WELFARE IMPACTS OF PROPERTY RIGHTS IN THE SEED INDUSTRY

Sergio H. Lence, Dermot J. Hayes, Alan McCunn, Stephen Smith, and Bill Niebur*

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*Lence is Associate Professor and Hayes is Pioneer Hi-Bred Professor of Agribusiness, Department of Economics, Iowa State University, Ames. McCunn, Smith and Niebur are affiliated with with Pioneer Hi-Bred International.

Corresponding author: Sergio H. Lence
166C Heady Hall
Department of Economics
Iowa State University
Ames, Iowa 50011-1070
Phone: (515) 294-8960
Fax: (515) 294-4545
Email: shlence@iastate.edu.

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Abstract

The paper examines the welfare impact of different intellectual property right (IPR) regimes in private sector seed research. The model takes into account the period after expiration of IPR protection, and requires a simultaneous equilibrium in the markets for R&D, seeds, and final product (grain). Simulation results show that with the exception of R&D productivity, the optimal level of IPR protection is remarkably insensitive to parameters of the model. There is a range of IPR appropriability levels where the interests of consumers and producers (taken together) are complementary to the interests of R&D firms, and another range of appropriability levels where the welfare of producers and consumers can be increased only at the expense of the welfare R&D firms. These results may explain some of the acrimony in the debate about plant gene patenting and genetic use-restriction technologies (GURTs). Results suggest that the optimum IPR appropriability level is greater than that which exists in the North American seed corn market, but lower than would exist if GURTs were to become widely used. The optimal appropriability level is much higher than that which is achieved in situations where crops are open pollinated or where IPR protection is limited, and this may help explain and justify the relevance of public research in these situations.

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I. Introduction

The ongoing debate concerning the patenting of plant genes and biotechnological advances motivates our interest in a model that links the protection of property rights in the private seed industry with welfare changes for producers, consumers and the research and development (R&D) sector. Private sector research will occur only if there is a reward system in place to encourage this research.[1] The reward system may allow R&D firms to capture all of the benefits associated with the technological advance and may lead to large deadweight losses associated with imperfectly competitive behavior.[2] The tradeoff among producers, consumers and the R&D sector has been encountered and debated for the development of medical drugs and for technology in the economic literature, but this literature has not yet been applied to the particular case of agricultural seeds.

The agricultural seeds market tends to be unique in that, unlike the medical sector where the customer usually consumes the benefits of the newly developed technology directly, the seed customer is a farmer who sells the resulting crop from the newly developed technology into a competitive market. The farmer further has the option of saving seed from the unimproved hybrid/variety, or possibly the newly developed technology from crops grown in previous years and utilizing the saved seed in the production of subsequent crops.[3] Yield improvements brought about by R&D encourage the farmer to utilize the newly developed hybrid/variety, but may or may not improve the overall welfare of these customer farmers in aggregate if the R&D firm is

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[1] We ignore public sector R&D throughout this paper because we do not have measures of the relative efficiency with which resources are used for research in the public and private sectors. Therefore, our results implicitly assume that private sector R&D is done in addition to public sector R&D. Pardey and Beintema provide an excellent review of both recent and long-term trends in agricultural R&D.

[2] The private sector does fund or conduct research whereby the benefits flow directly to the public sector and are not captured in this study. Examples would be public research conducted at universities specifically funded by private foundations where the results are turned over to the public domain or where the results of private research are turned over to the public as in the case of Golden Rice.

[3] Farmers have historically have used saved seed in variety crops such as wheat and rice. However, currently in the seed markets worldwide farmers tend to not use farmer-saved seed and purchase certified seed from cooperatives, governmental sources, and private companies for both varieties and hybrids.

able to capture the greater amount of the benefits. This impact needs to be factored in to measure the welfare impact for society.

Recent related work in this area includes Moschini and Lapan, Alston and Venner, and Tongeren and Eaton. Moschini and Lapan examine the welfare impact of a particular seed innovation, but their model does not extend backwards to motivate the incentive structure that generated this innovation, nor do they take into account the welfare impacts that occur after the intellectual property right (IPR) protection period or the uncertainties associated with R&D. Alston and Venner and Tongeren and Eaton incorporate the incentive structure for the R&D firms, but they do not incorporate the market for the crop. Hence, they cannot examine issues related to the welfare of those who produce and consume the crop.

