# Optimal Licensing for Public Intellectual Property: Theory and Application to Plant Variety Patents

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## Abstract

In the United States, public universities may choose to license a plant variety to a limited number of producers (an exclusive license) or to an unlimited number of producers (an open license). This choice has implications for the quantity and distribution of total benefits from the variety. Universities have traditionally released new apple varieties under open licenses, but several universities have now begun exploring or implementing exclusive licensing. In this paper, we consider the choice faced by a public university when licensing a plant variety patent, with a focus on apples. Our work differs from the majority of past studies on patent licensing because we allow licensees to determine the signal of product quality through a trademark and we consider welfare objectives for a public university that differ from simple maximization of patent income. In this context, we compare monopoly licensing and two oligopoly licensing scenarios. We then solve for the optimal choice of licensing fees for the university. Using numerical simulations, we find that consumer surplus and social welfare may be higher under exclusive licensing if consumers are relatively responsive to expenditure on the trademark but relatively insensitive to price. However, exclusive licenses may create distributional concerns among producers. Furthermore, different objective functions of the university can imply different optimal outcomes for both the number of licensees and the licensing fees. Although we focus on apples, this model and its results could apply in a variety of settings.

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## Introduction

The arrangements for funding and managing agricultural R&D in the United States have been evolving to accommodate changes in the economy broadly, in science itself, and in the institutional framework in which science is conducted (e.g., see Alston et al. 2010). Important elements of these changes include: (a) declining public support for using general government revenue to fund public agricultural R&D, (b) the rise of modern biotechnology, (c) the emergence of stronger intellectual property (IP) rights over biological innovations following *Diamond v. Chakrabarty* in 1980, and (d) the Bayh-Dole Act of 1980, which allowed universities to patent results from research financed with federal funds (e.g., Graff et al. 2003). In an ever-tighter research funding environment, the option of using technology patents to augment traditional research funding sources has contributed to shifts in the approaches taken to financing and managing agricultural R&D in public universities.

Along with the new funding opportunities have come some new challenges for universities, producer groups, research scientists, and others, as they engage in public-private partnerships in the production of patented technologies. Leaders in public universities continue to grapple with unresolved issues about the appropriate management of the resulting intellectual property in terms of access to the technology, pricing, and sharing of royalties with researchers.[1] In this paper we explore some of these issues in the context of patented horticultural varieties. The results may be applicable more generally, but some aspects of the model are specific to horticultural crops.

Public universities in the United States have long been key players in producing new horticultural varieties through traditional breeding and, more recently, through genetic engineering. Alston et al. (2010) reported that 34.6% of all U.S. spending on agricultural R&D in 2007 was at universities, the majority of it through state agricultural experiment stations at land grant universities.[2] Examples of horticultural research programs at land grant universities include the apple breeding programs at the University of Minnesota, Washington State University, and Cornell University, the strawberry breeding program at the University of California, Davis, and the blueberry breeding program at the University of Florida. About one-sixth of public agricultural research spending

[1] The recent dispute between UC Davis and others over patented strawberry varieties illustrates the types of problems that can arise in the case of publicly patented horticultural varieties.

[2] Land grant universities are mostly public. One exception is Cornell University, the land grant university for the state of New York. However, given its land grant status, Cornell shares the public-spirited mission of public universities in the area of agricultural research.

in the U.S. is devoted to specialty crops, including horticultural breeding programs (Alston and Pardey 2008).[3] In this paper, we consider the question faced by public universities in determining how to license new horticultural varieties.

## The issue

The broad mission of university horticultural breeding programs is to provide benefits to consumers and producers of the varieties they develop, a relatively straightforward purpose in the bygone era that did not involve private-sector partners or IP considerations. This broad mission implies a different set of objectives to consider beyond the simple profit maximization that is often applied in models of private IP management.[4] However, in the current funding environment, other considerations are pertinent in defining the optimal licensing arrangements in addition to the broad payoffs to society. University administrators might seek to recoup the costs of the research program or to earn revenue for use elsewhere at the institution (typically significant imposts are applied to any extramural research funds); breeders employed by the university might demand a share of any royalties they generate as additional personal income or to help cover the costs of the lab (and in a competitive market for scientific talent, some such sharing is typical); industry partners who contributed to research support might insist on some say over the pricing of the resulting technology.

Moreover, the licensing arrangements might have implications for the productivity of the investment. Jensen and Thurby (2001) found that the use of royalties is important for inducing inventor effort. Along these same lines, Lach and Schankerman (2008) found that universities offering higher royalty shares to inventors garner more licensing income. Coupling these incentive considerations with the range of possible objectives highlighted above, clearly public universities have a more complicated set of choices compared to a technology firm that seeks to simply maximize profit. To capture these features, we characterize the optimization problem of the university in a way not yet considered in the economic literature on patenting.

[3] Alston and Pardey (2008) also documented that, over the years 1975–2004, a roughly constant share of total public agricultural research spending was devoted to specialty crops, which meant a comparative decline in research intensity given the rise in relative importance of production and consumption of specialty crops.

[4] Indeed, in a survey of technology transfer offices (TTOs) conducted by Belenzon and Schankerman (2009), local development objectives were reported to be either "very important" or "relatively important" by 82% of the public universities surveyed. Although this objective is just one of the objectives other than revenue maximization that we discuss, the results of this survey do support our assertion that public universities have a different set of objectives than the standard profit-maximizing licensor.

The complicated set of choices faced by the university has implications for licensing arrangements. Land grant universities have traditionally offered open patent licenses. Under this system, anyone who is willing to pay the required patent royalties and/or fees is free to license the variety.[5] However, some universities have moved to or are considering exclusive licensing. With exclusive licensing of a variety, the number of licensees is limited and controlled by the university, creating an oligopoly or monopoly on the production of that variety. Some universities have claimed that moving to exclusive licensing could be beneficial to consumers if restricting the number of licensees incentivizes licensees to produce a higher quality product than they would under open licensing. A 2006 report released by the University of Minnesota said of the SweeTango apple (a trademark name for the Minneiska cultivar): "The University believes exclusive licensing of MN 1914 will serve the interests of the consumer, Minnesota apple growers and the University's breeding program" (UMN 2006). The ability to benefit consumers through an increase in quality rests on producers being able to credibly signal quality and consumers being able to receive this signal. For some of the most visible horticultural varieties, this signaling is achieved through the use of trademarks and an associated marketing program. Notable examples include Sun-Maid raisins and Pink Lady apples. Assuming consumers associate the trademark with a higher quality product, they will be willing to pay more for this product than for a similar product without a trademark. Consumers who prefer this product will benefit from the higher quality they associate with the trademark, and producers of the trademarked variety will benefit from the price premium.[6]

These outcomes would appear to align with public universities seeking to provide benefits to both producers and consumers. However, producers who are excluded from use of these new varieties may claim that, in allowing only certain producers to participate, universities who adopt this policy are not fulfilling their obligation to provide public benefits. Said one Minnesota apple grower to a Minnesota Public Radio reporter, "Really, Sweetango can be the poster child for putting small, local growers out of business.... I just feel it's terribly unethical of the university to select one grower to form a monopoly with this apple" (Baier 2009). Such excluded producers are not able to benefit from the introduction of the new variety and could even lose if consumers prefer the

[5] Usually the variety is licensed to a nursery which in turn licenses openly to growers.

[6] We refer to the differentiating characteristic of the trademarked variety as "quality," but we could just as easily think about some other characteristic of product differentiation for which some consumers are willing to pay a premium – in apples this might be sweetness or crispness.

new variety produced under exclusive licensing compared with older varieties produced by growers not included in this licensing arrangement. A Minnesota apple wholesaler shared his view with Good Fruit Grower magazine. "The growers of Minnesota took Honeycrisp to the marketplace and brought it to world prominence.... [By exclusively licensing the SweeTango apple,] the university has made itself a competitor to us, and the consequences need to be looked at.... The university has played a key role in developing a unique apple industry in this region. We want to support the university and the symbiotic relationship we've had for decades. This agreement drives a nail in our industry. This could have been done differently" (Lehnert 2010). Even some of the more traditional breeders working at the universities exploring exclusive licensing are not supportive of the shift in licensing—indicating they want those varieties developed by the university to remain available to the public (Cahoon 2007).

