firms that license patents to new products have an incentive to purchase a license as long as the new profit brought by the innovation exceeds the benchmark profit, or the profit implied by the equilibrium to the second-stage of the game played downstream. After choosing whether to use a royalty, fee, or a combination of the two, the innovator faces the option of either selling to one firm or to both firms. Whether one or two firms purchase the license changes the fundamental structure of the market because under non-exclusive licensing both firms produce high-quality products and the low-quality products will be forced from the market. Because the innovator's decision is driven by the willingness-to-pay of the downstream firms, her decision depends upon how much downstream profit the licensing scheme can create. With the model developed above, we showed that non-exclusive licensing is preferred under price competition in almost all cases, particularly when the degree of innovation is substantial. Licensing through a royalty scheme tends to increase competition between firms by creating asymmetrical returns for high- and low-quality firms, whereas licensing through a fixed fee tends to moderate competition and creates a market with only high-quality products. We find that two-part tariffs are never optimal because it is impossible for the innovator to facilitate a downstream equilibrium in which either firm benefits. In general, which of the two effects—generating market volume or relaxing downstream competition—dominates depends on the specific parameterization of demand and the extent of the innovation.

For each strategy, the innovator's profit depends on the degree of innovation (λ). Because TTO administrators are tasked with licensing innovations that are sent to them by their faculty/inventors, the extent of innovation is assumed to be exogenous to the licensing system.[13] Allowing net license revenue to vary with the degree of innovation sheds some light on how potential licensing revenue changes if the extent of innovation they are tasked with marketing varies. By calculating innovator profit over a range of λ values, we find two critical values for λ. There are two effects involved: First, lower values of λ imply more vertical differentiation and higher profits for the high-quality good. This is the "quality-improvement" effect. Second, lower values of λ also imply greater asymmetry in returns and a lower volume-enhancing effect. When the degree of innovation is relatively small ($0.25 < \lambda < 1$), the quality-improvement effect is dominated by the volume-increasing effect, and the innovator does not make as much profit. When the innovation is relatively large ($0.15 < \lambda < 0.25$), higher quality begins to dominate the volume effect, and the outcome for the innovator improves. When the innovation is very large ($0 < \lambda < 0.15$) the innovator is almost certain to make a large profit. Therefore, when developing and licensing a new technology, university

[13] However, Lach and Schankerman (2008) point out that the innovation process is not exogenous to the larger issue of how royalties and fees are divided among stakeholders within the university. We are not concerned with this more detailed problem.

Table 1. Comparison of Innovator Profits and the Extent of Innovation

		Fixed Fee	Royalty	Two-Part
$b = 0.50, \lambda = 0.50$	Exclusive	−0.14	−1.93	N.A.
	Non-Exclusive	1.97	−0.34	N.A.
$b = 0.50, \lambda = 0.25$	Exclusive	49	17	N.A.
	Non-Exclusive	97	45	N.A.
$b = 0.50, \lambda = 0.15$	Exclusive	458	209	N.A.
	Non-Exclusive	873	433	N.A.
$b = 0.50, \lambda = 0.05$	Exclusive	39,850	19,788	N.A.
	Non-Exclusive	77,636	39,118	N.A.

Notes: N.A. indicates that licensing will not occur as doing so is in neither downstream firm's interest.

TTO administrators should be aware of the existence of this "threshold effect" when determining an optimal licensing strategy. More specifically, we show that for our specific parameterization, there are two such thresholds: The first, at $\lambda = 0.25$, guarantees a positive profit, and the second, at $\lambda = 0.15$, offers the promise an even larger profit. The exact values of these thresholds will clearly depend on the nature of the product and the existing competitive structure, but we provide at least theoretical evidence that they are likely to exist.