The purpose of this paper is to develop and implement a model that allows us to examine the welfare impact of different IPR regimes on both producers and consumers and on society. Our model is based on Dixit, and Srinivasan and Thirtle. The model structure requires a simultaneous equilibrium in three markets. The seed industry must in equilibrium conduct an amount of research that can be justified by the expected earnings from that research, and each R&D industry participant must respond to incentives and to competition from other seed companies in an optimal way. The market for seeds must also be in equilibrium and the farmers who purchase the improved seed should do so only if the premium charged for the seed is less than the additional profits they can expect. Finally, the market for the final product (grain) must be in equilibrium, and changes in costs and farm productivity must eventually impact market prices.

Once these equilibrium conditions are satisfied, we can parameterize the model and simulate the impact of changes in the strength of the IPR regime. Seed industry participants make R&D decisions based on the perceived premium that they could expect for the improved hybrid/variety. This means that optimal research expenditures will change in response to changes in the R&D firms' ability to capture these benefits. In turn, changes in R&D expenditures will affect the likelihood that an improved variety or hybrid will emerge. If the seed company charges an optimal premium for these improvements, some farmers will choose to adopt and utilize the improved variety or hybrid in the production of their crop. Crop output and market prices will therefore respond in a predictable way and welfare changes can be measured.

The contributions of this paper are as follows. To the best of our knowledge, this is the first attempt to incorporate the literature on R&D policy to the unique structure that exists in the agricultural seed industry. We capture the somewhat complex interactions among the three sectors into a simulation model that has relatively few parameters. In addition, we provide a set of simulation results that shows an optimal level of IPR protection, and we show that this optimal level is remarkably robust with respect to alternative parameterizations. A final innovation is that we take into account the impact of the improved hybrid/variety on welfare in the period after the expiration of the IPR protection. This latter attribute is important because the simulation model we propose can be used to measure welfare impacts that might occur if time-limited legal protections offered to the seed industry are replaced with genetic use-restriction technologies (GURTs) which have potentially infinite protection periods.[4]

II. A Model of Investment in Agricultural R&D

The objective of the present section is to introduce the model used to assess the impact of the existing IPR regime on agricultural R&D investment. The strength of the IPR regime is embedded in a parameter $\mu \equiv \mu_{IPR} + \mu_{cost} \geq 0$, which measures the degree to which the developer of an improved farm input can appropriate the benefits associated with the innovation. For example, μ would measure the appropriability of the benefits associated with new seed traits if the innovator were a seed company. The level of μ determines the degree of market power that the developer of the improved input can exercise when selling it to farmers. Parameter $\mu_{IPR} \geq 0$ is assumed to be increasing with the extent up to which the developer is granted IPRs on the innovation, and with the level of enforcement of such IPRs. Appropriability μ also increases

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[4] This technology, commonly referred to as the "terminator gene," allows the seed company to insert a gene that prevents a particular seed from germinating. Farmers who purchase improved varieties containing this technology would not be able to use the improved technology in subsequent years without purchasing new seed each year.

with parameter $\mu_{cost} \geq 0$, which reflects the costs of transferring or copying the output-enhancing innovation.