## Our modeling approach

These views notwithstanding, it remains unclear what is the optimal licensing structure for patented horticultural technologies developed by public universities—any innovation is likely to result in some stakeholders being made worse off, regardless of the intellectual property and pricing arrangements. The harder question is what the university should do in light of its multidimensional objective function, constrained by the realities of mixed public-cum-private elements in financing and managing public agricultural R&D that yields patented technologies. In this paper we seek a partial answer to this question.

We develop a two-stage optimization model that considers the optimization problem faced by the grower and the optimization problem of the university. The application is specifically oriented to apples. The results may be applicable more generally, but the fact that apples are identified by varietal names throughout the marketing chain, and sometimes with a trademark, is an important feature of that industry that is captured specifically in our model. We assume each grower chooses the quality and quantity of apples to produce, and credibly signals quality through the use of a trademark and associated marketing program. The university chooses the type of royalty and/or fee (per-unit royalty, fixed fee or both), the number of licensees, and the financial measure to use

in its objective function, taking the growers' optimal output and quality as given.[7] The university can choose (or act as if it chooses) to maximize its own revenue, producer profits, consumer welfare, social welfare or some weighted average of these elements of social welfare, reflecting the political, institutional and economic constraints implied by the juxtaposition of the public purpose with private patents. Using simulations, we find that consumers will be better off under exclusive licensing if they are sensitive to trademark signals and are not sensitive to price. We also find that industry profits (and thus social welfare) may be higher under exclusive licensing. Finally, we find that the optimal fee structure and number of licensees depends on the specification of the university's objective function and the implicit weights given to the welfare of different groups in society. However, some distributional impacts that the university may want to consider (e.g. among growers who do or do not have access to a variety) are not resolved by our model.

Our work differs from previous studies in that we focus on the connection between the number of licensees and the university's objectives. Those studies that have looked at the university's objectives in patent licensing (e.g., Jensen and Thurby (2001) and Belenzon and Schankerman, (2008)) have focused on how these objectives relate to internal incentives for researchers, abstracting from the complexities of the downstream licensees. Furthermore, previous studies in the patent literature have taken the quality of the variety as given.[8] As the primary claim about the benefits from exclusive licensing centers on the ability of producers to affect the product quality perceived by consumers, we assume instead that the perceived quality of the new variety is endogenous and chosen by the licensee. The licensee affects the perceived quality through investment in a trademark, which can be seen as analogous to investing in branded product promotion more generally.

[7] In the literature, two royalty types are generally considered – per unit and ad valorem. In apples, patent royalties are generally charged per tree and trademark royalties are generally charged per unit weight of apples. In light of these practices, either of which can be modeled as per-unit royalties if we make several simplifying assumption about yield, we have chosen to leave out ad valorem royalties for the ease of analysis.

[8] Examples include Kamien et al. (1988) and Stamatopoulos and Tauman (2008). Kamien et al. (1988) consider a fixed fee licensing structure and identify circumstances in which an inventor will license to producers of an inferior incumbent product. The inventor will license to a single licensee if the new product is "drastically" superior in the sense that the monopoly price of the new product is below the marginal cost of the incumbent product. Stamatopoulos and Tauman (2008) consider a quality-improving innovation with a logit demand framework and an auction, royalty, or combined auction/royalty licensing fee structure. They find that when all consumers purchase the new product, the innovator licenses to a duopoly, because this allows the innovator to extract all of the potential consumer surplus, which is not possible with a monopoly.

## Empirical context

The primary motivation for this paper comes from recent considerations and moves by apple breeding programs at public universities in the United States to change the way they license apple varieties. Unlike most horticultural crops, the names of apple varieties are known to consumers and used in marketing. Empirical evidence indicates that consumers are willing to pay more for certain varieties than others. Consumers are willing to pay a premium for trademarked apples such as Honeycrisp and SweeTango (Yue and Tong 2011).

Several interesting examples in apples highlight the different choices universities face when patenting varieties and the advantages and disadvantages associated with these choices. Cripps Pink apples were developed not at a land grant university, but by a public agency, the Western Australian Department of Agriculture (now the Department of Agriculture and Food, or DAFWA) in 1973 (Cripps 1992). These apples are known to most of us as Pink Lady, their trademarked name. To use the trademark, producers must meet certain quality standards (APAL 2014). Although DAFWA does not use exclusive licensing for Cripps Pink, the success of the Pink Lady international trademark and associated marketing program in credibly signaling quality to consumers resulted in 72% of the Cripps Pink apples produced around the globe (excluding China) being marketed as Pink Lady in 2012 (Warner 2012). In the fiscal year ending in March 2013, Apple and Pear Australia Ltd. (APAL), the organization that manages the trademark, reported earning more than 1.5 million AUD that year alone from royalties for the Pink Lady and Sundowner (variety "Cripps Red") trademarks. This is an impressive figure given that the apple has been on the market for 20 years (APAL 2013). Moreover, this revenue does not include the royalty revenue earned by DAFWA on the Cripps Pink variety.

At the other end of the spectrum we have the Honeycrisp apple. Patented by the University of Minnesota in 1988, this variety was openly licensed by the university in the United States until its patent expired in 2008 (although the university still maintains enforceable patent rights in other regions of the world) (UMN 2014). In 2007, the university reported revenues of only $6 million from patent royalty revenues over the entire 20-year lifespan of the patent, although revenues continued to flow in from other countries after the U.S. patent expired.[9] At the same time, University of

[9]When considering the difference in revenue between Honeycrisp and Pink Lady, it is important to note that the University of Minnesota charged a per-tree royalty for Honeycrisp, which means it was only charged once over the

Minnesota officials reported being unsure if the name was even trademarked (Olson 2007). U.S. Patent and Trademark Office records show that the university trademarked the variety name in 1991 and abandoned the trademark in the next year (USPTO 2014). Although Honeycrisp remains a popular variety, its name may not provide as strong a quality signal to consumers as the Pink Lady, and this may be reflected in lower revenues to the university.

Recognizing the possible benefits from both exclusive licensing and trademarking, in light of the success of such managed varieties as Pink Lady, the University of Minnesota took a very different approach when it trademarked the SweeTango apple in 2005. The university licensed the Minneiska cultivar exclusively to a single grower, which in turn formed a cooperative of a select group of fewer than 50 large growers in the United States and eastern Canada to produce the variety. The university also allowed growers in Minnesota to grow up to 1,000 trees of the cultivar under the brand name, but they were permitted to sell their output only through direct sales. Minnesota growers challenged this limitation in Minnesota district court, and although the judge in the case deemed the arrangement to be legal in his 2011 ruling, the limit on the number of trees was increased to 2,000 per grower with a state cap of 100,000 trees. The limit will increase to 3,000 trees per grower and 150,000 trees in the state in 2017 (Lehnert 2011).

The differences in licensing arrangements for these three apple varieties and their marketing highlight the different options available to universities and the possible benefits from credibly signaling quality to consumers. Both Cripps Pink and Minneiska apples must meet certain quality standards to be marketed under their trademarked names, creating a higher quality, branded product. These cases highlight why allowing the quality signal to be endogenous may provide a different result than the more common assumption of exogenous quality.

Beyond apples, another interesting case to consider is that of the University of California, Davis (UC) strawberry licensing program. Although strawberries are not marketed to consumers under varietal names, the strawberry program highlights several interesting and important aspects that we consider in our analysis. The California Strawberry Commission (CSC) helps to fund the strawberry breeding program in California. The CSC is funded by a mandatory levy (or checkoff) on sales of strawberries, which means all members of the strawberry industry in California contribute

lifetime of the tree. For trademarked varieties, such as Pink Lady, revenues come in part from per-tree royalties on the variety, but also as a stream for as long as the output is marketed under the trademark.

in ways that have policy implications. The breeding program has produced a number of successful varieties and has been a highly lucrative program for the university; four strawberry varieties were among the top 25 revenue-generating inventions in the UC system in 2013. These four varieties earned the university nearly $6 million in that year alone. Like many other public universities, the university administration splits its revenue with the breeder (UC 2014a). Since 1997, the policy has been to give the breeder 35% of annual income net of direct expenses of administering the patent (UC 1997). This policy is relevant to our work because private individuals are not bound by the same mission as the university. The actions of the breeder can potentially skew the university's outcome away from social benefit and toward revenue maximization. In their survey of TTOs, Jensen and Thurby (2001) found that managers of TTOs found themselves trying to balance the objectives of both inventors and the university administration. In a controversial lawsuit that is still pending, the CSC is suing the UC to ensure the strawberry breeding program will be sustained. This followed an announcement by the current principal breeder that he planned to leave the UC, taking his breeding stock with him (which will also be retained by the UC) and start a private company. The CSC and the UC are currently in negotiations, but this episode highlights the politicization of the university's decision-making environment.