In order to demonstrate which of the two effects shown above dominates over a reasonable parameterization of the model, we provide a numerical simulation of the net license revenue attainable by the innovator under a range of possible λ values. In table 1 below, we illustrate the relationship between innovator profit and the magnitude of the innovation under each strategy. To keep our simulation as "clean" an experiment as possible, we fix b at a moderate level of $b = 0.50$ and consider the following levels of λ: $\lambda = 0.50$, $\lambda = 0.25$, $\lambda = 0.15$, and $\lambda = 0.05$. The results in table 1 show that, under each licensing strategy, the patent holder's profit increases as the extent of innovation becomes larger. When innovation is sufficiently large ($\lambda = 0.15$, $\lambda = 0.05$), profit is substantially higher than when the innovation is relatively small ($\lambda = 0.25$, $\lambda = 0.50$). Overall, however, this experiment shows that the preferred strategy is a non-exclusive fixed fee. The potential profit under this preferred strategy is followed closely by a non-exclusive royalty. At least for the range of parameters that are reasonable for our problem, therefore, it appears as though the competitive exclusion of low-quality products is a desirable outcome from the perspective of the innovator.

The extent of innovation is clearly important to the potential for innovator profits. However, we also maintain throughout that horizontal differentiation is also likely to influence the amount of revenue innovators can earn from licenses. We examine the horizontal differentiation effect by allowing the b parameter to vary and calculate a range of innovator profits over a range of λ values. These results are shown in table 2. When selling an exclusive license, we find that the more innovator profits rise the more substitutable are the products downstream. This is because firm 2 is able to draw consumers more easily from the low-quality market and the innovator benefits accordingly, both when royalties and fixed fees are used. On the other hand, innovator profit falls in the degree of substitutability when licenses are sold on a non-exclusive basis. When products from the two firms are not substitutable, we have the usual horizontal differentiation effect: Each enjoys a measure of local monopoly power and earns higher margins as a result. Because both purchase a license, the innovator is able to extract more profit from them, whether through a fixed fee, or through a royalty scheme.

In general, our results also reconcile nicely with the empirical evidence, as the optimal result tends to favor non-exclusive contracts, with fixed fees likely to be more common. In the next section, we review this evidence in the specific case of horticultural innovations.

Table 2. Comparison of Profits and Horizontal Differentiation

		Fixed Fee	Royalty	Two-Part
$b = 0.90, \lambda = 0.10$	Exclusive	2,506	1,230	N.A.
	Non-Exclusive	4,477	2,301	N.A.
$b = 0.60, \lambda = 0.10$	Exclusive	2,444	1,104	N.A.
	Non-Exclusive	4,612	2,331	N.A.
$b = 0.30, \lambda = 0.10$	Exclusive	2,410	1,158	N.A.
	Non-Exclusive	4,752	2,364	N.A.
$b = 0.10, \lambda = 0.10$	Exclusive	2,400	1,150	N.A.
	Non-Exclusive	4,850	2,387	N.A.

Notes: N.A. indicates that licensing will notoccur as doing so is in neither downstream firm's interest.

Empirical Evidence

Existing databases of university patenting activity, such as the Association of University Technology Managers (AUTM) data used by Bulut and Moschini (2009), do not contain enough detail to formally test our model. However, there is anecdotal evidence that the contracts we find to be optimal are the most common for horticultural products. In the case of Cornell University, Cahoon (2007) explains that "all domestic licenses for Cornell fruit varieties have been non-exclusive" (p. 1015)and that common payment schemes "include fixed-fee payments based on some type of added-value calculation" (p. 1012), so our findings describe contracts that are typically observed. Because of the evident heterogeneity even within horticultural crops, however, it is apparent that technology managers do not follow a single pricing model that is generally regarded as optimal. Perhaps parameterizing a model similar to ours in a way that is specific to individual products would help resolve some of the uncertainty around pricing horticultural innovations.

The implications of our findings extend beyond the example considered here. For any consumer product for which differentiation is important, downstream firms will compete in price and not quantity. Consequently, the optimal scheme that we find here—licensing via a non-exclusive fixed fee—may indeed be the best strategy for other products. Second, we find that the value of the fee and/or royalty is critically dependent on the magnitude of the innovation, and it depends on the extent of innovation in a highly non-linear way. The implication of this finding is that researchers should be incentivized to "swing for the fences" in developing new products, as small innovations may not cover the often considerable costs of investment. If this is indeed the case, then future research in this area should integrate a structural model like ours with a model of uncertainty similar to Bousquet et al. (1998).