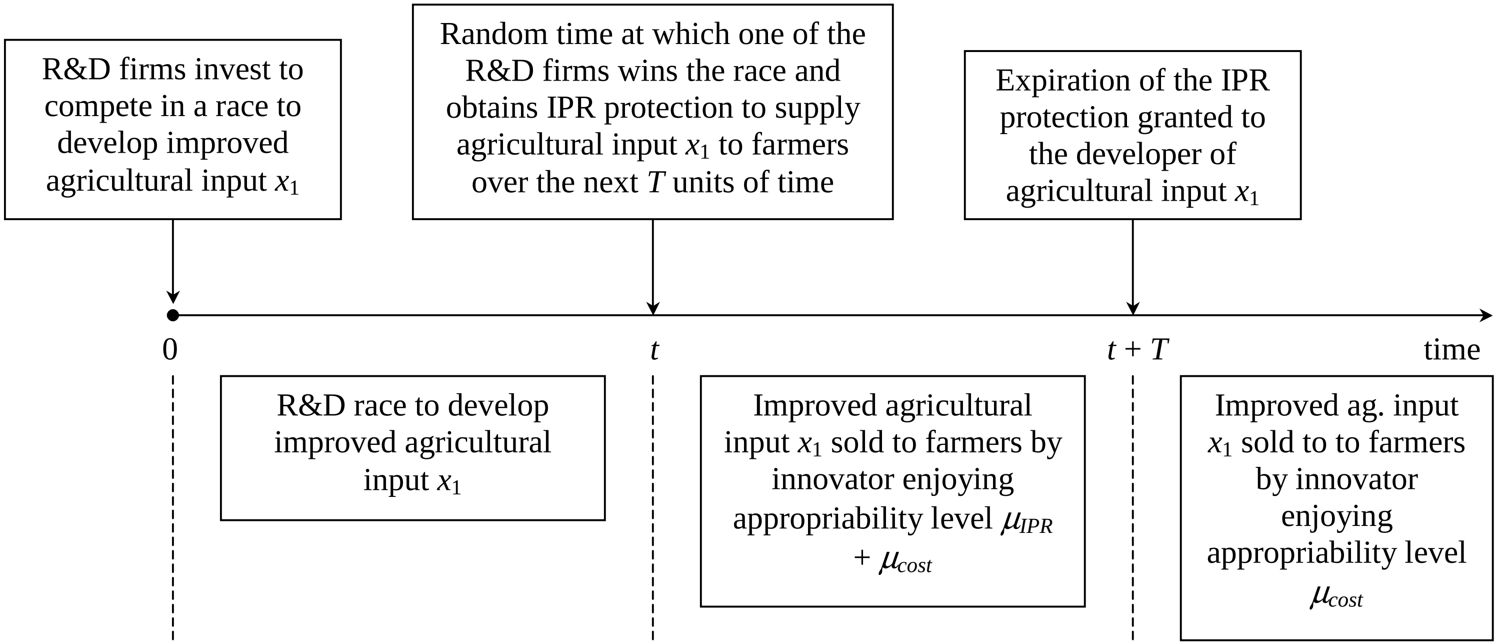
Figure 1 depicts the timing of the events involved in the R&D investment decision as modeled here. At time 0, R&D firms invest resources to compete in a race to develop x_1, a more productive version of an existing farm input (e.g., seed) x_0. A successful outcome (x_1) of the development process is random and the R&D competition ends at time t, when x_1 is first obtained. The first developer of x_1 is granted IPR protection for T periods, so the successful innovator enjoys appropriability level $\mu_{IPR} + \mu_{cost}$ over the period $[t, t + T]$. During this period of IPR protection, the improved farm input x_1 is sold at price $w_1 = min(w_1^m, \mu_{IPR} + \mu_{cost} + c_1)$. This price is equal to the monopoly price (w_1^m) if the innovator's appropriability level is high enough. Otherwise, the innovator will charge a markup of $\mu_{IPR} + \mu_{cost}$ over its marginal cost of producing x_1 (c_1). Once the IPR protection expires at time $t + T$, μ_{IPR} is reduced to zero so that the innovator's appropriability level decreases to μ_{cost}. This further restricts the innovator's ability to charge the monopoly price, as the price of the improved input is given by $w_1 = min(w_1^m, \mu_{cost} + c_1)$ after time $t + T$.

The previous discussion highlights the need to address the various components affecting the R&D investment decision at time 0. Such components include the derived demand for the improved farm input x_1 --which in turn involves the end-demand for farm output, the monopoly pricing decision w_1^m, the nature of the R&D process, and the determination of equilibrium in the R&D market at time 0. Each of these components is the object of the following subsections.

II.1. Farm Production

The derived demand for the improved farm input x_1 depends on the type of technological improvement that x_1 represents with respect to the existing input x_0. Given limited space, rather than addressing all possible types of innovations, the following analysis will focus on the case where x_1 is a Hicks-neutral improvement in x_0, a variable input used by farmers to produce some

Figure 1. Timing framework for the R&D analysis.