All of these situations illustrate the complex optimization problem of the technology transfer office at a land grant university. Although the objective of the university is ostensibly one of public benefit, the university must consider many factors in interpreting that purpose. First, phrases like "public use and benefit," (from the UC Technology Transfer Office mission statement) are ambiguous (UC 2014b). Consumers, producers and university employees are all part of the "public," yet their desires may well be at odds. Furthermore, technology transfer offices are just one small component of a larger university bureaucracy and must answer to university administrators with potentially different goals. Finally, individual inventors (in this case, breeders) affect the timing and quality of inventions, which affects the timing and magnitude of benefits to consumers and producers. In our model, we thus consider several interpretations of these university objectives to find the optimal licensing arrangement in each case.

## Model and analytical results

As highlighted above, the university's decision-making process entails a complex balance between the often conflicting goals of different stakeholders. One way to represent this complexity is to model the the decisions of the university (or its TTO) as though it seeks to maximize a weighted welfare function, with different interest groups having different weights. One special case of this weighted objective function is one with equal weights—maximum social welfare. Others involve unequal weights. To better understand how the differing goals of different university stakeholders might influence the actions of the university, and to illustrate the individual elements of social welfare, we can consider several other special cases. We consider the optimal outcomes for the per-unit royalty rate, fixed fee and number of licensees when the university maximizes patent revenue, consumer surplus, or producer profits, or the simple sum of all three—social welfare. In order to optimize, however, the university must take into account how producers will react to its choices. First we present models of producers' profit-maximization problems given an exogenous per-unit royalty rate and fixed fee under three different sets of assumptions about the licensing structure. We then present our model of the university's optimization problem in these three scenarios.

We assume a single variety of apple patented by a university. The inverse demand for this variety is given by: $D^{-1} = P(Q, A)$, where $A$ is the cost of the trademark. This cost could include expenditure on legal fees, advertising and promotion, grading and packaging or other aspects of marketing and brand creation. It is a lump-sum cost in the sense that it does not depend on $Q$. We assume complete information—in other words, demand and costs are known.[10] We assume that greater investment in a trademark signals higher quality of the output to all consumers. The university charges a per-unit royalty, $r$, and a fixed fee, $F$, for the use of the patent for this variety.[11] For the purposes of our simulations, we assume a demand function of the constant elasticity form, $Q = e^{\beta} P^{\eta} A^{\alpha}$, where $\eta < -1$, $0 < \alpha < 1$ and $\beta > 0$ is a scaling parameter.[12]

[10] Bousquet et al. (1998) consider the implications of incomplete information.

[11] In the context of apples, one might consider the fixed fee to be a minimum per-tree royalty or another type of one-time fee. Although it appears that most apple royalties are charged as per-tree royalties, this is equivalent to a per-apple royalty under the assumption that all trees of the same variety have equal yield and lifespan.

[12] Although our setting is one in which we consider a new variety, for simplicity in our model we explicitly consider only the price and quality for that variety and abstract away from other factors that might affect demand for the new variety. This could include prices and qualities of other varieties of apples or other related products such as pears or bananas. In our analysis, all of these other variables are treated as constant, and subsumed in the intercept parameter, $\beta$. In a more complete model, the prices and qualities of competing products might be jointly endogenous. Some previous studies (e.g. Sen and Tauman (2007)) differentiate between "drastic" and "non-drastic" innovations to

### Monopoly

First, consider a profit-maximizing monopolist. The monopolist's problem is:

$$\max_{Q_M, A_M} \quad \Pi_M = [P(Q_M, A_M) - c - r]Q_M - A_M - F. \tag{1}$$

Rearranging, the first-order conditions yields the following conditions:

$$\frac{P_M^* - c - r}{P_M^*} = -\frac{1}{\eta} \text{ and } -\frac{\alpha}{\eta} = \frac{A_M^*}{P_M^* Q_M^*}, \tag{2}$$

where $\eta$ is the elasticity of demand with respect to price and $\alpha$ is the elasticity of demand with respect to investment in the trademark. This is analogous to Dorfman-Steiner's (1954) result related to advertising, with an additional term, $r$, relating to the patent.[13] The fixed fee does not affect the result. Using this result in the constant elasticity demand function, defined above, we get:

$$A_M^* = \left[ -\frac{\alpha}{\eta} e^{\beta} \left( \frac{\eta(c+r)}{\eta+1} \right)^{\eta+1} \right]^{\frac{1}{1-\alpha}} \tag{3}$$

$$P_M^* = \frac{\eta(c+r)}{\eta+1} = \frac{c+r}{1+\frac{1}{\eta}} \tag{4}$$

$$Q_M^* = \left[ \left( -\frac{\alpha}{\eta} \right)^{\alpha} e^{\beta} \left( \frac{\eta(c+r)}{\eta+1} \right)^{\eta+\alpha} \right]^{\frac{1}{1-\alpha}} \tag{5}$$

$$\Pi_M^* = \left( \frac{1-\alpha}{\alpha} \right) \left[ -\frac{\alpha}{\eta} e^{\beta} \left( \frac{\eta(c+r)}{\eta+1} \right)^{\eta+1} \right]^{\frac{1}{1-\alpha}} = \left( \frac{1-\alpha}{\alpha} \right) A_M^* - F \tag{6}$$

$$CS_M^* = -\frac{1}{\eta} \left[ \left( -\frac{\alpha}{\eta} \right)^{\alpha} e^{\beta} \left( \frac{\eta(c+r)}{\eta+1} \right)^{\eta+1} \right]^{\frac{1}{1-\alpha}} = -\frac{1}{\eta} Q_M^* P_M^* \tag{7}$$

$$R|_{Q_M^*} = r \left[ \left( -\frac{\alpha}{\eta} \right)^{\alpha} e^{\beta} \left( \frac{\eta(c+r)}{\eta+1} \right)^{\eta+\alpha} \right]^{\frac{1}{1-\alpha}} + F = rQ_M^* + F \tag{8}$$

$$\tag{9}$$

better understand how a new variety fits into the existing market. While this is an important aspect of understanding the introduction of new varieties, it is not something we consider in this paper.

[13] Dorfman and Steiner (1954) found that in the case of monopoly, the profit-maximizing advertising to sales ratio is equal to the elasticity of demand with respect to advertising divided by the elasticity of demand with respect to price. The first equality in equation (2) simply indicates the basic mark-up is equal to the absolute value of the inverse price elasticity – the standard monopoly result. Our work expands on this result in that we consider oligopolies with two different possibilities for trademark investment and then consider the upstream licensor's actions given the optimal investment in the trademark by the firm.

When either the royalty rate or the cost of production increases, price also increases and investment in the trademark, quantity produced, consumer surplus and profits all decrease. Furthermore, the Hessian of the profit function is negative semi-definite as long as $|\eta| > 1$ and $|\eta| > \alpha$, confirming that we are indeed looking at a maximum. $R|_{Q_M^*}$ represents the royalty revenue to the university given values for $r$ and $F$, and profit maximization by the monopolist.

