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Commercialization of a Demand-Enhancing Innovation by a Public University

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Abstract

This article is motivated by the increase in the number of patented fruit varieties developed by plant-breeding programs at U.S. land grant universities. New demand-enhancing fruit varieties are often licensed by the university innovator to its stakeholder growers as a way to generate additional revenues for plant-breeding through the use of fees and royalties. We develop a model to analyze optimal contracts for an innovator that wishes to maximize the weighted sum of its own profits and the licensees' profits, which corresponds to the land grant university case. We find that the optimal commercialization mechanism differs depending on the degree of innovation offered by the patent and by the number of firms in the industry. We test the model with data from experimental auctions conducted with Washington apple growers bidding on access to a promising new apple variety under different commercialization mechanisms. Our theoretical and empirical results suggest that an exclusive contract for a patent funded by per-unit royalties would lead to the greatest overall profits in an industry with a small number of firms.

JEL Classification: L24, O32, Q16.

Key words: Licensing; Patents; Apples; Land Grant University

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Commercialization of a Demand-Enhancing Innovation by a Public University

1. Introduction

Developing and marketing of new crop varieties are essential for the long-term profitability of U.S. farmers. Traditional varieties of most crops can be improved by either increasing product quality or from increasing yields and thereby reducing costs. Consumer expectations for quality are increasing and, at the same time, consumers expect increasingly customized or differentiated products (Yue and Tong 2011, Rickard et al. 2013). There are many examples of new specialty crop varieties that have been developed specifically to enhance eating quality for consumers. For many horticultural products, notably for apples, plant breeders have developed several new differentiated varieties that have the capacity to be marketed with premium prices and that can compete on world markets (Brown and Maloney 2009, Bareuther 2011). Once these new varieties are developed, they must be commercialized. If the innovations are not commercialized or commercialized in a sub-optimal way, then the benefits of the research are greatly reduced. In the face of declining federal and state support for research and development (R&D) at public universities (Alston et al. 2010), addressing inefficiencies in the release of the intellectual properties is of utmost importance to funding and managing universities' agricultural R&D activities.

This research is motivated by an increase in the number of patented fruit varieties released by universities, and the real world and recent controversies that exist in the licensing of publicly developed horticultural varieties in the United States. In the present study, we analyze licensing mechanisms for an innovator who wishes to maximize the weighted sum of its own profits and the licensees' profits, which corresponds to the land grant university case in which the licensees are university stakeholders who support research.[1] Given the historical relationship between U.S. land

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[1] We use the words "producer", "grower", "firm" and "licensee" interchangeably throughout the manuscript. Similarly, "university", "innovator", and "licensor" are used interchangeably also.

grant universities and agricultural producers, and the long tradition of dissemination of university research to the public, it is important to consider how the decision to use a particular type of licensing scheme will affect producers as well as university plant-breeding programs.

The traditional arguments for public funding of research are that knowledge spillovers and imperfect intellectual property rights (IPR) protection cause innovators not to realize the economic value of their discoveries, leading to private-sector underinvestment in basic research. Public land grant universities are a special case of government funding of academic research. The land grant mission of research and extension faculty is to deliver and apply research and new knowledge to positively impact communities. As such, U.S. public universities have been key players in generating new research and innovations. In particular, U.S. academic institutions conducted 56% of all basic research (Lach and Schankerman 2008) and received 34.6% of all U.S. spending on agricultural R&D (Alston et al. 2010), with the number of U.S. academic patents rising from 500 to 3,225 between 1982 and 2006, an increase rate of 8.1% per annum (Lach and Schankerman 2008). In comparison, in Europe, between 1978 and 1993 the number of academic patents increased from 950 to 1,700 in France (4% per annum), from 1,000 to 1,100 in Italy (0.6% per annum), and from 375 to 850 in Sweden (5.6% per annum) (Lissoni et al. 2008).

With dwindling government support for U.S. public agricultural R&D over the last few decades, especially for new horticultural varieties (Cahoon 2007, Alston and Pardey 2008), the need for alternative arrangements to sustain R&D activities has emerged (Huffman and Just 1999, Just and Huffman 2009). The Bayh-Dole Act of 1980 granted universities the right to patent the IPRs from university-conducted research projects that are financed with federal funds and has provided universities with additional sources of revenue (Henderson et al. 1998, Jensen and Thursby 2001, Thursby and Thursby 2003). The use of technology patents can help augment conventional research funding sources so long as they are released using appropriate licensing mechanisms.[2] However, the question that remains unclear is, given the political and funding constraints surrounding the development of horticultural varieties, what is the optimal way to commercialize publically developed innovations?

To answer this question, this article develops a theoretical model that considers the optimization problem faced by the innovator who cares about both its own profits and its licensees' profits. Although our model is oriented specifically to apples, the methods can be applicable to other contexts as well. In our formulation, each licensee decides on (i) whether to pay for the license to use the innovation that improves the quality of the product, and (ii) what quantity of output to produce using either old or new technology. Given the producer's participation and output decisions, the innovator chooses the licensing mechanism to maximize the *weighted sum* of its own profits and the licensees' profits. We consider a range of weights assigned to the innovator (and hence the producers) to provide a more complete understanding of how the licensing decision affects the joint economic outcome.

This scenario corresponds to the case of a U.S. land grant university (the innovator) and its stakeholder growers (the licensees). We carry out the above analysis for three different licensing schemes (fixed fee, per-unit royalty, and two-part tariff[3]) under two types of contracts (exclusive and nonexclusive), and compare the joint profits of the innovator and the growers across different licensing arrangements in order to identify a scheme that maximizes their joint profits. To test our theoretical predictions empirically, we also conducted experimental auctions with Washington apple growers to evaluate the potential joint benefits of the innovator and the growers under different commercialization mechanisms.

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[2] See Akhundjanov et al. (2018) for further discussion.

[3] A two-part tariff is a combination of a fixed fee and a per-unit royalty.

Our theoretical and empirical analyses indicate that the type of licensing mechanism that maximizes joint profits depends on the number of growers and the innovation level. In particular, the joint profits of the innovator and the licensee are generally the greatest under exclusive per-unit royalty scheme, followed by the exclusive two-part tariff. Theoretical analysis further suggests that this result holds specifically when the industry consists of a small number of firms. However, when the number of growers is relatively large, we find that the joint profits are the largest under nonexclusive contract, either with a two-part tariff (when the innovation level is high) or a per-unit royalty (when the innovation level is low).

There is a rich theoretical and empirical literature that considers the optimal licensing of patents for cost-reducing innovations.[4] Since such innovations primarily focus on internal incentives of the innovator, the quality of new product is assumed to be exogenous, thus abstracting from the complexities of the downstream licensees. Consequently, the provisions of the above studies cannot be directly applicable to horticultural industry, as the bulk of R&D in this area tends to aim at improving the fruit quality (i.e., demand-side innovations), which affects consumers' preferences and their willingness to purchase a product.

Our analysis on the agricultural innovation from a U.S. land grant university perspective is different from previous work that focuses solely on the innovator's profits.[5] Li and Wang (2010) analyze the profits of an innovator from a vertical product quality innovation under different licensing schemes and contracts. They find that, in the context of a duopoly model, which allows for a single and two licensees, the innovator generates greater profits from licensing its patented innovation by means of a two-part tariff compared to licenses based on fixed fees or per-unit royalties. Fang et al.

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[4] See, for instance, Shapiro (1985), Kamien and Tauman (1986), Katz and Shapiro (1986), Gallini and Wright (1990), Kamien et al. (1992), Muto (1993), Choi (2001), Fauli-Oller and Sandonis (2002), Kamien and Tauman (2002), Saracho (2002), and Sen and Taumann (2007).