Equilibrium Price of x_1:	Not applicable (x_1 does not exist yet)	$w_1^e = min(w_1^m, \mu_{IPR} + \mu_{cost} + c_1)$	$w_1^e = min(w_1^m, \mu_{cost} + c_1)$
Equilibrium Crop Price:	$p_0^e(\cdot)$	$p^e(\cdot)\|_{\mu=\mu_{IPR}+\mu_{cost}}$	$p^e(\cdot)\|_{\mu=\mu_{cost}}$
Equilibrium Farm Surplus:[a]	$\pi_0^e[p_0^e(\cdot), c_0, r]$	$\pi^e[p^e(\cdot), c_0, w_1^e(\cdot), r]\|_{\mu=\mu_{IPR}+\mu_{cost}}$	$\pi^e[p^e(\cdot), c_0, w_1^e(\cdot), r]\|_{\mu=\mu_{cost}}$
Equil. Consumer Surplus:[a,b]	$\int_{p_0^e(\cdot)}^{\bar{p}} D(\zeta)\, d\zeta$	$\int_{p^e(\cdot)\|_{\mu=\mu_{IPR}+\mu_{cost}}}^{\bar{p}} D(\zeta)\, d\zeta$	$\int_{p^e(\cdot)\|_{\mu=\mu_{IPR}}}^{\bar{p}} D(\zeta)\, d\zeta$
Equil. Rents to Suppliers of x_1:[a]	0	$\{[w_1^e(\cdot) - c_1]\, x_1(\cdot)\}\|_{\mu=\mu_{IPR}+\mu_{cost}}$	$\{[w_1^e(\cdot) - c_1]\, x_1(\cdot)\}\|_{\mu=\mu_{cost}}$

[a] Surpluses and rents are expressed in $ per unit of time.

[b] Variable $\bar{p}$ is the upper bound for the domain of $D(\cdot)$.

crop y.[5] More specifically, let z be a vector of other variable inputs, and $f(x_0, z)$ and $g(x_1, z)$ denote the production functions under x_0 and x_1, respectively. Then, the R&D improvement is represented by $g(x, z) = (\alpha +1)\, f(x, z)$, with improvement factor $\alpha > 0$ and function $f(\cdot)$ assumed to satisfy standard regularity conditions. That is, the type of R&D improvement considered here is akin to a new hybrid/variety of a crop with yield α% higher than existing hybrids/varieties.

Given prices p, w_0, w_1, and r associated with farm output y and farm inputs x_0, x_1, and z, respectively, farmers' profit functions dual to the "traditional" and "new" technologies are (2.1) and (2.2), respectively:

$$(2.1) \qquad \pi_0(p, w_0, r) \equiv \max_{x_0, z} [\, p\, f(x_0, z) - w_0\, x_0 - r\, z],$$

$$(2.2) \qquad \pi_1(p, w_1, r) \equiv \max_{x_1, z} [\, p\, g(x_1, z) - w_1\, x_1 - r\, z].$$

If farmers can choose either technology, the unrestricted farmers' profit function is (2.3):

$$(2.3) \qquad \pi(p, w_0, w_1, r) \equiv max[\pi_0(p, w_0, r),\, \pi_1(p, w_1, r)].$$

Profit functions (2.1) through (2.3) are used below to analyze equilibrium in the output and input markets. Note that farmers are assumed to behave as perfect competitors, so that they do not take into account the market impact (i.e., on industry production and overall prices) of the improved input.[6]

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[5] A Hicks-neutral improvement seems the type of innovation that best represents seed improvements. However, other types of R&D innovations can be studied in analogous manner.

[6] We assume competitive behavior but this may not be the case in some markets. Specifically, farmers may not behave under perfect competition assumptions in niche or downstream markets where farmers/growers may have control of the output or end-use product.

II.2. Equilibrium in the Market for Farm Output

Using Hotelling's lemma, farm supply $y^* \equiv y(p, w_0, w_1, r)$ may be obtained by taking the partial derivatives of $\pi_0(p, w_0, r)$ or $\pi_1(p, w_1, r)$, as appropriate, with respect to the crop output price:

$$(2.4) \quad y^* = \begin{cases} \partial\pi_0(p, w_0, r)/\partial p \text{ if } \pi_0(p, w_0, r) > \pi_1(p, w_1, r), \\ \partial\pi_1(p, w_1, r)/\partial p \text{ if } \pi_0(p, w_0, r) < \pi_1(p, w_1, r), \\ \text{and a convex combination of } \partial\pi_0(p, w_0, r)/\partial p \text{ and } \partial\pi_1(p, w_1, r)/\partial p \text{ otherwise.} \end{cases}$$

Supply function (2.4) is increasing in p as long as $\pi_0(p, w_0, r)$ and $\pi_1(p, w_1, r)$ are increasing and convex in p.