Conclusion

This study investigates optimal licensing strategies for product-based agricultural innovations, specifically new horticultural products with improved eating, nutritional, or health attributes. Although most of the prior research on optimal licensing strategies for new technologies focuses on cost-reducing innovations, most innovations in the horticultural industry are quality-improving instead of cost-reducing. In an environment of limited research dollars for product-based horticultural innovations, it is critically important that universities develop research funding mechanisms that make best use of their rights to market innovations under the auspices of the Bayh-Dole Act. Without an efficient pricing system for patents on new horticultural products, universities risk discouraging new research and pushing researchers into more lucrative areas of inquiry. Technology transfer offices fail both their own institutions and the industries they serve if they do not have an accurate understanding of how licenses to new innovations should be priced. We develop a framework for the optimal pricing of licenses for horticultural innovations that reflects the reality of the horticultural industry and provides guidelines for pricing university-based horticultural patents.

We assume price competition between two downstream firms, in which price rivalry comes from differentiation generated by new products. We consider strategies of licensing by a fixed fee, royalty licensing, and a two-part tariff that consists of a combination of royalty and fee licensing. Under each strategy we study the option of licensing to one firm (exclusive) and licensing to both firms (non-exclusive). We model the innovator's revenue as conditional on the outcome of a game played between downstream firms, so that if the licensing decision does not generate more profit for each firm in the output market, licenses will not be purchased.

We find that non-exclusive licensing is preferred under both a fixed fee and a royalty and that a two-part tariff will never be used because it does not improve the downstream firms' profit over their non-licensing benchmark. Under a royalty strategy, the innovator's profit is linked to the output of the licensing firms. By licensing to only one firm, the innovator sharpens competition and increases the market power of the high-quality firm. Under a fixed-fee strategy, the innovator does not control the final market, so she prefers to license to both firms and collect as much additional profit as possible from the downstream firms. In other words, a fixed-fee strategy helps to soften competition between the two downstream firms, while a royalty strategy sharpens the intensity of competition between them. Overall, we find that dampening competition through a fixed-fee strategy but licensing to both firms is the preferred strategy.

We also find that the innovator's license revenue depends on the magnitude of the innovation and the degree of substitutability between the products. Generally speaking, the more drastic the innovation, the greater the license revenue to the innovator. Moreover, we find that there are likely to be "innovation thresholds" beyond which potential license revenue is likely to be significantly greater than if the innovation were less drastic. License revenue in the preferred, non-exclusive arrangement also rises the less substitutable the firms' products in the consumer market. The implication of this finding is that there is a greater reward to the innovator's institution if the innovation is large and firms can still differentiate downstream, so research offices should foster an environment of risk taking if they want to maximize returns from their portfolio of research.

Our research has some limitations. In our model we consider two downstream firms with an outside innovator, which may not always be the case in the horticultural industry. Future research should extend our framework to study the optimal licensing strategies when the innovator is an incumbent and when there are more than two players in the downstream market.

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Appendix A

In this appendix, we derive the expressions for the inverse demand functions, first- and second-order derivatives for the innovator's profit function, optimal royalties, innovator profits under exclusive royalty, and two-part tariff-licensing schemes.

1. To get the inverse demand function for firm i, we take derivative of the utility function with respect to q_i.

(A1) $$p_1 = \frac{dU(q_1,q_2)}{dq_1} = c(s_1) - q_1 - \frac{b}{s_1}q_2$$

for inverse demand of firm 1.

(A2) $$p_2 = \frac{dU(q_1,q_2)}{dq_2} = c(s_2) - q_2 - \frac{b}{s_2}q_1$$

for inverse demand of firm 2.