[5] A related topic is patent price. Richards and Rickard (2014) apply an option-value approach to estimate patent prices. They find that accounting for path-dependence in license revenue streams generates prices that more nearly approximate observed patent prices.

(2015) offer a model of optimal licensing schemes for quality-improving horticultural innovations applied to a duopoly downstream horticultural industry with implications for pricing university-based horticultural patents.

Rickard et al. (2016) extend the model developed by Li and Wang (2010) to the n-firm case, which allows for more than two licensees, and show that the innovator's profits are greatest under per-unit royalties in a nonexclusive contract. We contribute to this line of research by analyzing licensing arrangement for an innovator who wants to maximize joint profits and multiple licensees. In particular, in our formulation, the innovator wishes to maximize the weighted sum of its own profits and those of the licensees, a scenario that corresponds to the case of a U.S. land grant university and its stakeholder growers.

Further, there is a need for more empirical studies that examine licensing mechanisms for patents covering demand-side innovations. To our knowledge, the only empirical study is by Rickard et al. (2016), who design an experiment that captures many of the important conditions facing fruit growers considering an investment in patented varieties. Similar to Rickard et al. (2016), we employ an economic experiment for our primary data. However, unlike Rickard et al. (2016), our experiment uses actual growers (i.e., Washington apple growers) as subjects. There is evidence that experiments using non-specialists as subjects provide results that have limited external validity. The adoption of new apple varieties is a complex decision that will have implications for many years and requires some specific knowledge about the idiosyncrasies related to production and marketing. Therefore, we feel that our subject pool is the appropriate one for the research question of interest.

The remainder of this article is organized as follows. First, we present the theoretical framework and derive testable hypotheses from numerical simulations. Next, we describe the experimental auction we used to collect data on growers' bidding behavior under different licensing arrangements.

We then present the results from econometric analysis of the experimental data. We conclude with discussion and implications of our findings.

2. Model of Innovator and Licensee Behavior

Consider a single, upstream innovator (the licensor) who owns a patent for a new technology, and n downstream firms (licensees) that (i) produce a homogenous product, (ii) interact in the output market as Cournot oligopolists, and (iii) must decide whether to compete for a license to the innovation that improves the quality of the product. In particular, the innovation is vertical in the sense that licensees have the opportunity to produce a product that is generally regarded as being better than the old technology. Firms have the same, constant unit production cost, which is normalized to zero (Li and Wang 2010, Rickard et al. 2016).

Consumers have a Mussa-Rosen utility structure (Mussa and Rosen 1978) given by

$$V = \begin{cases} \theta s^k - p^k, & \text{if consumers buy a good with quality } s^k \\ 0, & \text{if they do not buy} \end{cases} \tag{1}$$

where s^k denotes the level of quality of the product being considered, for $k \in [L, H]$, $\theta \in [0,1]$ is a taste-for-quality parameter which is uniformly distributed over consumers, and p^k is the market price. The level of quality of existing (low-quality, L) product s^L is set equal to 1, whilst that of the new (high-quality, H) product s^H is set equal to $1/\lambda$, where $\lambda \in (0,1)$ is the degree of vertical product innovation, with a larger value of λ indicating a smaller quality improvement. Consumers are assumed to buy only one unit of output, and the population size is normalized to 1.

We develop a three-stage, complete-information game with the following time structure. In the first stage, the benevolent innovator decides to license its innovation to either a single firm (under exclusive contract, E) or multiple firms (under non-exclusive contract, NE), by making a take-it-or-leave-it offer. The licensing contract can be either a fixed fee (F), a per-unit royalty (R), or a two-part tariff (T). In the second stage, a firm that accepts the offer decides how much to produce as a Stackelberg leader. In the third stage, firms that do not adopt a new technology decide simultaneously and independently how much to produce as Stackelberg followers. We solve the sub-game perfect equilibrium by using backward induction. We analyze the following cases in particular: 1) no licensing (benchmark case), 2) fixed fee, exclusive, 3) fixed fee, non-exclusive, 4) per-unit royalty, exclusive, 5) per-unit royalty, non-exclusive, 6) two-part tariff, exclusive, and 7) two-part tariff non-exclusive. Cases 1 to 5 follow, while cases 6 and 7 are analyzed in Appendix A. The results across cases are then compared via numerical simulations.

2.1 No Licensing

We begin our analysis by considering the case where technology licensing does not occur. In this case, consumers can only consume low-quality goods. The demand for low-quality goods is

$$Q^L = \sum_{i=1}^{n} q_i^L = 1 - \left(p^L / s^L \right) = 1 - p^L . \tag{2}$$

The standard Cournot equilibrium applies in this case, which yields firm output and profits of

$$\hat{q}_i^L = \frac{1}{n+1}, \quad \hat{\pi}_i^L = \frac{1}{\left(n+1\right)^2} . \tag{3}$$

Since the innovator does not license its innovation, his equilibrium profits will be zero, $\hat{\pi}^* = 0$.

2.2 Fixed-Fee Licensing: Exclusive Contract

If the innovator sells its patent to a single downstream firm, the firm has to pay a fixed fee, $f^{F,E}$, to improve its product quality from s^L to s^H. Solving for the θ of the marginal consumer and noting $s^L = 1$ and $s^H = 1/\lambda$, we obtain

$$\theta = \frac{p^{H,F,E} - p^{L,F,E}}{s^H - s^L} = \frac{\lambda\left(p^{H,F,E} - p^{L,F,E}\right)}{1-\lambda}. \tag{4}$$

The corresponding demand functions are then

$$q^{H,F,E} = 1 - \frac{\lambda\left(p^{H,F,E} - p^{L,F,E}\right)}{1-\lambda}, \quad Q^{L,F,E} = \frac{\lambda\left(p^{H,F,E} - p^{L,F,E}\right)}{1-\lambda} - p^{L,F,E}. \tag{5}$$

Simultaneously solving (5) for prices yields the inverse demand functions for the two types of products

$$p^{H,F,E} = \frac{1}{\lambda}\left(1 - q^{H,F,E} - \lambda Q^{L,F,E}\right), \quad p^{L,F,E} = 1 - q^{H,F,E} - Q^{L,F,E}. \tag{6}$$

In the third stage, firms that do not adopt a new technology maximize their profits given by

$$\max_{q_i^{L,F,E}} \quad \pi_i^{L,F,E} = \left(1 - q^{H,F,E} - q_i^{L,F,E} - Q_{-i}^{L,F,E}\right) q_i^{L,F,E}, \tag{7}$$

where $Q_{-i}^{L,F,E} = \sum_{j \neq i} q_j^{L,F,E}$. The first-order condition yields the reaction function $q_i^{L,F,E}\left(q^{H,F,E}\right) = \frac{1 - q^{H,F,E}}{n}$. In the second stage, the firm that adopts a new technology solves its maximization problem

$$\begin{aligned} &\max_{q^{H,F,E}} \quad \pi^{H,F,E} = \frac{1}{\lambda}\left(1 - q^{H,F,E} - \lambda Q^{L,F,E}\right) q^{H,F,E} - f^{F,E} \\ &\text{s.t.} \quad q_i^{L,F,E}\left(q^{H,F,E}\right) = \frac{1 - q^{H,F,E}}{n} \end{aligned} \tag{8}$$

which yields the Cournot equilibrium outputs and profits (assuming interior solution)

$$\begin{aligned} &\hat{q}^{H,F,E} = \frac{1}{2}, \quad \hat{q}_i^{L,F,E} = \frac{1}{2n}, \\ &\hat{\pi}^{H,F,E}\left(f^{F,E}\right) = \frac{n + \lambda - n\lambda}{4n\lambda} - f^{F,E}, \quad \hat{\pi}_i^{L,F,E} = \frac{1}{4n^2}. \end{aligned} \tag{9}$$