### Oligopoly with individual trademark investment

Now, we can examine the same market, but with a Cournot oligopoly selling the new variety. In this case, all of the producers are still investing in a single trademark, and each firm invests the amount in the trademark that maximizes its profits. We define output and investment in the trademark such that $Q_O = \Sigma_i q_O^i$ and $A_O = \Sigma_i A_O^i$. For the oligopolist we will consider a sequential problem.[14] In the first stage, the oligopolist chooses how much to spend on a trademark, $A_O^i$. In the second stage, the oligopolist chooses the quantity, $q_O^i$, taking $A_O^i$ and $A_O$ as given. Solving by backwards induction, the oligopolist's second-stage problem is:

$$\max_{q_O^i} \ \Pi_O = P(Q_O, A_O)q_O^i - (c+r)q_O^i - A_O^i - F. \tag{10}$$

Rearranging the first-order condition and assuming identical firms yields:

$$\frac{P_O^* - c - r}{P_O^*} = -\frac{1}{N\eta}, \tag{11}$$

where $N > 1$ is the number of oligopolists. The second-order condition requires $N > 1$ for a maximum. Equation (10) can also be expressed as:

$$q_O^{i*}(A_O) = \frac{1}{N} e^{\beta} A^{\alpha} \left( \frac{N\eta(c+r)}{N\eta + 1} \right)^{\eta}. \tag{12}$$

The oligopolist's first-stage problem is thus:

$$\max_{A_O^i} \ \Pi_O^i|_{q_O^{i*}} = P_O^* q_O^{i*}(A_O) - (c+r)q_O^{i*}(A_O) - A_O^i - F. \tag{13}$$

[14] For the monopolist, the sequential problem and the simultaneous problem yield the same result, hence the simultaneous treatment of that problem.

Rearranging the first-order condition yields:

$$-\frac{\alpha}{N\eta} = \frac{A_O^*}{P_O^* q_O^{i*}}. \tag{14}$$

This second-order condition holds for a maximum if $0 < \alpha < 1$, which we have already assumed. Assuming the same constant elasticity demand function as in the previous problem, and identical firms, we get:

$$A_O^{i*} = \frac{1}{N}\left[-\frac{\alpha}{N^2\eta}e^{\beta}\left(\frac{N\eta(c+r)}{N\eta+1}\right)^{\eta+1}\right]^{\frac{1}{1-\alpha}} \tag{15}$$

$$P_O^* = \frac{N\eta(c+r)}{N\eta+1} = \frac{c+r}{1+\frac{1}{N\eta}} \tag{16}$$

$$Q_O^{i*} = \frac{1}{N}\left[\left(-\frac{\alpha}{N^2\eta}\right)^{\alpha} e^{\beta}\left(\frac{N\eta(c+r)}{N\eta+1}\right)^{\eta+\alpha}\right]^{\frac{1}{1-\alpha}} \tag{17}$$

$$\Pi_O^{i*} = \left(\frac{N-\alpha}{N\alpha}\right)\left[-\frac{\alpha}{N^2\eta}e^{\beta}\left(\frac{N\eta(c+r)}{N\eta+1}\right)^{\eta+1}\right]^{\frac{1}{1-\alpha}} = \left(\frac{N-\alpha}{N\alpha}\right)A_O^* \tag{18}$$

$$CS_O^* = -\frac{1}{\eta}\left[\left(-\frac{\alpha}{N^2\eta}\right)^{\alpha} e^{\beta}\left(\frac{N\eta(c+r)}{N\eta+1}\right)^{\eta+1}\right]^{\frac{1}{1-\alpha}} = -\frac{1}{\eta}Q_O^* P_O^* \tag{19}$$

$$R|_{Q_O^*} = r\left[\left(-\frac{\alpha}{N^2\eta}\right)^{\alpha} e^{\beta}\left(\frac{N\eta(c+r)}{N\eta+1}\right)^{\eta+\alpha}\right]^{\frac{1}{1-\alpha}} + F = rQ_O^* + F \tag{20}$$

We again have the case that when either the royalty rate or the cost of production increases, price increases, while quantity, investment in trademarks, profits and consumer surplus all decrease. Furthermore, an increase in the number of firms implies decreases in firm-level quantity of output produced, amount of individual investment in the trademark, and profit, as well as industry investment in trademarks. If the number of firms, $N$, is such that $N < \frac{1}{2\alpha}$, then when the number of firms increases, total quantity produced increases, but if $N > \frac{1}{2\alpha}$, total quantity produced decreases. If the number of firms, $N$, is such that $N < \frac{1}{4\alpha}$, then when the number of firms increases, consumer surplus increases, but if $N > \frac{1}{4\alpha}$, consumer surplus decreases.

### Oligopoly with joint trademark investment

We can also look at what happens when oligopolistic producers jointly optimize their investment in the trademark (for instance, as part of a marketing order). In this case, solving by backwards induction, the second stage is the same as for the oligopoly case above:

$$\underset{q_J^i}{max} \;\; \Pi_J = h(Q_J, A_J)q_J^i - (c+r)q_J^i - A_J^i - F. \tag{21}$$

Rearranging the first-order condition yields the following condition:

$$\frac{P_J^* - c - r}{P_J^*} = -\frac{1}{N\eta}, \tag{22}$$

where $N$ is the number of oligopolists. An alternative form of equation (21) yields an expression for $q_J^{i*}$ as a function of $A_J$, which we can then use in solving the oligopolists' first-stage problem. Again, we assume firms are identical in terms of quantity produced. However, now the oligopolists jointly optimize investment in the trademark. The oligopolists' joint first-stage problem is thus:

$$\underset{A_J}{max} \;\; \Pi_J|_{Q_J} = P_J^* Q_J^{i*}(A_J) - (c+r)Q_J^{i*}(A_J) - A_J - NF. \tag{23}$$

Rearranging the first-order condition yields the following condition:

$$-\frac{\alpha}{N\eta} = \frac{A_J^*}{P_J^* Q_J^*}. \tag{24}$$

Assuming the same demand function as in the previous problems and identical firms, we get:

$$A_J^{i*} = \frac{1}{N}\left[-\frac{\alpha}{N\eta}e^{\beta}\left(\frac{N\eta(c+r)}{N\eta+1}\right)^{\eta+1}\right]^{\frac{1}{1-\alpha}} \tag{25}$$

$$P_J^* = \frac{N\eta(c+r)}{N\eta+1} = \frac{c+r}{1+\frac{1}{N\eta}} \tag{26}$$

$$Q_J^{i*} = \frac{1}{N}\left[\left(-\frac{\alpha}{N\eta}\right)^{\alpha}e^{\beta}\left(\frac{N\eta(c+r)}{N\eta+1}\right)^{\eta+\alpha}\right]^{\frac{1}{1-\alpha}} \tag{27}$$

$$\Pi_J^{i*} = \left(\frac{N-\alpha}{N\alpha}\right)\left[-\frac{\alpha}{N\eta}e^{\beta}\left(\frac{N\eta(c+r)}{N\eta+1}\right)^{\eta+1}\right]^{\frac{1}{1-\alpha}} = \left(\frac{1-\alpha}{N\alpha}\right)A_J^* \tag{28}$$

$$CS_J^* = -\frac{1}{\eta}\left[\left(-\frac{\alpha}{N\eta}\right)^{\alpha}e^{\beta}\left(\frac{N\eta(c+r)}{N\eta+1}\right)^{\eta+1}\right]^{\frac{1}{1-\alpha}} = -\frac{1}{\eta}Q_J^*P_J^* \tag{29}$$

$$R|_{Q_J^*} = r\left[\left(-\frac{\alpha}{N\eta}\right)^{\alpha}e^{\beta}\left(\frac{N\eta(c+r)}{N\eta+1}\right)^{\eta+\alpha}\right]^{\frac{1}{1-\alpha}} + F = rQ_J^* + F \tag{30}$$

As in the previous case, as the royalty rate and cost of production increase, price increases, and quantity, total investment in the trademark and consumer surplus decrease. Furthermore, an increase in the number of firms implies decreases in firm-level quantity produced, investment in the trademark, and profits, as well as industry-wide investment in the trademark and profits. If the number of firms, $N$, is such that $N < \frac{1}{\alpha}$, then when the number of firms increases, total quantity produced increases, but if $N > \frac{1}{\alpha}$, total quantity produced decreases. When the number of firms, $N$, increases, if $N < \frac{1}{2\alpha}$, then consumer surplus increases, but if $N > \frac{1}{2\alpha}$, consumer surplus decreases.