Equilibrium in the market for farm output requires output price p to equate the quantity demanded for the crop with the quantity supplied y^*. That is, for given w_0, w_1, and r the equilibrium output price $p^* \equiv p(w_0, w_1, r)$ satisfies:

$$(2.5) \quad D(p^*) = y(p^*, w_0, w_1, r).$$

Equilibrium will be unique if the crop demand function $D(p)$ is well-behaved (i.e., strictly decreasing).

II.3. The Innovation Supplier's Pricing Decision and Equilibrium in the Input Market

Derived demands for the standard farm input $x_0^* = x_0(p, w_0, w_1, r)$ and the improved farm input $x_1^* = x_1(p, w_0, w_1, r)$ are also obtained from application of Hotelling's lemma:

$$(2.6) \quad x_0^* = \begin{cases} -\partial\pi_0(p, w_0, r)/\partial w_0 \text{ if } \pi_0(p, w_0, r) > \pi_1(p, w_1, r), \\ 0 \text{ if } \pi_0(p, w_0, r) < \pi_1(p, w_1, r), \\ \text{and a convex combination of } 0 \text{ and } -\partial\pi_0(p, w_0, r)/\partial w_0 \text{ otherwise,} \end{cases}$$

$$(2.7)\quad x_1{*} = \begin{cases} -\partial\pi_1(p, w_1, r)/\partial w_1 \text{ if } \pi_0(p, w_0, r) < \pi_1(p, w_1, r), \\ 0 \text{ if } \pi_0(p, w_0, r) > \pi_1(p, w_1, r), \\ \text{and a convex combination of } 0 \text{ and } -\partial\pi_1(p, w_1, r)/\partial w_1 \text{ otherwise.} \end{cases}$$

Equilibrium in the farm output and input markets depends on the behavior of the producers of the farm inputs x_0 and x_1. Market equilibrium for an R&D innovation is affected by whether the producers of x_0 behave as perfect competitors or not (Moschini and Lapan). Further, if producers of x_0 don't behave as perfect competitors, the equilibrium outcome depends on the type of strategic game played by the producers of x_0 and x_1. In the interest of space, attention will be restricted to scenarios where x_0 is supplied by perfectly competitive firms.[7] Also for simplicity, it will be assumed that x_0 is produced at constant marginal cost c_0, and that x_1 is produced by the IPR holder at constant marginal cost c_1. To make the problem interesting, it will also be assumed that c_1 and c_0 are such that the improved farm input x_1 represents a Pareto improvement over the standard farm input x_0. This requires that the marginal cost of producing x_1 not be "too large" relative to the marginal cost of producing x_0.[8]

Under perfect competition and constant marginal costs c_0, the price of the standard farm input x_0 is $w_0 = c_0$. Hence, if the IPR holder behaves as a monopoly, it will set $w_1 = w_1^m(c_0, c_1, r)$ to maximize profits. That is:

$$(2.8)\quad w_1^m = \arg\max_w \{(w - c_1)\, x_1[p(c_0, w, r), c_1, w, r]\}.$$

Embedded in (2.8) is the pricing constraint imposed by the competition from the traditional input being supplied at price c_0. It must be noted, however, that there are realistic circumstances under which it would be suboptimal for the holder of IPRs to charge $w_1 = w_1^m$. For example, x_1 may be

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[7] Analysis of the scenario with less than perfectly competitive suppliers of x_0 is more cumbersome, but it can be performed in an analogous manner.