In the first stage, the licensor sets a fixed fee for the access to his innovation. The optimal fixed fee is determined based on the difference between the profits that the licensee obtains under the new technology, $\hat{\pi}^{H,F,E}\left(f^{F,E} = 0\right)$, and the old technology, $\hat{\pi}_i^L$ (in equation (3)):

$$\hat{f}^{F,E} = \frac{1}{m}\left(\frac{n+\lambda-n\lambda}{4n\lambda} - \frac{1}{(n+1)^2}\right), \tag{10}$$

where $1/m$, $m>0$, is the weight attached to the profit difference $\hat{\pi}^{H,F,E}\left(f^{F,E}=0\right)-\hat{\pi}_i^L$. In particular, if $m=1$, the licensor sets a fixed fee high enough to seize the entire increased profit of the licensee. In contrast, if $m=2$, the licensor and the licensee equally share the increased profit of the licensee, a scenario that closely corresponds to the mission of U.S. land grant universities. Given the equilibrium fee, the adopter firms' equilibrium profits are

$$\hat{\pi}^{H,F,E} = \left(\frac{m-1}{m}\right)\left(\frac{n+\lambda-n\lambda}{4n\lambda}\right) + \frac{1}{m(n+1)^2} \tag{11}$$

and the innovator's equilibrium profit is $\hat{\pi}^* = \hat{f}^{F,E}$.

2.3 Fixed-Fee Licensing: Non-Exclusive Contract

If the license to a patented innovation is sold to all firms in the industry, then the firms face the same market demand

$$Q^{H,F,NE} = 1-\left(p^{H,F,NE}/s^H\right), \quad p^{H,F,NE} = \frac{1}{\lambda}\left(1-Q^{H,F,NE}\right). \tag{12}$$

Consequently, firms' profit maximization problem becomes

$$\max_{q_i^{H,F,NE}} \quad \pi_i^{H,F,NE} = \frac{1}{\lambda}\left(1-q_i^{H,F,NE}-Q_{-i}^{H,F,NE}\right)q_i^{H,F,NE} - f^{F,NE}, \tag{13}$$

where $Q_{-i}^{H,F,NE} = \sum_{j\neq i} q_j^{H,F,NE}$. Solving the profit-maximization problem, we have the Cournot equilibrium outputs and profits of

$$\hat{q}_i^{H,F,NE} = \frac{1}{n+1}, \quad \hat{\pi}_i^{H,F,NE}\left(f^{H,NE}\right) = \frac{1}{\lambda(n+1)^2} - f^{F,NE}. \tag{14}$$

The optimal fixed fee $f^{F,NE}$ is again determined based on the weighted gross profit difference between the new technology, $\hat{\pi}_i^{H,F,NE}\left(f^{F,NE}=0\right)$, and the old technology, $\hat{\pi}_i^L$ (in equation 3):

$$\hat{f}^{F,NE}=\frac{1}{m}\left(\frac{1}{\lambda(n+1)^2}-\frac{1}{(n+1)^2}\right). \tag{15}$$

This implies that a firm's equilibrium profits are

$$\hat{\pi}_i^{H,F,NE}=\left(\frac{m-1}{m}\right)\left(\frac{1}{\lambda(n+1)^2}\right)+\frac{1}{m(n+1)^2} \tag{16}$$

and the innovator's equilibrium profit is $\hat{\pi}^*=n\cdot\hat{f}^{F,NE}$.

2.4 Per-unit Royalty Licensing: Exclusive Contract

In this case, the innovator licenses its patent to a single firm, and the firm pays a per-unit royalty, $r^{R,E}$ to improve its product quality from s^L to s^H. In the third stage, firms that do not adopt a new technology maximize their profits

$$\max_{q_i^{L,R,E}} \quad \pi_i^{L,R,E}=\left(1-q^{H,R,E}-q_i^{L,R,E}-Q_{-i}^{L,R,E}\right)q_i^{L,R,E}, \tag{17}$$

where $Q_{-i}^{L,R,E}=\sum_{j\neq i}q_j^{L,R,E}$. The first-order condition yields the reaction function $q_i^{L,R,E}\left(q^{H,R,E}\right)=\frac{1-q^{H,R,E}}{n}$. In the second stage, the firm that adopts a new technology solves

$$\begin{aligned}&\max_{q^{H,R,E}} \quad \pi^{H,R,E}=\left[\frac{1}{\lambda}\left(1-q^{H,R,E}-\lambda Q^{L,R,E}\right)-r^{R,E}\right]q^{H,R,E}\\ &\text{s.t.} \quad q_i^{L,R,E}\left(q^{H,R,E}\right)=\frac{1-q^{H,R,E}}{n}\end{aligned} \tag{18}$$

Solving the profit-maximization problem, we obtain the firms' Cournot equilibrium outputs and profits of

$$\begin{aligned}
&\hat{q}^{H,R,E}\left(r^{R,E}\right)=\frac{n+\lambda-n\lambda\left(1+r^{R,E}\right)}{2\left(n+\lambda-n\lambda\right)}, \quad \hat{q}_i^{L,R,E}\left(r^{R,E}\right)=\frac{n+\lambda-n\lambda\left(1-r^{R,E}\right)}{2n\left(n+\lambda-n\lambda\right)},\\
&\hat{\pi}^{H,R,E}\left(r^{R,E}\right)=\frac{\left[n+\lambda-n\lambda\left(1+r^{R,E}\right)\right]^2}{4n\lambda\left(n+\lambda-n\lambda\right)}, \quad \hat{\pi}_i^{L,R,E}\left(r^{R,E}\right)=\frac{\left[n+\lambda-n\lambda\left(1-r^{R,E}\right)\right]^2}{4n^2\left(n+\lambda-n\lambda\right)^2}.
\end{aligned} \tag{19}$$

In the first stage, the benevolent innovator chooses $r^{R,E}$ to maximize joint profits of the licensor and the licensee

$$\max_{r^{R,E}} \quad \alpha\pi^* + \left(1-\alpha\right)\hat{\pi}^{H,R,E}\left(r^{R,E}\right), \tag{20}$$

where $\pi^* = r^{R,E}\cdot\hat{q}^{H,R,E}\left(r^{R,E}\right)$ and $\alpha\in\left(0,1\right)$ is the weighting parameter similar to $1/m$ discussed in the previous section. The first-order condition yields the equilibrium per-unit royalty

$$\hat{r}^{R,E}=\frac{\left(1-2\alpha\right)\left(n+\lambda-n\lambda\right)}{n\lambda\left(1-3\alpha\right)}. \tag{21}$$

Note that the per-unit royalty is positive, $\hat{r}^{R,E}\geq 0$, if and only if $\alpha\geq 1/2$ or $\alpha<1/3$. Given the equilibrium royalty, firms' equilibrium outputs and profits can be derived:

$$\begin{aligned}
&\hat{q}^{H,R,E}=\frac{\alpha}{2\left(3\alpha-1\right)}, \quad \hat{q}_i^{L,R,E}=\frac{5\alpha-2}{2n\left(3\alpha-1\right)},\\
&\hat{\pi}^{H,R,E}=\frac{\alpha^2\left(n+\lambda-n\lambda\right)}{4n\lambda\left(3\alpha-1\right)^2}, \quad \hat{\pi}_i^{L,R,E}=\frac{\left(5\alpha-2\right)^2}{4n^2\left(3\alpha-1\right)^2}.
\end{aligned} \tag{22}$$

Note that the licensee's output is positive, $\hat{q}^{H,R,E}\geq 0$, if and only if $\alpha>1/3$; whilst the outputs of the other (non-licensee) firms are positive, $\hat{q}_i^{L,R,E}\geq 0$, if and only if $\alpha<1/3$ or $\alpha\geq 2/5$. Therefore, when $\alpha\geq 1/2$, both firms' outputs and the per-unit royalty are positive. Lastly, the innovator's profit is $\hat{\pi}^*=\hat{r}^{R,E}\cdot\hat{q}^{H,R,E}$.