### Comparison across different market structures

Table 1 reports a summary of all the above results for comparison, as well as the analytical results of the model of the university's optimization problem to be described below. We can determine certain relationships among key results for the different market structures by comparing the corresponding first-order conditions. From the first-order conditions determining price (jointly determined with output), we have:

$$c + r = (1+\frac{1}{N\eta})P_O^* = (1+\frac{1}{N\eta})P_J^* = (1+\frac{1}{\eta})P_M^*, \tag{31}$$

where $P_O^*$ is the equilibrium price under oligopoly, $P_J^*$ is the equilibrium price under oligopoly with joint investment in the brand, and $P_M^*$ is the equilibrium price under monopoly. From this, we learn:

$$P_O^* = P_J^* \text{ and } P_O^* = \frac{N\eta + N}{N\eta + 1} P_M^*. \tag{32}$$

From the first-order conditions determining investment in the trademark, we have:

$$-\frac{\alpha}{\eta} = \frac{A_M^*}{P_M^* Q_M^*} = \frac{N^2 A_O^*}{P_O^* Q_O^*} = \frac{N A_J^*}{P_J^* Q_J^*}. \tag{33}$$

This tells us that: $P_O^* Q_O^* = \frac{N^2 A_O^*}{A_M^*} P_M^* Q_M^*$. We find that $\frac{N^2 A_O^*}{A_M^*} > 1$, indicating that $P_O^* Q_O^* > P_M^* Q_M^*$. In other words, industry revenue under the oligopoly is higher than industry revenue under the monopoly. Furthermore, $Q_J^* > Q_O^*$ tells us: $P_J^* Q_J^* > P_O^* Q_O^* > P_M^* Q_M^*$, which means industry revenue under the oligopoly with joint investment in the trademark is greater than industry revenue under oligopoly or monopoly.

We also learn from the first-order conditions related to trademark investment that: $A_J^* N > A_O^* N^2 > A_M^*$, thus $A_J^* > A_O^*$. Thus, investment in the trademark is greater under the oligopoly with joint investment in the trademark than under the oligopoly without it. It is unclear whether the amount of investment in the trademark is greater under the monopoly or under the oligopoly with joint investment in the trademark. The relative magnitudes of $A_M^*$ and $A_J^*$, as well as $Q_M$ and $Q_J$, are ambiguous analytically. We find that $A_M^* > A_J^*$ if $N^{-\frac{\eta}{\eta+1}} < \frac{\eta+1}{N\eta+1}$ and $Q_M > Q_J$ if $N^{-\frac{\eta}{\eta+\alpha}} < \frac{\eta+1}{N\eta+1}$ but cannot show general cases in which these inequalities hold. We say more about the relative magnitudes of the optimal values of these variables in the discussion of the simulation results.

Overall, we find the case in which oligopolists invest jointly in the trademark dominates the case in which they invest individually; both consumers and producers are better off. However, whether a monopoly might be even better for consumers and producers depends on the parameter values.

### The university's objective function

As previously discussed, the university's decision problem is potentially very complex and is influenced by a number of factors. We consider four possible optimization problems of the university to help resolve and characterize this complexity. The university might maximize patent revenue, producer profits, consumer surplus, or social welfare. A more realistic representation of the university's decision process is given by assuming the university (acts as though it) maximizes a weighted function of patent revenue, industry profits, and consumer surplus with unequal weights based on political and institutional considerations.

If the university chooses to maximize its patent income, the university's problem is:

$$\max_{r} \;\; R = rQ(r) + \Pi(r). \tag{34}$$

This set-up assumes that the university extracts the maximum possible fixed fee from producers (i.e., total industry profits). The optimal royalty rate under each market structure is then given by:

$$r_M^*(R_{MAX}) = 0 \tag{35}$$

$$r_O^*(R_{MAX}) = \frac{c[N(\eta - \eta N)(1-\alpha) + \alpha(N-1)(\eta+1)]}{\alpha(\eta+1) + N^2(\eta^2+\eta)} \tag{36}$$

$$r_J^*(R_{MAX}) = \frac{c[(\eta - \eta N)(1-\alpha)]}{\alpha(\eta+1) + N(\eta^2+\eta)}. \tag{37}$$

In the case of monopoly, the optimal choice for the university is a fixed fee equal to the monopoly rents. In the case of oligopoly, so long as the optimal royalty rate is positive, the optimal choice for the university is a royalty together with a fixed fee equal to oligopoly rents.

Alternatively, the university could choose to maximize social welfare. The university's problem is then:

$$\max_{r,F} \;\; SW = CS(r) + \Pi(r,F) + R(r,F). \tag{38}$$

Solving the optimization problem in equation (38), we find the following optimal royalty rates:

$$r_M^*(SW_{MAX}) = 0 \tag{39}$$

$$r_O^*(SW_{MAX}) = -\frac{c[N^2 + N^2\eta\alpha + N\alpha + N\eta - \eta\alpha - \alpha]}{N^2 - \eta\alpha - \alpha - N^2\eta^2} \tag{40}$$

$$r_J^*(SW_{MAX}) = -\frac{c(N\eta\alpha + N - \alpha\eta + \eta)}{-N\eta^2 + N - \alpha\eta - \alpha} \tag{41}$$

Here again we find that the optimal royalty is zero for a monopoly. Since the fixed fee is simply a transfer from producers to the university, changing the fixed fee does not affect social welfare. Thus, any fixed fee less than or equal to monopoly rents that the university chooses will also maximize social welfare. Likewise, in the oligopoly situation, the university will charge the optimal royalty rate to maximize social welfare, and it can then charge any fixed fee it chooses, less than the oligopoly rents, to achieve its income objectives.

Finally, we consider the case of maximizing either consumer surplus or producer profits. Consumer surplus is maximized where royalties are zero, but the fixed fee can be of any magnitude less than or equal to producer profits since the fixed fee will not affect the quantity of output or investment in the trademark and thus will not affect consumer surplus. Therefore, consumers will always prefer a revenue-equivalent fixed fee to a royalty.

On the other hand, producer profits are affected by both the royalty and the fixed fee. Producers' profits are maximized when both the royalty and fixed fee are equal to zero. We might expect that producers would prefer a royalty rate to a revenue-equivalent fixed fee, as a portion of the cost will be borne by the consumer in the case of a royalty. However, in our model it is not always the case that producers prefer a royalty rate. In some cases, producers prefer a fixed fee. For ease of analysis, we express the royalty rate, $r$ as a function of the marginal cost, $c$, such that: $r = \gamma c$. Then for each of the three cases, the conditions under which producers prefer a

revenue-equivalent fixed fee to a royalty are:

$$\text{Monopoly: } (1+\gamma)^{\left(\frac{\eta+\alpha}{1-\alpha}\right)} < \frac{\alpha-1}{\alpha-1+\gamma(\alpha+\eta)} \tag{42}$$

$$\text{Oligopoly (Individual): } (1+\gamma)^{\left(\frac{\eta+\alpha}{1-\alpha}\right)} < \frac{\alpha-N}{\alpha-N+\gamma(\alpha+N^2\eta)} \tag{43}$$

$$\text{Oligopoly (Joint): } (1+\gamma)^{\left(\frac{\eta+\alpha}{1-\alpha}\right)} < \frac{\alpha-1}{\alpha-1+\gamma(\alpha+N\eta)} \tag{44}$$

As the the number of firms, $N$, increases, the magnitudes of the denominators of the right hand side of equations 43 and 44 increase relative to the magnitudes of the numerators, indicating the inequalities may not hold when the number of firms is large. This result is due to the effect of the royalty rate on investment in the trademark. The royalty rate affects the quantity demanded through price and investment in the trademark. As the royalty rate increases, the optimal price increases and the optimal investment in the trademark decreases. For scenarios in which the number of firms is relatively large, because the trademark is a public good, the optimal investment in the trademark at a royalty rate of zero is relatively low, so when the royalty is increased, the distorting effect on investment in the trademark is relatively small and the loss to producers is outweighed by the benefit from sharing the cost of the royalty with consumers. However, when the number of firms is relatively small, the optimal investment in the trademark is relatively high when the royalty rate is zero, and the distorting affect of the royalty is more severe than in the case with more firms. In this case, the negative affect of the royalty on trademark investment and resulting decreasing in quantity outweigh the positive benefits of sharing the cost of the royalty with consumers, and firms may prefer a fixed fee.

## Simulations

To better understand the implications of these analytical results, we ran numerical simulations. All reported simulations assume a scaling parameter of $\beta = 10$ and marginal cost of production of $c = 1$. We assume an own-price elasticity of demand of $\eta \in [-2, -10]$ and elasticity of demand with respect to investment in the trademark of $\alpha \in [0.05, 0.15]$. These elasticities allow for a fairly wide range of substitutability of the new variety for incumbent apple varieties, and a rate of response to investment in the trademark comparable to observed elasticities of demand response to generic

promotion for agricultural products. For the figures labeled "low," we assume that $\alpha = 0.05$ and $\eta = -10$. In this case, the effect of brand investment on demand is small, and consumers are sensitive to price changes. For those labeled "high," we assume $\alpha = 0.15$ and $\eta = -2$. In this case, demand is considerably more affected by the branding and consumers are less sensitive to price. In Figure 1 we assume $r = 0.5$.