If both firms produce at low quality level, the demand functions are

(A3) $$p_1 = 1 - q_1 - bq_2$$

(A4) $$p_2 = 1 - q_2 - bq_1$$

Solving the above we get

(A5) $$q_1 = \frac{1}{1-b^2}(1 - b + bp_2 - p_1)$$

(A6) $$q_2 = \frac{1}{1-b^2}(1 - b + bp_1 - p_2)$$

If firm 1 produces at low quality level and firm 2 produces at high quality level, then the demand functions are

(A7) $$p_1 = 1 - q_1 - bq_2$$

(A8) $$p_2 = \frac{1}{\lambda^2} - q_2 - b\lambda q_1$$

Solving the above we get

(A9) $$q_1 = \frac{1}{1-b^2\lambda}(1 - \frac{b}{\lambda^2} + bp_2 - p_1)$$

(A10) $$q_2 = \frac{1}{1-b^2\lambda}(\frac{1}{\lambda^2} - b\lambda + bp_1 - p_2)$$

If both firms produce at high quality level, then the demand functions are

(A11) $$p_1 = \frac{1}{\lambda^2} - q_1 - b\lambda q_2$$

(A12) $$p_2 = \frac{1}{\lambda^2} - q_2 - b\lambda q_1$$

Solving the above we get

(A13) $$q_1 = \frac{1}{1-b^2\lambda^2}(\frac{1}{\lambda^2} - \frac{b}{\lambda} + b\lambda p_2 - p_1)$$

(A14) $$q_2 = \frac{1}{1-b^2\lambda^2}(\frac{1}{\lambda^2} - \frac{b}{\lambda} + b\lambda p_1 - p_2)$$

2. To get the expression of the optimal prices for firm 1 and 2, we take derivative of the prices with respect to each profit function and set them to 0.

$$\frac{\partial \pi_2^{RE}}{\partial p_2} = \frac{1 - 2p_2\lambda^2 + r\lambda^2 - b\lambda^3 + bp_1\lambda^3}{\lambda^2 - b^2\lambda^3} = 0 \tag{A15}$$

$$\frac{\partial \pi_1^{RE}}{\partial p_1} = \frac{b + (-1 + 2p_1)\lambda^2 - bp_2\lambda^2}{\lambda^2(-1 + b^2\lambda)} = 0 \tag{A16}$$

Solving the above functions together, optimal price for firm 2 can be expressed as a function of b, r, and λ.

$$p_2 = -\frac{2 - b^2\lambda + 2r\lambda^2 - b\lambda^3}{\lambda^2(-4 + b^2\lambda)} \tag{A17}$$

Substitute the above expression of p_2 into the demand function to get q_2, then we get the expression of the innovator's profit as a function of b, r, and λ.

$$\pi_3^{RE} = rq_2 - c_3 = \frac{-4 + 5b^2\lambda - b^4\lambda^2 + r^2\lambda^2\left(-2 + b^2\lambda\right) - r\left(-2 + b^2\lambda + b\lambda^3\right)}{\lambda^2(4 - 5b^2\lambda + b^4\lambda^2)} \tag{A18}$$

Solving for the first-order condition of the above function with respect to r and set it to 0,

$$\frac{\partial \pi_3^{RE}}{\partial r} = \frac{2 - 4r\lambda^2 - b\lambda^3 + b^2\lambda\left(-1 + 2r\lambda^2\right)}{\lambda^2(4 - 5b^2\lambda + b^4\lambda^2)} = 0 \tag{A19}$$

we get the optimal r:

$$r^{RE} = \frac{-2 + b^2\lambda + b\lambda^3}{2\lambda^2(-2 + b^2\lambda)} \tag{A20}$$

Substitute the expression for r back to the profit function: π_3^{RE} to get the profit as a function of sole b and λ.