2.5 Per-unit Royalty: Non-Exclusive Contract

When the license is sold to all firms in the industry, firms' solve

$$\max_{q^{H,R,NE}} \quad \pi_i^{H,R,NE} = \left[\frac{1}{\lambda}\left(1 - q_i^{H,R,NE} - Q_{-i}^{H,R,NE}\right) - r^{R,NE} \right] q_i^{H,R,NE} \tag{23}$$

where $Q_{-i}^{H,R,NE} = \sum_{j \neq i} q_j^{H,R,NE}$. Solving the profit-maximization problem, we have the Cournot equilibrium outputs and profits of

$$\hat{q}_i^{H,R,NE}\left(r^{R,NE}\right) = \frac{1-\lambda r^{R,NE}}{n+1}, \quad \hat{\pi}_i^{H,R,NE}\left(r^{R,NE}\right) = \frac{\left(1-\lambda r^{R,NE}\right)^2}{\lambda\left(n+1\right)^2}. \tag{24}$$

In the first stage, the benevolent innovator chooses $r^{R,NE}$ to maximize joint profits of the licensor and the licensees

$$\max_{r^{R,NE}} \quad \alpha\pi^* + \left(1-\alpha\right) n \hat{\pi}_i^{H,R,NE}\left(r^{R,NE}\right), \tag{25}$$

where $\pi^* = r^{R,NE} \cdot n \cdot \hat{q}_i^{H,R,NE}\left(r^{R,NE}\right)$. First order condition yields the equilibrium per-unit royalty of

$$\hat{r}^{R,NE} = \frac{\alpha\left(n+3\right)-2}{2\lambda\left[\alpha\left(n+2\right)-1\right]}. \tag{26}$$

We can then recover firms' equilibrium output and profits as follows

$$\hat{q}_i^{H,R,NE} = \frac{\alpha}{2\left[\alpha\left(n+2\right)-1\right]}, \quad \hat{\pi}_i^{H,R,NE} = \frac{\alpha^2}{4\lambda\left[\alpha\left(n+2\right)-1\right]^2}. \tag{27}$$

Finally, the innovator's profit is given by $\hat{\pi}^* = \hat{r}^{R,NE} \cdot n \cdot \hat{q}_i^{H,R,NE}$.

2.6 Numerical Simulations of the Model

In this section, using equilibrium profits for the innovator and licensee derived in the previous section, we simulate the predicted profits under the six licensing arrangements. In particular, we consider different industry sizes in number of firms, $n = 2$ and $n = 20$, and different levels of the degree of innovation, $\lambda \in [0.10, 0.60]$, where the smaller (greater) values of λ correspond to higher (smaller, respectively) levels of innovation. Further, we set the weighting parameters ($m = 2$ and $\alpha = 0.5$) such that the innovator places equal weight to the profits of itself and those of the licensee.

The intent of the innovator is to release the innovation using a licensing mechanism that maximizes the joint profits of the innovator and the licensee. In Figure 1, we plot the sum of the innovator's and licensees' profits under different licensing arrangements. Our results indicate that, when the industry is composed of a small number of firms ($n = 2$), the joint profits are generally the greatest under exclusive contract, with a small difference between licensing schemes (i.e., fixed fee, per-unit royalty, and two-part tariff). However, when the size of the industry is relatively large $(n = 20)$, the joint profits become the largest under nonexclusive contract, either with a two-part tariff or a per-unit royalty, depending on the innovation level. In particular, when the innovation level is high (small λ), a two-part tariff produces the greatest joint profits for the innovator and the licensee. In contrast, when the level of innovation is marginal (i.e., a high λ), a per-unit royalty delivers the largest joint benefits. In the next section, the results predicted by the theoretical model are evaluated with experimental data from actual growers' bids.

3. Experimental Design

Washington apple growers were invited to participate in the auctions during the Washington State Horticultural Association Annual Meeting in December 2014. Growers who agreed to participate signed a consent form stating that participation was voluntary and that all individual-level information provided during the experiment would be kept strictly confidential. Each individual was compensated with a baseline payment of $20 for participating in the experiment. We conducted Becker-DeGroot-Marschak (BDM) auctions (Becker et al. 1964) with the growers bidding on access to a new apple variety using six different licensing schemes. The BDM auction mechanism is incentive compatible and does not require a specific number of participants, since the market-clearing price is exogenous and randomly drawn.

At the beginning of the experiment, researchers explained the BDM auction mechanism to participating growers, and conducted a practice round to familiarize them with the auction mechanism. With the BDM auction, each participant places a bid on each of the six licensing schemes that would hypothetically grant access to grow a new promising apple variety. Researchers presented to growers six licensing options: three schemes (e.g., a one-time, per-tree payment; per-box royalty; and two-part payment with both a one-time per-tree payments and per-box payments) under two types of contracts (e.g., exclusive and non-exclusive). Growers were asked to submit a bid for each licensing scheme. After the six bids were placed, one of them was randomly selected as the binding bid. Once the binding licensing scheme and the type of contract were known, the researcher randomly drew a clearing price, corresponding to the binding licensing scheme and the type of contract for each individual.[6] If the participant's bid for a licensing scheme was greater than or equal to the exogenous market-clearing price, then the participant was required to purchase the right to grow the new variety. Otherwise, the experiment was finalized without any purchase.

In our experiment, a license to the patent gave growers access to one acre of trees that would be used to produce the new demand-enhancing variety; this was explained to growers as 1,450 trees which is the typical tree density per acre following modern tree-fruit-wall architectures. The researchers

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[6] There were six random lists of market-clearing prices. Each list was created with Monte Carlo simulation. To simulate the lists of clearing licensing prices, we used as a reference the means for each licensing scheme under the two contracts used in Rickard et al. (2016). See Table 1B in Appendix B for summary statistics of the clearing prices.

provided information on the horticultural management costs of the new promising apple variety, based on detailed cost of production information from Galinato and Gallardo (2012). That is, costs for growing the new variety included per-acre costs for a full production year plus the additional cost implied by the chosen licensing scheme. The net yield was set at 70 bins per acre, and the price of the new apple variety was set at $54 per 40-lb box. With the information on costs, expected yields, and market prices, participants had a notion of the profits that could be achieved from growing the new variety under a given licensing scheme.

Hypothetical profits were calculated for each participant who was eligible to grow the new variety (that is, the participant that submitted a bid higher than the randomly drawn clearing price). Depending on the hypothetical profit calculation, the eligible participant could gain or lose from their initial $20 participant compensation. If growers achieved hypothetical profits exceeding $20,000 per acre, they received an additional payment of $10 for a total of $30. If these profits were less than $15,000 per acre, then they had to pay $10 out of their $20 baseline payment, for a net payment of $10. Thus, after the completion of the experiment, participating growers received a compensation ranging between $10 and $30 depending on their hypothetical profits. At the completion of each session, the participants completed a survey to collect demographic information and details about their farming operation.

4. Empirical Analysis

In this section, we investigate how the Washington apple grower participants responded to different licensing arrangements within the experimental auctions. Our experimental design allowed a subject to bid for access to a patented apple variety and their bid was compared to a randomly chosen market clearing price. For any given subject, this procedure effectively mimicked a scenario with two firms potentially adopting the patent. Therefore, we analyze the data from our experiment to test the theoretical predictions from the $n=2$ case.