We find that investment in the trademark is larger in the case of a monopoly than in either oligopoly case. The trademark investment is also relatively large for oligopolists when the number of firms is small, but drops precipitously as the number of firms increases. This can be seen in Panels A and B of Figure 1. As the investment in the trademark goes down, we see the quantity of output follows it, as shown in Panels C and D of Figure 1. With the exception of the addition of the first few firms, total output actually decreases as the number of firms increases, as does price and consequently, industry profits, as shown in Panels E and F of Figure 1. As we show in Figures G and H of Figure 1, consumers see a boost in surplus with the addition of the first several firms. In the "low" case ($\alpha = 0.05$ and $\eta = -10$), in which consumers are affected relatively less by investment in the trademark and relatively more by price (Panel H), consumer surplus declines slowly as the number of firms increases. However, in the "high" case ($\alpha = 0.15$ and $\eta = -2$), in which consumers are affected relative more by investment in the trademark and relatively less by price (Panel G), we see that consumer surplus declines quite quickly with increases in the number of firms. Importantly, we also find that in the case of investment in the trademark by individual firms, consumer surplus is actually greater with a monopoly than with a relatively small oligopoly. Panels I and J of Figure 1 show social welfare, given by adding university revenue to consumer surplus and producer profits. Panel I clearly demonstrates how a monopoly or small oligopoly could be beneficial compared with a more competitive industry under specific demand conditions.

In Figure 1, we assumed $r$ was fixed to better demonstrate the relationship between market structures. However, the university chooses $r$. In Figure 2, we show social welfare and university revenue as a function of $r$. "Joint" refers to the case in which oligopolists jointly optimize their investment in the trademark. "Individual" refers to the case in which they optimize individually. We see that in the "low" case ($\alpha = 0.05$ and $\eta = -10$) where consumers are comparatively sensitive to price but not to investments in the trademark, the optimal royalty rate is zero if the university wants to maximize social welfare (Panels B and D of Figure 2); it is positive but small in magnitude

if the university wants to maximize revenue for $N > 1$ (Panels F and H of Figure 2). The optimal royalty rate is positive and larger in magnitude when consumers are not responsive to price but are affected by investment in the trademark (see Panels A, C, E and G). Furthermore, we see that in all cases, as the number of firms increases, the optimal royalty rate increases or stays constant. Given the optimal royalty rate in each case, social welfare is higher with an oligopoly that jointly maximizes investment in the trademark than with a monopoly (see Panels A and B). However, for the other four cases under consideration, the monopoly outcome dominates. Finally, the optimal royalty rate is higher under revenue maximization than under social welfare maximization regardless of the number of firms.

## Conclusion

In this paper we have considered two critical aspects of patenting horticultural varieties developed by public universities: the role of investment in a trademark and the complicated optimization problem faced by land-grant institutions. We develop a simple model that abstracts from many of the complexities of the situation. These include but are not limited to: the role of risk and uncertainty in decision-making by the university and firms, the complexities of substitution between the new variety and existing varieties and products if their prices and qualities are jointly endogenous, the inherently dynamic nature of economic problems concerning perennial crops and IP management, and the complex internal and external political influences that affect university TTO managers.

Nevertheless, several important insights stem from our work. First, consumers (and society—in a social welfare sense) could benefit from a university choosing to license fewer firms to produce a new variety. However this is true only if consumers are not very responsive to price and are relatively responsive to investment in a trademark (i.e., if they attach a high value to the perceived quality of the trademarked product). This result helps defend universities against claims that, by using exclusive licensing, they are not fulfilling their public mission. However, with exclusive licensing the producer benefits are shared among a small number of firms; others are excluded. Presumably this distributional issue is of concern to the university, but we have not addressed it explicitly in our analysis. This was the concern raised by farmers in Minnesota when the SweeTango

apple was introduced and has been considered extensively by Cornell University and Washington State University as they develop licenses.

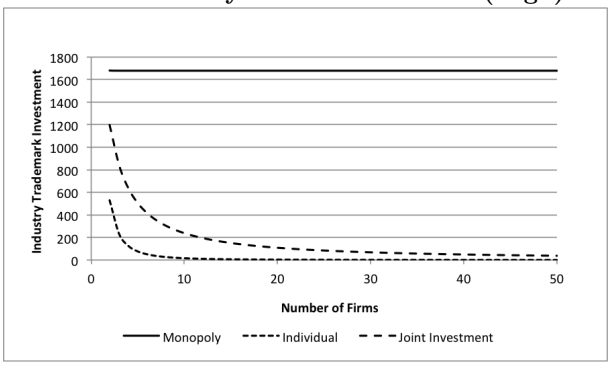
The detail of the university's objective function matters both in determining the optimal number of licensees and the optimal licensing fee structure. We find that the university will license to a monopoly and charge a fixed fee if maximizing revenue, but will license to more than one firm and will charge an optimal royalty (and may or may not extract additional producer surplus in the form of a fixed fee) if maximizing social welfare. In practice, we see university technology transfer offices negotiating with commodity boards, industries, inventors and university administrators to set their fees. Given the many stakeholders, the political complexities, and other constraints, it seems likely that universities are setting their fees and licensing structures in a more complicated context than previous models have allowed—profit-maximization or maximization of social welfare. Our analysis sheds some light on this issue in a comparatively short-run context in which we take as given the amount of research investment, and the quality and quantity of resulting inventions. The structure of the licensing arrangements and fees (and their implications for funds available for university research) are also likely to have implications for the rate of innovation in a longer-run analysis.