[8] The condition that $c_1 \leq (\alpha + 1)\, c_0$ ensures that x_1 is a Pareto improvement over x_0, but it is typically much more restrictive than necessary.

produced illegally by firms other than the IPR holder, or some firms may be allowed to produce small quantities of x_1 without violating IPRs.[9]

For concreteness, suppose that there is a large number of firms that may produce small amounts of the improved farm input at constant marginal cost $(\mu_{cost} + c_1) \geq c_1$. In the instance of a seed innovation, μ_{cost} would represent the additional costs associated with transferring the trait without access to the original parent lines. This cost would obviously be greater for hybrid lines than for open pollinated varieties. Suppose also that if a firm produces the innovated input in violation of IPRs, it may be caught and found guilty with probability $\mu_{Prob} \in [0, 1]$, in which case it is imposed a penalty of $\mu_{Pen} \geq 0$ per unit produced. The expected profits per unit produced by such a firm are therefore $[w_1 - (\mu_{cost} + c_1)] - \mu_{IPR}$, where $\mu_{IPR} \equiv \mu_{Prob}\, \mu_{Pen}$. If there are sufficiently many potential producers of x_1 under these conditions and $w_1^m > \mu_{IPR} + \mu_{cost} + c_1$, the IPR holder is better off setting $w_1 = \mu_{IPR} + \mu_{cost} + c_1$ to avoid the entry of such potential competitors.[10]

The magnitude of $\mu_{IPR} \equiv \mu_{Prob}\, \mu_{Pen}$ is directly related to the extent to which IPRs are being enforced. If IPR violators are rarely prosecuted or convicted, μ_{Prob} will be small. Alternatively, if convicted IPR violators are subject to small penalties, μ_{Pen} will be small. The additional marginal cost μ_{cost} reflects the difficulty of producing x_1 on a small scale, and need not be related to the strength of the IPR regime. In summary, the market power of the IPR holder is constrained by the strength of the existing IPR regime (μ_{IPR}) and by the size of the extra marginal cost incurred by potential producers of x_1 (μ_{cost}). Hence, the improved farm input price $w_1 = w_1(c_0, c_1, r, \mu)$ will be given by:

$$(2.9) \quad w_1 = min[w_1^m(c_0, c_1, r), \mu + c_1],$$

where $\mu \equiv \mu_{IPR} + \mu_{cost}$.

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[9] For the case of seeds, an example of the latter situation would be allowing farmers to save seed from an improved variety for their own usage.

[10] More precisely, the IPR holder should set w_1 an infinitesimally small amount below $\mu_{IPR} + \mu_{cost} + c_1$.

In summary, given production costs c_0 and c_1, and prices of other variable inputs r, (2.8) yields the monopoly price for input x_1. The monopoly price together with the IPR holder's degree of market power μ and its cost of production c_1 determines the actual input price w_1 via (2.9). In turn, w_1 determines equilibrium farm output price p from (2.5), total farm output from (2.4), and the amount of x_1 bought by farmers from (2.7).

II.4. A Firm’s Decision to Invest in R&D

The previous subsections address the farm input and farm output markets assuming that x_1 already exists. The R&D investment decision is concerned with such markets because they determine the rents accruing to the firm that first gets the innovation x_1.

More specifically, if the improved input x_1 is first obtained at time t and the innovator is granted an effective IPR protection level μ_{IPR} through the next T periods, the innovator's appropriability levels will be $\mu = \mu_{IPR} + \mu_{cost}$ over the interval $(t, t + T)$ and $\mu = \mu_{cost}$ afterward. Hence, at time t the present value of the rents extracted by the successful innovator are given by (2.10):[11]

$$(2.10)\quad v(c_0, c_1, r, \mu_{IPR}, \mu_{cost}, T, i) = \int_t^{t+T} \{[w_1(\cdot) - c_1]\, x_1(\cdot)\}\,|_{\mu=\mu_{IPR}+\mu_{cost}}\ exp(-\,i\ \tau)\, d\tau$$

$$+ \int_{t+T}^{\infty} \{[w_1(\cdot) - c_1]\, x_1(\cdot)\}\,|_{\mu=\mu_{cost}}\ exp(-\,i\ \tau)\, d\tau,$$

$$(2.10')\quad = i^{-1}\,[1 - exp(-\,i\ T)]\ \{[w_1(\cdot) - c_1]\, x_1(\cdot)\}\,|_{\mu=\mu_{IPR}+\mu_{cost}}$$

$$+\, i^{-1}\, exp(-\,i\ T)\ \{[w_1(\cdot) - c_1]\, x_1(\cdot)\}\,|_{\mu=\mu_{cost}}\,,$$