4.1 Calculating Willingness to Pay Measures for Different Licensing Arrangements

We use the growers' bids in the auction to obtain their willingness to pay (WTP) for an acre of trees of the new apple variety, which is based on the net present value. Bids under the fixed fee scheme are defined in terms of payments for one acre of trees, whilst those under per-unit royalty and two-part tariff schemes first need to be converted to equivalent payment units. We calculate total payments under the per-unit royalty scheme that subjects would incur from licensing the patent by summing the net present value across 20 years (the assumed life span of an apple tree):

$$WTP_{i,R} = \sum_{t=1}^{20} \delta^{t-1} \left(B_{i,R} \cdot Y_t \right), \tag{28}$$

where $WTP_{i,R}$ is the present value of payments by grower i under per-unit royalty (R) scheme; δ is the discount rate, which is set at 5%; $B_{i,R}$ is grower i's per-unit royalty bid; and Y_t is the yearly production of apples (in boxes) from an acre of land, for $t = 1, 2, ..., 20$ years. The estimates used for yearly production costs of apples are based on Galinato and Gallardo (2012).[7]

Since the two-part tariff has both fixed and royalty components, we derive the present value of payments arising from the license by adding the fixed fee and the present value of the per-unit royalty payments:

$$WTP_{i,T} = B_{i,F} + \sum_{t=1}^{20} \delta^{t-1} \left(B_{i,R} \cdot Y_t \right), \tag{29}$$

where $WTP_{i,T}$ is the present value of the payment by grower i under two-part tariff (T) scheme and $B_{i,F}$ is grower i's fixed fee (F) bid, which is defined in terms of per acre payments.

To identify the effect of a contract type (i.e., exclusive and nonexclusive) and grower characteristics on their WTP, we first estimate a linear regression for the bid equation separately for each type of

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[7] In particular, the assumed per-acre production of apples is 0 boxes for years 1-2, 222.75 boxes for year 3, 668.25 boxes for year 4, 965.25 boxes for year 5, and 1039.5 boxes for years 6-20.

licensing mechanisms (i.e., fixed fee, per-unit royalty, and two-part tariff). In particular, the WTP of grower i under a licensing arrangement with contract type j, for $j = \{\text{exclusive, nonexclusive}\}$ is specified as:

$$WTP_{i,j} = \alpha + \beta excl + \boldsymbol{\gamma}\mathbf{z}_i + \boldsymbol{\omega}\mathbf{x}_i + \upsilon_i + \varepsilon_{i,j} \,. \tag{30}$$

In equation (30), $excl$ is an indicator variable that is equal to 1 if the contract is exclusive and zero otherwise; $\mathbf{z}_i$ is a vector of grower i's orchard characteristics; $\mathbf{x}_i$ is a vector of grower *i*'s demographics; υ_i is an individual-specific error term; and $\varepsilon_{i,j}$ is the normally distributed overall error term with mean zero. Since individuals under each licensing arrangement provided bids for two types of contracts (i.e., exclusive or non-exclusive), we clustered the standard errors by individuals in order to account for the panel nature of the data.

Second, we examine the joint effect of three licensing arrangements and two types of contracts on individual's WTP, using data for all auctions. In this context, the WTP of subject i under the licensing mechanism k, for $k = \{F, R, T\}$, with contract exclusivity j is specified in the following way:

$$WTP_{i,k,j} = \alpha + \beta excl + \sum_k \varphi_k scheme_k + \sum_k \eta_k excl \times scheme_k + \boldsymbol{\gamma}\mathbf{z}_i + \boldsymbol{\omega}\mathbf{x}_i + \upsilon_i + \varepsilon_{i,k,j} \,, \tag{31}$$

where $scheme_k$ is an indicator variable that is equal to one if the contract type is k and zero otherwise. In our empirical analysis we treated fixed fee as the reference category. Since the subjects submitted bids for six different contractual arrangements in the experiment, the standard errors of the parameter estimates are clustered at the individual level.

4.2 Calculating Profits from Willingness-to-Pay Measures

For the analysis of the joint profits of the innovator and the licensee under different licensing schemes, we first determined which growers were eligible to access the patented variety by randomly drawing a market price and comparing it against the grower's bid. Following the BDM auction approach, if a submitted bid was greater than or equal to the market price, the bidder "purchases" the tree under that licensing arrangement.[8] Using these market prices, we simulate grower profits following Galinato and Gallardo (2012). Profits are based on producing the new apple variety on either 10% of grower's total apple land or 10 acres of land, whichever is higher, over ten-, fifteen-, and twenty-year horizons. Combining the grower profits with those of the innovator (obtained from WTP measures), we analyze the joint profits under various licensing arrangements.

To quantify the effect of different licensing arrangements on the innovator and licensee profits, we estimate the following model separately for the innovator and the licensee:

$$\pi_{i,k,j} = \alpha + \beta excl + \sum_k \varphi_k scheme_k + \sum_k \eta_k excl \times scheme_k + \gamma land_i + \upsilon_i + \varepsilon_{i,k,j}\,, \tag{32}$$

where $\pi_{i,k,j}$ is the simulated profits received by the innovator/licensee from a contractual arrangement k with contract exclusivity j. Because of fewer degrees of freedom offered by the sample of eligible bidders, we did not include all the orchard and demographic controls in the above regression equation. Only the size of the farm used to produce apples ($land_i$) for each grower is included in the model. We use cluster-robust standard errors in our estimations and inference.

5. Empirical Results

Table 1 presents descriptive statistics for 32 apple growers who participated in our experimental auction. On average, the participants had 23 years of experience in apple production. Collectively, they

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[8] See Table 2B in Appendix B for descriptive statistics for the eligible bids (those greater than the market-clearing price in the BDM auction) for each licensing arrangement, including the mean acreage that each bidder holds.

operate on a total of 26,080 acres representing 16% of all apple acreage in the state of Washington. As expected, within each licensing arrangement, the growers were willing to pay significantly more (almost twice as much) for exclusive contracts than non-exclusive contracts, which makes intuitive sense as the growers who want exclusive access to an IPR are also willing to pay an extra premium for it. More specifically, grower participants were willing to pay on average $5,207.58 for an acre of the patented apple variety in a fixed fee payment under the exclusive contract versus $3,368.75 under the nonexclusive contract. Similarly, with per-unit royalty the growers were willing to pay $2.02 per box of apples (or, a total of $21,135.31 in the present value of 20-year payments at 5% discount rate)[9] under the exclusive contract versus $1.10 (or, a total of $11,544.08 in the present value of 20-year payments at 5% discount rate) under the nonexclusive contract. The same general observation holds for the two-part tariff.

Table 2 reports regression results for how different factors affect grower bids for the fixed fee, per-unit royalty, and two-part tariff. Across all specifications, contract exclusivity is the largest statistically significant non-constant factor that determines grower bids. The last column in Table 2 presents estimation results for all bids. As in the previous columns, contract exclusivity has a statistically significant positive effect on growers' bids. Moreover, both the per-unit royalty and the two-part tariff schemes, and their interactions with contract exclusivity, have statistically significant positive effects on the bids relative to the fixed fee. In some of our specifications, the grower acreage variables have a significant negative effect, but the magnitude is generally small. Grower demographic variables are not statistically significant in any estimation; however, we expect that this is due, in part, to our small sample size.

We calculate average profits for the eligible bids under different licensing arrangements and time horizons according to the methodology discussed in Section 4.2. To identify a licensing scheme that

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[9] See Section 4.1 for the calculation of the WTP measures for per-unit royalty and two-part tariff schemes.

maximizes the joint profits for the innovator and the licensee, in Figure 2, we report the sum of the innovator's and the licensees' profits under various licensing options. Our results indicate that the joint profits are the greatest under exclusive per-unit royalty scheme, followed by exclusive two-part tariff, across time horizons. This finding is generally in line with our theoretical predictions from a small industry ($n = 2$) model, where the exclusive contract generated the highest joint profits and that the difference between exclusive per-unit royalty and exclusive two-part tariff schemes was indistinguishable.