**Table 1: Analytical Results of University (Licensor) and Firm (Licensee) Optimization**

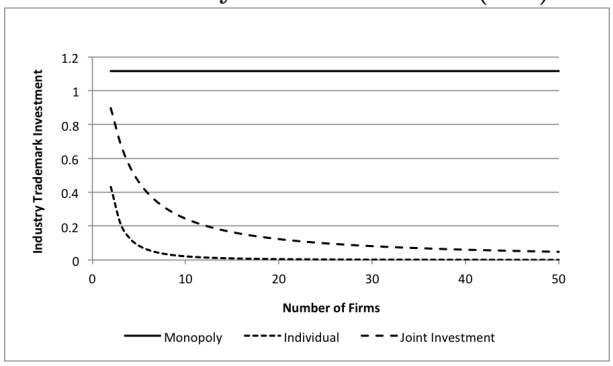
| *Result* | *Definition* | *Monopoly* | *Oligopoly* | *Oligopoly with Joint Branding* |
|---|---|---|---|---|
| $P^*$ | Output price | $\frac{c+r}{1+\frac{1}{\eta}}$ | $\frac{c+r}{1+\frac{1}{N\eta}}$ | $\frac{c+r}{1+\frac{1}{N\eta}}$ |
| $Q^*$ | Industry output | $\left[\left(-\frac{\alpha}{\eta}\right)^{\alpha} e^{\beta}\left(\frac{\eta(c+r)}{\eta+1}\right)^{\eta+\alpha}\right]^{\frac{1}{1-\alpha}}$ | $\left[\left(-\frac{\alpha}{N^2\eta}\right)^{\alpha} e^{\beta}\left(\frac{N\eta(c+r)}{N\eta+1}\right)^{\eta+\alpha}\right]^{\frac{1}{1-\alpha}}$ | $\left[\left(-\frac{\alpha}{N\eta}\right)^{\alpha} e^{\beta}\left(\frac{N\eta(c+r)}{N\eta+1}\right)^{\eta+\alpha}\right]^{\frac{1}{1-\alpha}}$ |
| $A^*$ | Industry trademark investment | $\left[-\frac{\alpha}{\eta}e^{\beta}\left(\frac{\eta(c+r)}{\eta+1}\right)^{\eta+1}\right]^{\frac{1}{1-\alpha}}$ | $\left[-\frac{\alpha}{N^2\eta}e^{\beta}\left(\frac{N\eta(c+r)}{N\eta+1}\right)^{\eta+1}\right]^{\frac{1}{1-\alpha}}$ | $\left[-\frac{\alpha}{N\eta}e^{\beta}\left(\frac{N\eta(c+r)}{N\eta+1}\right)^{\eta+1}\right]^{\frac{1}{1-\alpha}}$ |
| $P^*Q^*$ | Industry revenue | $-\frac{\eta}{\alpha}A^*$ | $-\frac{N^2\eta}{\alpha}A^*$ | $-\frac{N\eta}{\alpha}A^*$ |
| $\frac{A^*}{P^*Q^*}$ | Trademark investment ratio | $-\frac{\alpha}{\eta}$ | $-\frac{\alpha}{N^2\eta}$ | $-\frac{\alpha}{N\eta}$ |
| $\Pi^*$ | Industry profits | $\left(\frac{1-\alpha}{\alpha}\right)A^* - F$ | $\left(\frac{N-\alpha}{\alpha}\right)A^* - NF$ | $\left(\frac{1-\alpha}{\alpha}\right)A^* - NF$ |
| $CS^*$ | Consumer surplus | $-\frac{1}{\eta}P^*Q^*$ | $-\frac{1}{\eta}P^*Q^*$ | $-\frac{1}{\eta}P^*Q^*$ |
| $SW^*$ | Social welfare | $\left(\frac{1-\alpha}{\alpha}\right)A^* + \left(r - \frac{1}{\eta}P^*\right)Q^*$ | $\left(\frac{N-\alpha}{\alpha}\right)A^* + \left(r - \frac{1}{\eta}P^*\right)Q^*$ | $\left(\frac{1-\alpha}{\alpha}\right)A^* + \left(r - \frac{1}{\eta}P^*\right)Q^*$ |
| $r^*(R_{MAX})$ | Optimal royalty under revenue max. | 0 | $\frac{c[N(\eta-\eta N)(1-\alpha)+\alpha(N-1)(\eta+1)]}{\alpha(\eta+1)+N^2(\eta^2+\eta)}$ | $\frac{c[(\eta-\eta N)(1-\alpha)]}{\alpha(\eta+1)+N(\eta^2+\eta)}$ |
| $r^*(SW_{MAX})$ | Optimal royalty under social welfare max. | 0 | $\frac{c[N^2+N^2\eta\alpha+N\alpha+N\eta-\eta\alpha-\alpha]}{N^2-\eta\alpha-\alpha-N^2\eta^2}$ | $-\frac{c(N\eta\alpha+N-\alpha\eta+\eta)}{-N\eta^2+N-\alpha\eta-\alpha}$ |

**Figure 1. Simulations: $r = 0.5$** (High: $\alpha = 0.15$, $\eta = -2$; Low: $\alpha = 0.05$, $\eta = -10$)

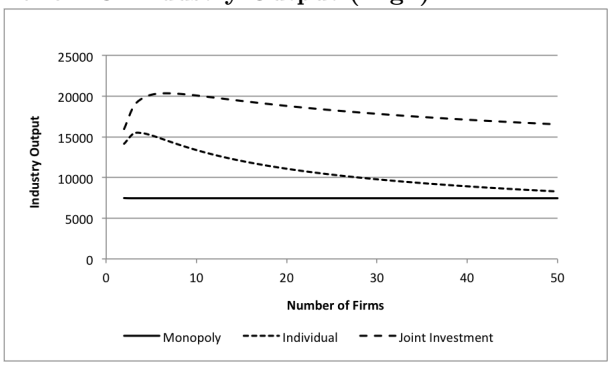
**Panel 1A: Industry Brand Investment (High)**