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[11] Expression (2.10') is derived by setting $t = 0$ in (2.10). This is not done explicitly in the latter expression to avoid confusion with the timing of the R&D investment decision, to be discussed later.

where i is the continuously-compounded interest rate per unit of time and τ is a variable of integration. The terms $\{[w_1(\cdot) - c_1]\, x_1(\cdot)\}$ represent the rents per unit of time accruing to the innovating firm. The present value of each period's rents is obtained by discounting them at the appropriate discount rate i by means of $exp(-\, i\ \tau)$. Finally, the present value of the discounted rents over the entire period is obtained by integrating with respect to time. Expression (2.10) implies that after the initial protected period, only rents associated with μ_{cost} accrue to the supplier of x_1 beyond time $t + T$ (see Figure 1).

R&D firms must decide whether to attempt to develop x_1 and obtain the associated IPRs before x_1 exists. Here, Dixit's standard model of R&D competition is used to represent such a decision. This model postulates that there are many potential R&D firms of different types, the latter indexed by n over an interval $[\underline{n},\ \bar{n}\ ]$ and with cumulative distribution $N(n)$.[12] To participate in the competition to develop the improved farm input x_1, firm n must make a lump-sum R&D investment (e.g., physical capital) k_n and then incur a recurrent cost (e.g., labor) l_n. R&D investment k_n and recurrent cost l_n jointly determine the firm's hazard rate $h_n = h(k_n, l_n; n)$ $\in [0, 1)$, where $h(\cdot)$ is differentiable, increasing, and concave in (k_n, l_n), decreasing in n, and such that $h(0, 0; n) = 0$. The firm's hazard rate h_n is the conditional probability that it will succeed in developing the improved x_1 in the next small unit of time, given that no firm has succeeded so far. Individual firms' hazard rates are thus functions of the respective lump-sum investments and recurrent costs, but are independent of the length of time elapsed since the R&D competition started.

The hazard rate for the R&D industry as a whole (H) is obtained by integrating across the individual hazard rates:

$$(2.11)\quad H = \int_{\underline{n}}^{\bar{n}} h_n \ dN(n).$$

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[12] It is irrelevant whether the distribution of types is discrete or continuous.

Given that H is the hazard rate for the R&D industry, the probability that no firm has won the race by time t is $exp(-H\,t)$ (Dixit, footnote 6). Further, if no firm has won the race, the probability that firm n (who invested k_n at the starting time 0) will win the R&D race in the next infinitesimally small interval $(t + dt)$ is $h_n\,dt$. Hence, the unconditional probability that such a firm wins the R&D race over the interval $(t, t + dt)$ is $exp(-H\,t)\,h_n\,dt$, and the present value of the expected rents associated with such a victory equals $v(\cdot)\,exp(-i\,t)\,exp(-H\,t)\,h_n\,dt$. As of time 0, the present value of the expected rents to firm n from winning the R&D race is the sum of the latter expression over all future infinitesimal time intervals. That is:

$$\text{(2.12)}\quad \int_0^\infty v(\cdot)\ exp(-i\ \tau)\ exp(-H\ \tau)\ h_n\ d\tau = v(\cdot)\ h_n/(i + H).$$

In addition to the lump-sum k_n invested at time 0, R&D firm n will incur the recurrent cost l_n until the race is over. The expected present value of the recurrent costs is (2.13):

$$\text{(2.13)}\quad \int_0^\infty \left[\int_0^{\tau_1} l_n\ exp(-i\,\tau_0)\ d\tau_0\right] exp(-H\ \tau_1)\ H\ d\tau_1 = \int_0^\infty \frac{l_n\ [1-exp(-i\,\tau_1)]}{i}\ exp(-H\ \tau_1)\ H\ d\tau_1,$$

$$\text{(2.13')}\qquad = l_n/(i + H).$$

The inner integral on the left-hand side of (2.13) represents the present value of the recurrent costs if the race finished at time τ_1, whereas the term $[exp(-H\ \tau_1)\ H\ d\tau_1]$ denotes the probability of such an event. The outer integral accounts for the fact that the race may finish at any time after the lump-sum investment is made.