In Tables 3 and 4, we report regression results for grower and innovator profits, respectively. It is clear that the contract exclusivity is more important for the profits of the grower than for the innovator, as it is statistically significant and positive for the former across different specifications of the model. Moreover, the per box royalty and the two-part tariff schemes, and their interactions with the contract exclusivity, consistently reduce the grower's profits relative to the fixed fee scheme (a reference scheme), whilst they consistently increase the innovator's profits relative to the fixed fee scheme.

6. Conclusions

This article considers the economic implications of how university plant breeding programs commercialize the new plant cultivars that they develop. New horticultural varieties are often developed by public universities that receive public funding in addition to funding from producers directly through commodity commissions. As a result, university administrations are increasingly giving thought to how the commercialization of a new variety impacts the growers in their state. The implications related to these sensitivities need to be considered in the economic analysis of the optimal licensing strategy.

The present study acknowledges political and institutional limitations in licensing contracts when the innovations are released by a public university, especially considering that plant breeding programs in public universities have a stated goal of creating new varieties available to all growers in the state. Therefore, this article contributes specifically to the literature by modelling economic implications for producers and breeders jointly. We evaluate three different licensing schemes under two types of contracts in terms of expected profits for both the innovator and the licensees. Our findings from theoretical and empirical analysis suggest that the joint profits of the innovator and the licensee are generally the greatest under exclusive per-unit royalty scheme when the industry consists of a small number of firms. In contrast, when the size of the industry is relatively large, we find that the joint profits are the largest under nonexclusive contract, either with a two-part tariff (if the innovation level is high) or a per-unit royalty (if the innovation level is low).

Several insights can be drawn from these findings. First, our work shows that it is not necessarily the case that universities that use exclusive licensing arrangements fail to fulfill their land grant mission. Our conceptual model and empirical results illustrate that an exclusive licensing arrangement can maximize the joint profits of the innovator and the licensee when the industry is composed of a small number of firms. In this setting, even though the producer benefits from an innovation are shared among a small number of firms, the distributional concern is alleviated by the fact that the industry consists of a small number of firms to start with.

Second, our conceptual model shows that when the industry consists of a large number of firms, the distributional effects and fairness concerns of the university innovation clearly becomes important. In this scenario, we show that nonexclusive licensing arrangements are beneficial for the joint profits of the university and the industry. In future research, we would like to extend our experimental work to test whether a nonexclusive contract would maximize joint profits when there are a large number of firms in the industry (the n=20 case). We feel that the apple industry in the United States may be better characterized as one with a large number of firms (farms), and if newly patented apple varieties are made available to all U.S. farmers then the large industry case might be more appropriate. In this case, an empirical application would develop a setting whereby multiple growers could bid (and gain access) to a patented variety and we could measure profits for the innovator and the licensed growers.

Overall, our findings help inform the patent-licensing process for agricultural innovations and/or some other technology that is aimed to increase both the upstream and downstream users' benefits more generally. Hence this study serves as a starting point for future work that explores the net societal impacts concerning the licensing of agricultural varieties.

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Table 1. Experimental Auction Data Summary

Variables			Units/Description	Mean	Standard deviation
Bids					
Fixed fee	Exclusive		Dollars per one acre of apples	5,207.58	4,909.85
	Non-Exclusive		Dollars per one acre of apples	3,368.75	3,714.13
Per-unit royalty	Exclusive		Dollars per one box of apples	2.02	2.14
			Present value of 20-year payments for one acre of apples at 5% interest	21,135.31	22,352.37
	Non-Exclusive		Dollars per one box of apples	1.10	1.95
			Present value of 20-year payments for one acre of apples at 5% interest	11,544.08	20,346.91
Two-part tariff	Exclusive	Fixed fee	Dollars per one acre of apples	2,905.53	3,919.64
		Per-unit royalty	Dollars per one box of apples	1.34	2.00
		Combined payment	Fixed fee + present value of 20-year payments for one acre of apples at 5% interest	16,513.51	21,621.30
	Non-Exclusive	Fixed fee	Dollars per one acre of apples	1,588.20	2,157.13
		Per-unit royalty	Dollars per one box of apples	0.71	1.48
		Combined payment	Fixed fee + present value of 20-year payments for one acre of apples at 5% interest	8,808.56	15,502.31
Orchard characteristics					
Total land			Acres	1,246.13	2,018.01
Total apple land			Acres	841.31	1,677.41
	Red delicious		Acres, entire sample (Acres, growers only)	9.19 (18.38)	11.19 (8.82)
	Gala		Acres, entire sample (Acres, growers only)	10.31 (13.75)	7.54 (5.23)
	Honeycrisp		Acres, entire sample (Acres, growers only)	4.13 (7.33)	4.58 (3.65)
Demographic characteristics					
Age			Years	49.17	12.24
Ethnicity	Caucasian/white		Percent	90.32	30.05
	Hispanic		Percent	9.68	30.05
Income	>$500,000		Percent	64.52	48.64
	≤$500,000		Percent	35.48	48.64
Education	Bachelor or higher		Percent	70.97	46.14
	High school/some college		Percent	29.03	46.14
Experience			Years in apple production	22.64	13.82

Number of participants = 32 Observations = 192

Table 2. Regression Results for Grower Bids for a New Variety of Apple

	Fixed Fee		Per-unit Royalty		Two-Part Tariff		All	
	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error
Total apple land	0.35	0.25	-0.54	1.58	-1.09	1.54	-0.43	0.98
Red delicious	-104.70	76.42	-171.36	252.08	-198.80	249.78	-158.29	162.62
Gala	-183.83	114.74	-701.66*	369.56	-289.25	309.67	-391.58*	215.13
Honeycrisp	-300.44*	170.89	1,203.56	1,728.67	1,274.70	1,650.39	725.94	1,065.45
Years in apple production	-86.48	89.44	-473.35	320.73	-125.85	290.49	-228.56	191.39
Age	49.46	157.17	122.95	278.43	-375.75	281.64	-67.78	165.45
Ethnicity (Hispanic)	2,763.03	2,214.15	-8,119.82	11,463.85	624.05	10,316.85	-1,577.58	6,748.64
Education (≥ Bachelor's)	-1,540.18	1,768.38	8,673.01	14,596.60	5,147.87	13,518.48	4,093.57	8,743.10
Income (>500,000)	-2,399.77	1,844.01	-4,421.64	11,959.20	-7,158.22	10,977.15	-4,659.88	7,395.71
Exclusive contract	1,823.88***	365.76	9,772.64***	2,523.74	8,495.07***	2,259.88	1,823.88***	346.44
Per-unit royalty							7,704.66*	3,835.84
Two-part tariff							6,204.31*	3,150.88
Per-unit royalty*Exclusive contract							7,948.76***	2,267.47
Two-part tariff*Exclusive contract							6,671.19***	1,989.75
Constant	8,968.13*	5,275.71	16,942.28	12,446.55	31,733.67***	9,981.30	14,578.37***	4,905.89
Clusters	29		29		29		29	
Observations	58		58		58		174	
R^2	0.48		0.21		0.22		0.23	

Notes: Standard errors are clustered at the individual level. * denotes $p < 0.10$, ** denotes $p < 0.05$, *** denotes $p < 0.01$.