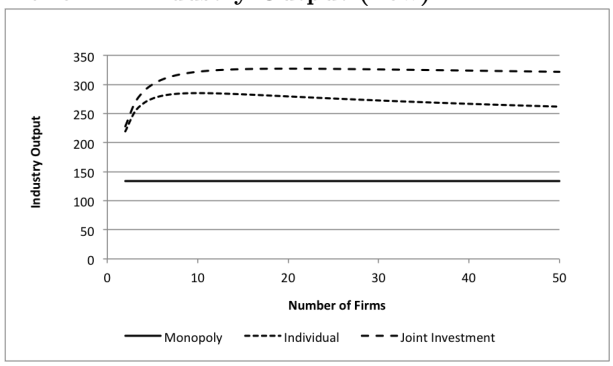

**Panel 1B: Industry Brand Investment (Low)**



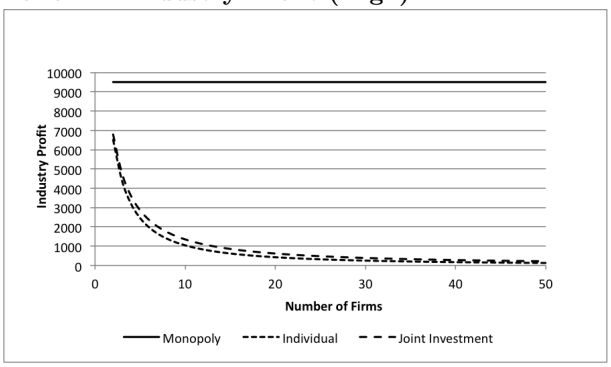

**Panel 1C: Industry Output (High)**



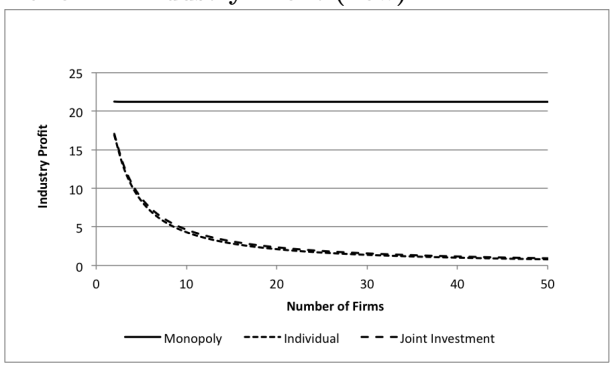

**Panel 1D: Industry Output (Low)**



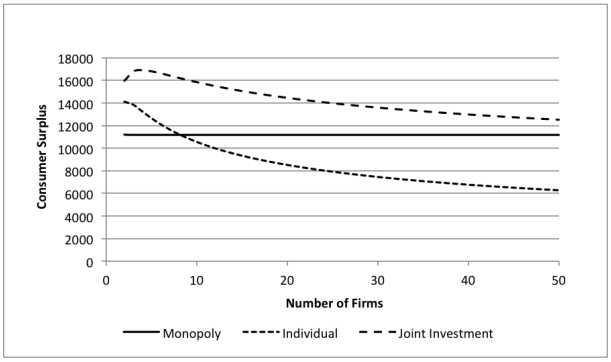

**Panel 1E: Industry Profit (High)**



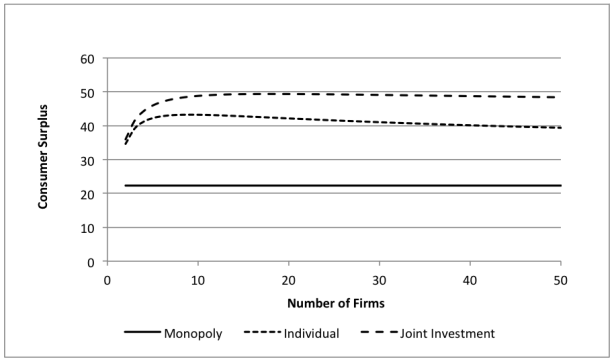

**Panel 1F: Industry Profit (Low)**



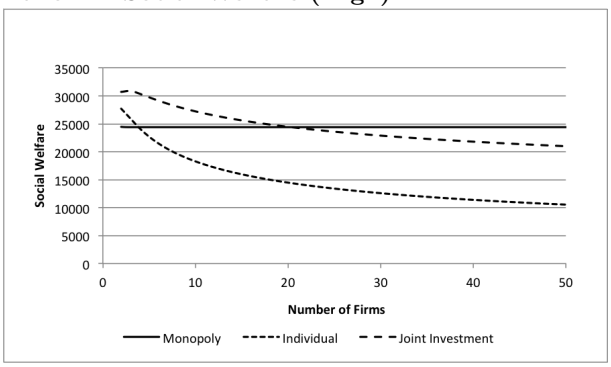

**Panel 1G: Consumer Surplus (High)**




**Panel 1H: Consumer Surplus (Low)**



**Panel 1I: Social Welfare (High)**




**Panel 1J: Social Welfare (Low)**

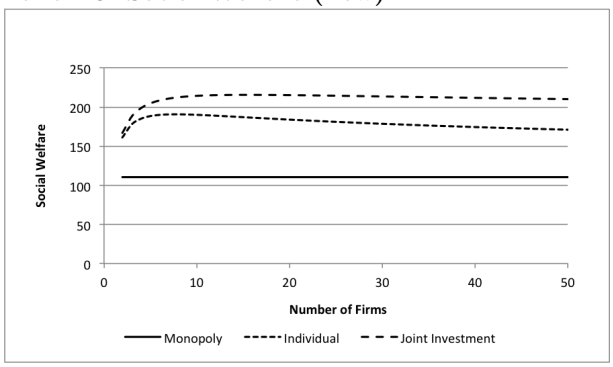
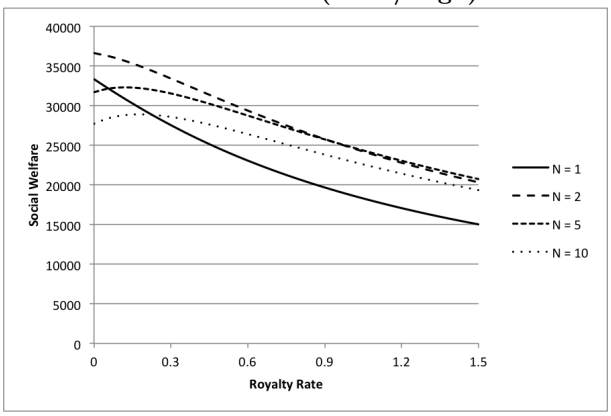
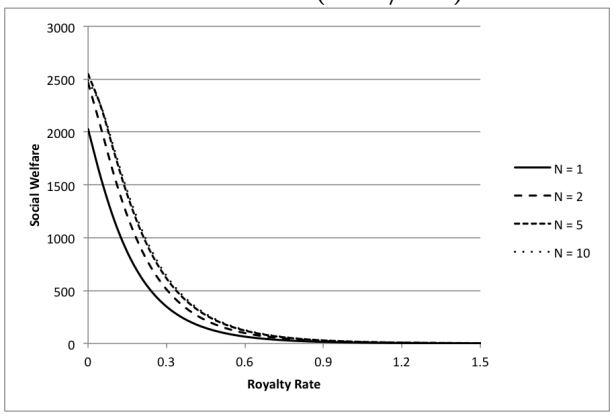


**Figure 2. Simulations: $N \in \{1, 2, 5, 10\}$** (High: $\alpha = 0.15$, $\eta = -2$; Low: $\alpha = 0.05$, $\eta = -10$)

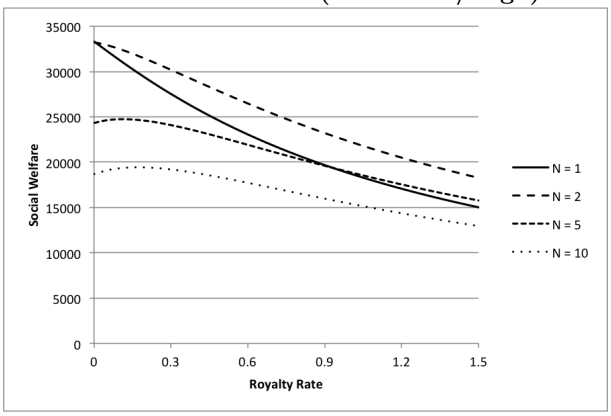
**Panel 2A: Social Welfare (Joint/High)**



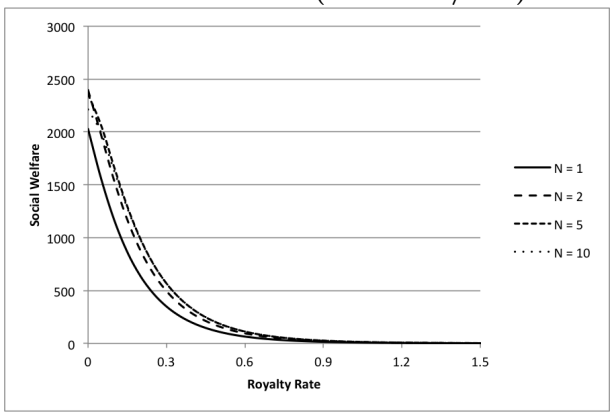

**Panel 2B: Social Welfare (Joint/Low)**



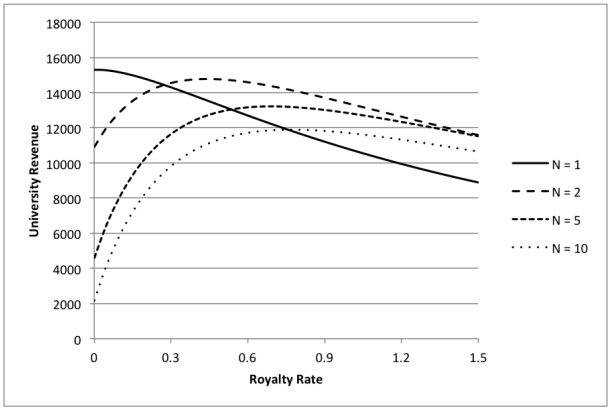

**Panel 2C: Social Welfare (Individual/High)**



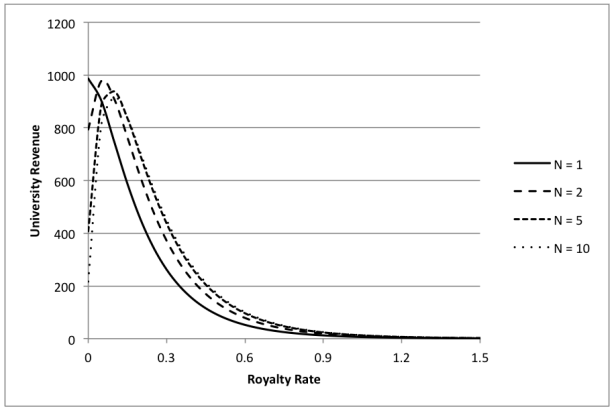

**Panel 2D: Social Welfare (Individual/Low)**



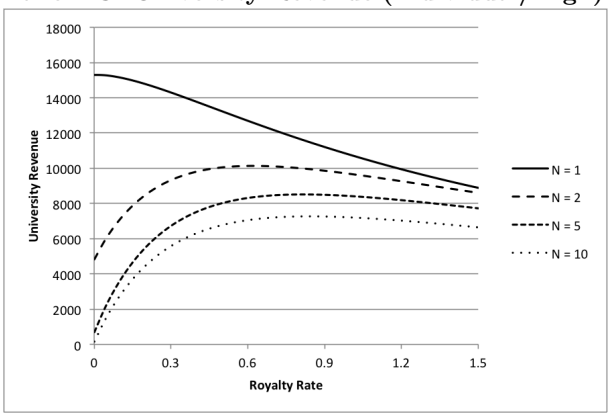

**Panel 2E: University Revenue (Joint/High)**



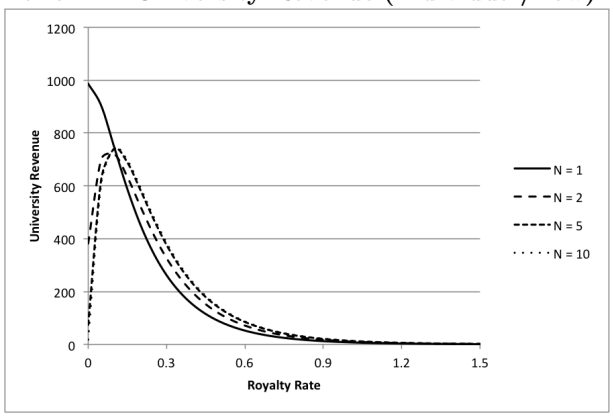

**Panel 2F: University Revenue (Joint/Low)**



**Panel 2G: University Revenue (Individual/High)**




**Panel 2H: University Revenue (Individual/Low)**



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