(A21)

$$\pi_3^{RE} = \frac{-4b^6\lambda^5 + b^4\lambda^2\left(28\lambda^2 - 1\right) - 2b^3\lambda^4 - b^2\lambda\left(\lambda^5 + 56\lambda^2 - 4\right) + 4b\lambda^3 + 32\lambda^2 - 4}{4\lambda^4(b^2\lambda - 4)(b^2\lambda - 2)(b^2\lambda - 1)}$$

3.

$$\pi_3^{RN} - \pi_3^{RE} = \frac{1 - 4\lambda^2 - 2b\lambda^3 + 2b^2\lambda^4}{4\lambda^4 + 2b\lambda^5 - 2b^2\lambda^6} - \frac{-4b^6\lambda^5 + b^4\lambda^2\left(28\lambda^2 - 1\right) - 2b^3\lambda^4 - b^2\lambda\left(\lambda^5 + 56\lambda^2 - 4\right) + 4b\lambda^3 + 32\lambda^2 - 4}{4\lambda^4(b^2\lambda - 4)(b^2\lambda - 2)(b^2\lambda - 1)} \tag{A22}$$

4. After solving for the optimal fee and royalty, the innovator's profit under exclusive two-part tariff and non-exclusive two-part tariff licensing, both as a function of b and λ, are given by

(A23)

$$\pi_3^{TE} = F^{TE} + r^{TE}q_2^{TE} - \frac{1}{\lambda^2} = \frac{-b^9\lambda^5+3b^8\lambda^5+b^7\lambda^2(\lambda^5+9\lambda^2-1)}{(b-2)^2(b+1)\lambda^4(b^2\lambda-6)(b^2\lambda-2)(b^2\lambda-1)} + \frac{-b^6\lambda^2(\lambda^5+4\lambda^3+29\lambda^2-3)+b^5(-10\lambda^6+6\lambda^4-20\lambda^3+4\lambda)}{(b-2)^2(b+1)\lambda^4(b^2\lambda-6)(b^2\lambda-2)(b^2\lambda-1)} + \frac{4b^4\lambda(3\lambda^5+9\lambda^3+16\lambda^2-\lambda-3)+4b^3(5\lambda^5-2\lambda^4-3\lambda^3+3\lambda^2-1)}{(b-2)^2(b+1)\lambda^4(b^2\lambda-6)(b^2\lambda-2)(b^2\lambda-1)} \frac{-4b^2(\lambda^6+5\lambda^5+20\lambda^3+9\lambda^2-4\lambda-3)-4b\lambda^3(3\lambda-4)+4(3\lambda^4+12\lambda^2-4)}{(b-2)^2(b+1)\lambda^4(b^2\lambda-6)(b^2\lambda-2)(b^2\lambda-1)}$$

for profit under exclusive two-part tariff licensing.

(A24)