Table 3. Regression Results for Grower Profits for a New Variety of Apple

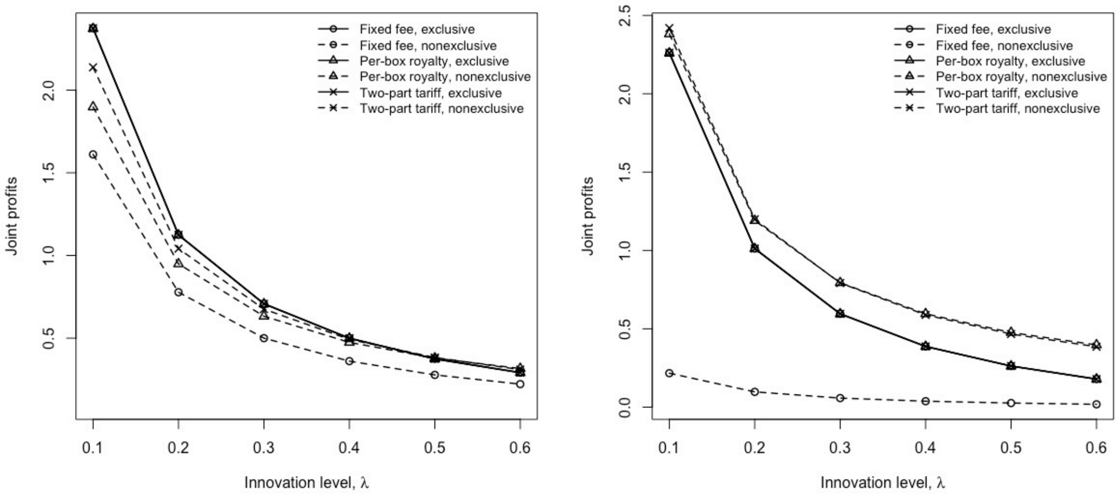
	10-year present value		15-year present value		20-year present value	
	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error
Exclusive contract	29,010.25***	258.65	46,084.33***	325.98	59,462.32***	378.81
Per-unit royalty	-4,392.47***	615.59	-7,858.03***	956.54	-10,573.38***	1,224.67
Two-part tariff	-3,849.75***	672.36	-6,535.82***	1,094.71	-8,640.43***	1,427.02
Per-unit royalty*Exclusive contract	-4,166.61**	1,725.56	-6,895.22**	2,706.21	-9,033.15**	3,475.38
Two-part tariff*Exclusive contract	-2,848.51***	722.41	-4,548.04***	1,190.45	-5,879.66***	1,560.78
Land	-25.87***	1.1747	-36.81***	1.8712	-45.38***	2.4186
Constant	48,134.26***	249.67	91,278.71***	356.22	125,083.50***	441.39
Clusters	27		27		27	
Observations	83		83		83	
R^2	0.97		0.97		0.97	

Notes: Standard errors are clustered at the individual level. *denotes $p < 0.10$, **denotes $p < 0.05$, ***denotes $p < 0.01$.

Table 4. Regression results for innovator profits for a new variety of apple

	10-year present value		15-year present value		20-year present value	
	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error
Exclusive contract	114,080.7	84,992.79	128,641.4	127,184.1	140,050.1	161,118.3
Per-unit royalty	493,988.8***	150,374.9	850,254.9***	258,979.5	1,129,399***	347,453.3
Two-part tariff	460,099.3**	170,842.4	733,939**	267,68236	948,499.6***	343,696.8
Per-unit royalty*Exclusive contract	988,529.3**	470,714.5	1,610,270**	745,806.9	2,097,420**	962,234.4
Two-part tariff*Exclusive contract	317,631.7	200,739.7	506,387.3	326,434.4	654,282.3	425,523.2
Land	5,034.51***	467.68	7,214.32***	721.84	8,922.26***	921.15
Constant	-476,788.4***	168,565.4	-755,481.5***	264,186.4	-973,844.8***	339,245.4
Clusters	27		27		27	
Observations	83		83		83	
R^2	0.68		0.64		0.62	

Notes: Standard errors are clustered at the individual level. *denotes $p < 0.10$, **denotes $p < 0.05$, ***denotes $p < 0.01$.



(a) $n = 2$ (b) $n = 20$

Fig. 1. Simulated theoretical joint profits under different licensing arrangements

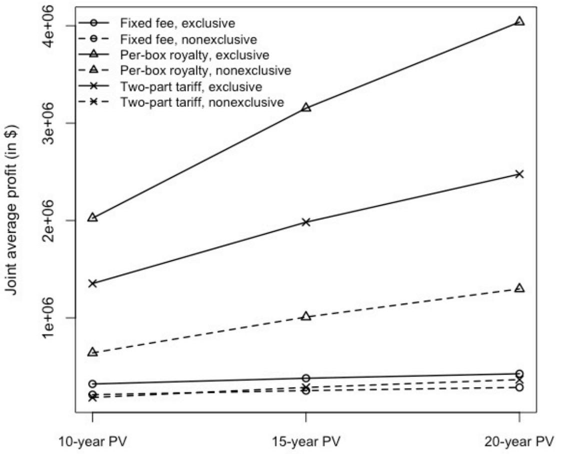


Fig. 2. Average empirical joint profits under different licensing arrangements

Appendix A

Both the exclusive and non-exclusive cases of a two-part tariff contract are derived below.

Two-Part Tariff, Exclusive Contract

If the patent is released by means of a two-part tariff contract, then, similar to Li and Wang (2010), the royalty rate $r^{T,E}$ is set to control the production behavior of the producer(s), and the fee $f^{T,E}$ is set to transfer the increased profit from the firms to the innovator. In the third stage, firms that do not adopt a new technology maximize their profits

$$\max_{q_i^{L,T,E}} \quad \pi_i^{L,T,E} = \left(1 - q^{H,T,E} - q_i^{L,T,E} - Q_{-i}^{L,T,E}\right) q_i^{L,T,E}, \tag{A1}$$

where $Q_{-i}^{L,T,E} = \sum_{j \neq i} q_j^{L,T,E}$. First order condition yields the reaction function $q_i^{L,T,E}\left(q^{H,T,E}\right) = \dfrac{1 - q^{H,T,E}}{n}$

. In the second stage, the firm that adopts a new technology solves

$$\begin{aligned} &\max_{q^{H,T,E}} \quad \pi^{H,T,E} = \left[\frac{1}{\lambda}\left(1 - q^{H,T,E} - \lambda Q^{L,T,E}\right) - r^{T,E}\right] q^{H,T,E} - f^{T,E} \\ &\text{s.t.} \quad q_i^{L,T,E}\left(q^{H,T,E}\right) = \frac{1 - q^{H,T,E}}{n} \end{aligned} \tag{A2}$$

Solving the profit-maximization problem, we obtain the firms' Cournot equilibrium outputs and profits

$$\begin{aligned} &\hat{q}^{H,T,E}\left(r^{T,E}\right) = \frac{n + \lambda - n\lambda\left(1 + r^{T,E}\right)}{2\left(n + \lambda - n\lambda\right)}, \quad \hat{q}_i^{L,T,E}\left(r^{T,E}\right) = \frac{n + \lambda - n\lambda\left(1 - r^{T,E}\right)}{2n\left(n + \lambda - n\lambda\right)}, \\ &\hat{\pi}^{H,T,E}\left(r^{T,E}, f^{T,E}\right) = \frac{\left[n + \lambda - n\lambda\left(1 + r^{T,E}\right)\right]^2}{4n\lambda\left(n + \lambda - n\lambda\right)} - f^{T,E}, \quad \hat{\pi}_i^{L,T,E}\left(r^{T,E}\right) = \frac{\left[n + \lambda - n\lambda\left(1 - r^{T,E}\right)\right]^2}{4n^2\left(n + \lambda - n\lambda\right)^2}. \end{aligned} \tag{A3}$$

In the first stage, the benevolent innovator chooses $f^{T,E}$ and $r^{T,E}$ to maximize joint profits of the licensor and the licensee. First, the optimal fixed fee is determined based on the weighted gross profit difference between the new technology, $\hat{\pi}^{H,T,E}\left(r^{T,E},\, f^{T,E}=0\right)$, and old technology, $\hat{\pi}_i^{L}$ (in equation (3)):

$$\hat{f}^{T,E}\left(r^{T,E}\right)=\frac{1}{m}\left(\frac{\left[n+\lambda-n\lambda\left(1+r^{T,E}\right)\right]^2}{4n\lambda\left(n+\lambda-n\lambda\right)}-\frac{1}{\left(n+1\right)^2}\right). \tag{A4}$$