$$\pi_3^{TN} = 2F^{TN} + r^{TN}(q_1^{TN} + q_2^{TN}) - \frac{1}{\lambda^2} = \begin{aligned}
&\frac{-b^{13}\lambda^8+b^{12}\lambda^7(3\lambda+2)+b^{11}\lambda^4(2\lambda^6+9\lambda^3+3\lambda^2-2)}{(b-2)^2(b+1)\lambda^4(b\lambda-3)(b\lambda+1)(b^2\lambda-6)^2(b^2\lambda-2)(b^2\lambda-1)}+\\
&\frac{-b^{10}\lambda^4(2\lambda^6+4\lambda^5+4\lambda^4+45\lambda^3+39\lambda^2-6)}{2(b-2)^2(b+1)\lambda^4(b\lambda-3)(b\lambda+1)(b^2\lambda-6)^2(b^2\lambda-2)(b^2\lambda-1)}+\\
&\frac{b^9\lambda^3(-26\lambda^6-6\lambda^5+8\lambda^4+16\lambda^3-45\lambda^2+4\lambda+30)}{(b-2)^2(b+1)\lambda^4(b\lambda-3)(b\lambda+1)(b^2\lambda-6)^2(b^2\lambda-2)(b^2\lambda-1)}+\\
&\frac{b^8\lambda^3(30\lambda^6+66\lambda^5+60\lambda^4+242\lambda^3+283\lambda^2-20\lambda-98)}{(b-2)^2(b+1)\lambda^4(b\lambda-3)(b\lambda+1)(b^2\lambda-6)^2(b^2\lambda-2)(b^2\lambda-1)}+\\
&\frac{2b^7\lambda^2(46\lambda^6+45\lambda^5-72\lambda^4-164\lambda^3+111\lambda^2+4\lambda-80)}{(b-2)^2(b+1)\lambda^4(b\lambda-3)(b\lambda+1)(b^2\lambda-6)^2(b^2\lambda-2)(b^2\lambda-1)}+\\
&\frac{-2b^6\lambda^2(80\lambda^6+197\lambda^5+148\lambda^4+272\lambda^3+469\lambda^2-84\lambda-256)}{(b-2)^2(b+1)\lambda^4(b\lambda-3)(b\lambda+1)(b^2\lambda-6)^2(b^2\lambda-2)(b^2\lambda-1)}+\\
&\frac{4b^5\lambda(14\lambda^6-106\lambda^5+160\lambda^4+206\lambda^3-107\lambda^2-20\lambda+78)}{(b-2)^2(b+1)\lambda^4(b\lambda-3)(b\lambda+1)(b^2\lambda-6)^2(b^2\lambda-2)(b^2\lambda-1)}+\\
&\frac{4b^4\lambda(4\lambda^7+66\lambda^6+252\lambda^5+116\lambda^4+252\lambda^3+329\lambda^2-172\lambda-242)}{(b-2)^2(b+1)\lambda^4(b\lambda-3)(b\lambda+1)(b^2\lambda-6)^2(b^2\lambda-2)(b^2\lambda-1)}+\\
&\frac{-4b^3(4\lambda^7+48\lambda^6-91\lambda^5+540\lambda^4+234\lambda^3-124\lambda^2-12\lambda+24)}{(b-2)^2(b+1)\lambda^4(b\lambda-3)(b\lambda+1)(b^2\lambda-6)^2(b^2\lambda-2)(b^2\lambda-1)}+\\
&\frac{-8b^2(24\lambda^6+135\lambda^5+20\lambda^4+198\lambda^3+73\lambda^2-156\lambda-72)}{(b-2)^2(b+1)\lambda^4(b\lambda-3)(b\lambda+1)(b^2\lambda-6)^2(b^2\lambda-2)(b^2\lambda-1)}+\\
&\frac{16b\lambda(18\lambda^4-27\lambda^3+48\lambda^2-8)+48(9\lambda^4+18\lambda^2-16)}{(b-2)^2(b+1)\lambda^4(b\lambda-3)(b\lambda+1)(b^2\lambda-6)^2(b^2\lambda-2)(b^2\lambda-1)}
\end{aligned}$$

for profit under non-exclusive two-part tariff licensing.

Appendix B

In this appendix, we derive expressions for downstream profits under exclusive and non-exclusive two-part tariff licensing. In each case, we show that the resulting maximum profit is less than that available in the benchmark, Nash subgame equilibrium in the second stage of the licensing game, so licensing will not occur. Maximizing innovator profit with respect to the royalty and the fixed fee and substituting the resulting expressions back into the downstream profit functions leads to equilibrium profits for each firm. In the exclusive licensing case, the profit for firm 2 is found from the equilibrium at the second-stage game to be:

$$\text{(B1)} \qquad \pi_2^{TE} = (p_2^{TE} - r^{TE})q_2^{TE} - F^{TE} = \begin{array}{l} \frac{b^9(-\lambda^8)+b^8\lambda^8+b^7\lambda^2(15\lambda^5-2)+b^6(-15\lambda^7-4\lambda^4+6\lambda^2)}{4(b-2)^2(b+1)\lambda^4(b^2\lambda-6)^2(b^2\lambda-2)(b^2\lambda-1)} + \\ \frac{b^5(-76\lambda^6+12\lambda^4+8\lambda)+8b^4\lambda(10\lambda^5+\lambda^2-\lambda-3)}{4(b-2)^2(b+1)\lambda^4(b^2\lambda-6)^2(b^2\lambda-2)(b^2\lambda-1)} + \\ \frac{4b^3(33\lambda^5-4\lambda^4-6\lambda^3-2)-4b^2(2\lambda^6+33\lambda^5-8\lambda-6)}{4(b-2)^2(b+1)\lambda^4(b^2\lambda-6)^2(b^2\lambda-2)(b^2\lambda-1)} + \\ \frac{-8b\lambda^3(9\lambda-4)+8(9\lambda-4)}{4(b-2)^2(b+1)\lambda^4(b^2\lambda-6)^2(b^2\lambda-2)(b^2\lambda-1)} < \pi^{NL}, \end{array}$$