Then, the optimal per-unit royalty is chosen to maximize the joint profits of the licensor and the licensee

$$\max_{r^{T,E}} \quad \alpha\pi^{*}+\left(1-\alpha\right)\hat{\pi}^{H,T,E}\left(r^{T,E},\, \hat{f}^{T,E}\left(r^{T,E}\right)\right), \tag{A5}$$

where $\pi^{*}=r^{T,E}\cdot\hat{q}^{H,T,E}\left(r^{T,E}\right)+\hat{f}^{T,E}\left(r^{T,E}\right)$. First order condition yields the equilibrium per-unit royalty

$$\hat{r}^{T,E}=\frac{(2\alpha-1)\left(m-1\right)\left(n+\lambda-n\lambda\right)}{n\lambda\left[1-m+\alpha\left(3m-2\right)\right]}. \tag{A6}$$

We can then recover the equilibrium fixed fee as

$$\hat{f}^{T,E}=\frac{1}{m}\left(\frac{\alpha^2m^2\left(n+\lambda-n\lambda\right)}{4n\lambda\left[1-m+\alpha\left(3m-2\right)\right]^2}-\frac{1}{\left(n+1\right)^2}\right) \tag{A7}$$

and firms' equilibrium output and profits

$$\begin{gathered}\hat{q}^{H,T,E}=\frac{\alpha m}{2\left[1-2\alpha-m\left(1-3\alpha\right)\right]},\quad \hat{q}_i^{L,T,E}=\frac{2\left(1-2\alpha\right)-m\left(2-5\alpha\right)}{2n\left[1-2\alpha-m\left(1-3\alpha\right)\right]}\\ \hat{\pi}^{H,T,E}=\left(\frac{m-1}{m}\right)\left(\frac{\alpha^2m^2\left(n+\lambda-n\lambda\right)}{4n\lambda\left[1-m+\alpha\left(3m-2\right)\right]^2}\right)+\frac{1}{m\left(n+1\right)^2},\quad \hat{\pi}_i^{L,T,E}=\frac{\left[2\left(m-1\right)-\alpha\left(5m-4\right)\right]^2}{4n^2\left[1-m+\alpha\left(3m-2\right)\right]^2}.\end{gathered} \tag{A8}$$

Finally, the innovator's equilibrium profits are given by $\hat{\pi}^{*}=\hat{r}^{T,E}\cdot\hat{q}^{H,T,E}+\hat{f}^{T,E}$.

Two-part Tariff, Non-Exclusive Contract

If the innovation is licensed to all firms in the industry, the firms' profit functions become

$$\max_{q^{H,T,NE}} \quad \pi_i^{H,T,NE} = \left[\frac{1}{\lambda}\left(1 - q_i^{H,T,NE} - Q_{-i}^{H,T,NE}\right) - r^{T,NE} \right] q_i^{H,T,NE} - f^{T,NE}, \tag{A0}$$

where $Q_{-i}^{H,T,NE} = \sum_{j \neq i} q_j^{H,T,NE}$. Solving the profit-maximization problem, we have the Cournot equilibrium outputs and profits

$$\hat{q}_i^{H,T,NE}\left(r^{T,NE}\right) = \frac{1 - \lambda r^{T,NE}}{n+1}, \quad \hat{\pi}_i^{H,T,NE}\left(r^{T,NE}, f^{T,NE}\right) = \frac{\left(1 - \lambda r^{T,NE}\right)^2}{\lambda (n+1)^2} - f^{T,NE}. \tag{A10}$$

In the first stage, the benevolent innovator chooses $f^{T,NE}$ and $r^{T,NE}$ to maximize joint profits of the licensor and the licensee. First, the optimal fixed fee is determined based on the weighted gross profit difference between the new technology, $\hat{\pi}_i^{H,T,NE}\left(r^{T,NE}, f^{T,NE} = 0\right)$, and old technology, $\hat{\pi}_i^L$ (in equation (3)):

$$\hat{f}^{T,NE}\left(r^{T,NE}\right) = \frac{1}{m}\left(\frac{\left(1 - \lambda r^{T,NE}\right)^2}{\lambda (n+1)^2} - \frac{1}{(n+1)^2} \right). \tag{A11}$$

The optimal per-unit royalty is then chosen to maximize the joint profits of the licensor and the licensee

$$\max_{r^{T,NE}} \quad \alpha \pi^* + (1-\alpha) n \hat{\pi}_i^{H,T,NE}\left(r^{T,NE}, \hat{f}^{T,NE}\left(r^{T,NE}\right)\right), \tag{A12}$$

where $\pi^* = r^{T,NE} \cdot n \cdot \hat{q}_i^{H,T,NE}\left(r^{T,NE}\right) + n \cdot \hat{f}^{T,NE}\left(r^{T,NE}\right)$. First order condition yields the equilibrium per-unit royalty

$$\hat{r}^{T,NE} = \frac{2(1-m) + \alpha\left[m(n+3) - 4\right]}{2\lambda\left\{1 - m + \alpha\left[m(n+2) - 2\right]\right\}}. \tag{A13}$$

Then, the equilibrium fixed fee, firms' output, and profits can then be recovered as

$$\begin{aligned}
\hat{f}^{T,NE} &= \frac{1}{m}\left(\frac{\alpha^2 m^2}{4\lambda\left\{1-m+\alpha\left[m\left(n+2\right)-2\right]\right\}^2}-\frac{1}{\left(n+1\right)^2}\right),\\
\hat{q}_i^{H,T,NE} &= \frac{\alpha m}{2\left\{1-m+\alpha\left[m\left(n+2\right)-2\right]\right\}},\\
\hat{\pi}_i^{H,T,NE} &= \left(\frac{m-1}{m}\right)\left(\frac{\alpha^2 m^2}{4\lambda\left\{1-m+\alpha\left[m\left(n+2\right)-2\right]\right\}^2}\right)+\frac{1}{m\left(n+1\right)^2}.
\end{aligned} \tag{A15}$$

Lastly, the innovator's equilibrium profits are given by $\hat{\pi}^{*} = \hat{r}^{T,NE}\cdot\hat{n}\cdot\hat{q}_i^{H,T,NE}+\hat{n}\cdot\hat{f}^{T,NE}$.

Appendix B

Table 1B. Summary Statistics for Randomly Generated Market Clearing Prices

	Fixed fee		Per-unit royalty		Two-part tariff			
					Exclusive		Non-exclusive	
	Exclusive	Non-exclusive	Exclusive	Non-exclusive	Fixed fee	Per box royalty	Fixed fee	Per box royalty
Mean	2,264.5	1,558.1	2.416	1.806	1,148.1	1.435	632.7	1.124
Standard deviation	882.37	327.74	0.8690	0.7047	387.11	0.4163	215.18	0.3241

Table 2B. Summary Statistics for Eligible Bids

Licensing arrangement			Number of eligible bidders	Market price ($)		Land (acres)	
				Mean	Standard deviation	Mean	Standard deviation
Fixed fee	Exclusive		25	1,935.28	500.02	121.17	186.25
	Non-Exclusive		19	1,449.89	363.84	127.85	199.77
Per-unit royalty	Exclusive		13	2.12	0.91	166.76	239.14
	Non-Exclusive		8	1.25	0.30	115.75	237.57
Two-part tariff	Exclusive	Fixed fee	12	1,170.50	376.91	173.20	248.69
		Per-unit royalty		1.41	0.45		
	Non-Exclusive	Fixed fee	6	720.33	235.46	31.00	39.27
		Per-unit royalty		0.92	0.36		

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