while firm 1 does not license by the definition of the exclusive contract. In the non-exclusive case, the maximum profit for both firms under two-part tariff licensing is

$$\text{(B2)} \qquad \pi_1^{TN} = \pi_2^{TN} = \begin{array}{l} \frac{(-b^{12}\lambda^{11}+24b\lambda(9\lambda^4-27\lambda^3+12\lambda^2-4))+72(9\lambda^4-8)}{4(b-2)^2(b+1)\lambda^4(b\lambda-3)^2(b\lambda+1)(b^2\lambda-6)^2(b^2\lambda-2)(b^2\lambda-1)} + \\ \frac{b^2(-432\lambda^6-1404^5+96\lambda^4+160\lambda^2+816\lambda+432)}{4(b-2)^2(b+1)\lambda^4(b\lambda-3)^2(b\lambda+1)(b^2\lambda-6)^2(b^2\lambda-2)(b^2\lambda-1)} + \\ \frac{b^6\lambda^2(-268\lambda^6-379\lambda^5-24\lambda^4-4\lambda^3+4\lambda^2+172\lambda+300)}{4(b-2)^2(b+1)\lambda^4(b\lambda-3)^2(b\lambda+1)(b^2\lambda-6)^2(b^2\lambda-2)(b^2\lambda-1)} + \\ \frac{b^{10}\lambda^4(10\lambda^6-3\lambda^5-2\lambda+3)-b^8\lambda^3(\lambda^6-54\lambda^5-12\lambda^4-20\lambda^3+26\lambda+51)}{4(b-2)^2(b+1)\lambda^4(b\lambda-3)^2(b\lambda+1)(b^2\lambda-6)^2(b^2\lambda-2)(b^2\lambda-1)} + \\ \frac{b^9\lambda^3(-15\lambda^7-72\lambda^6-9\lambda^5-4\lambda^4+6\lambda^2+10\lambda+5)+b^{11}\lambda^4(\lambda^7+5\lambda^6-1)}{4(b-2)^2(b+1)\lambda^4(b\lambda-3)^2(b\lambda+1)(b^2\lambda-6)^2(b^2\lambda-2)(b^2\lambda-1)} + \\ \frac{4b^4\lambda(10\lambda^7+147\lambda^6+287\lambda^5-12\lambda^4-18\lambda^3-22\lambda^2-122\lambda-159)}{4(b-2)^2(b+1)\lambda^4(b\lambda-3)^2(b\lambda+1)(b^2\lambda-6)^2(b^2\lambda-2)(b^2\lambda-1)} + \\ \frac{4b^3(12\lambda^7-9\lambda^6+257\lambda^5-36\lambda^4-62\lambda^3+24\lambda^2+18\lambda-36)}{4(b-2)^2(b+1)\lambda^4(b\lambda-3)^2(b\lambda+1)(b^2\lambda-6)^2(b^2\lambda-2)(b^2\lambda-1)} + \\ \frac{b^7\lambda^2(80\lambda^7+335\lambda^6+135\lambda^5-52\lambda^4-20\lambda^3-24\lambda^2-22\lambda-92)}{4(b-2)^2(b+1)\lambda^4(b\lambda-3)^2(b\lambda+1)(b^2\lambda-6)^2(b^2\lambda-2)(b^2\lambda-1)} + \\ \frac{4b^5\lambda(2\lambda^8+33\lambda^7+105\lambda^6+151\lambda^5-30\lambda^4-41\lambda^3+8\lambda-51)}{4(b-2)^2(b+1)\lambda^4(b\lambda-3)^2(b\lambda+1)(b^2\lambda-6)^2(b^2\lambda-2)(b^2\lambda-1)}, \end{array} < \pi^{NL}$$

so again licensing will not occur and the potential innovator profit remains just that, potential profit that will not be realized.