With expected returns and expected recurrent costs given by (2.12) and (2.13'), respectively, the expected profits to firm n from investing the lump-sum k_n at time 0 to participate in the R&D race are:

(2.14) $V(k_n, l_n, H, n; \cdot) = v(\cdot)\, h(k_n, l_n; n)/(i + H) - k_n - l_n/(i + H)$.

The decision problem for expected-profit-maximizing R&D firm n consists of choosing $k_n = k_n^*(H;\cdot)$ and $l_n = l_n^*(H;\cdot)$ so as to maximize $V(k_n, l_n, H, n; \cdot)$, given the industry hazard rate H (which is taken parametrically by firm n because of the perfect competition assumption). Optimal values $k_n^*(H;\cdot)$ and $l_n^*(H;\cdot)$ are obtained from the first-order necessary conditions for the maximization of (2.14).

II.5. Equilibrium in the R&D Market

Optimal lump-sum investment and recurrent costs for each of the R&D entrants are obtained as indicated in the preceding subsection. Since each firm takes the industry hazard rate H as given, equilibrium in the R&D industry requires that the consistency condition (2.11) be met. That is, industry equilibrium is defined by:

(2.15) $$H^e = \int_{\underline{n}}^{\overline{n}} h[k_n^*(H^e;\cdot), l_n^*(H^e;\cdot); n]\; dN(n),$$

where $k_n^*(H^e;\cdot)$ and $l_n^*(H^e;\cdot)$ are firm n's optimal lump-sum investment and recurrent costs , respectively, under the equilibrium industry hazard rate H^e.

Quantification of the equilibrium industry hazard rate H^e is essential to analyze R&D scenarios under alternative parameterizations, as H^e represents the (equilibrium) probability that the innovation will occur in the next unit of time. In addition, the quantity $1/H^e$ is the (equilibrium) average time that it takes to obtain the innovation. Besides H^e, other variables related to R&D that are useful to quantify are the equilibrium aggregate lump-sum investment and recurrent costs, given by (2.16) and (2.17), respectively:

(2.16) $$K^e = \int_{\underline{n}}^{\overline{n}} k_n^*(H^e;\cdot)\; dN(n),$$

$$(2.17)\quad L^e = \int_{\underline{n}}^{\overline{n}} l_n^*(H^e; \cdot)\ dN(n).$$

Given K^e, L^e, and H^e, the present value of the aggregate total expected R&D costs in equilibrium is $K^e + L^e/(i + H^e)$.

II.6. Welfare Analysis

Let $\pi_0^e(\cdot)$, $\pi^e(\cdot)|_{\mu=\mu_{IPR}+\mu_{cost}}$, and $\pi^e(\cdot)|_{\mu=\mu_{cost}}$ denote farmers' equilibrium profits before the innovation, after the innovation but under IPR protection, and after expiration of the IPR protection, respectively (see Figure 1). Then, if the innovation occurred at time τ_1, the change in producer surplus per unit of time would be zero up to time τ_1, $[\pi^e(\cdot)|_{\mu=\mu_{IPR}+\mu_{cost}} - \pi_0^e(\cdot)]$ from time τ_1 until time $\tau_1 + T$, and $[\pi^e(\cdot)|_{\mu=\mu_{cost}} - \pi_0^e(\cdot)]$ afterward. Discounting such changes up to time zero and adding them up yields the present value of the change in producer surplus if the innovation happened at time τ_1, which is the term within curly brackets in (2.18):

$$(2.18)\quad \Delta PS = \int_0^{\infty} \{ \int_{\tau_1}^{\tau_1+T} [\pi^e(\cdot)|_{\mu=\mu_{IPR}+\mu_{cost}} - \pi_0^e(\cdot)]\ exp(-\,i\ \tau_0)\, d\tau_0$$

$$+ \int_{\tau_1+T}^{\infty} [\pi^e(\cdot)|_{\mu=\mu_{cost}} - \pi_0^e(\cdot)]\, exp(-i\,\tau_0)\, d\tau_0\ \}\ exp(-\,H\ \tau_1)\ H\, d\tau_1,$$

$$(2.18')\qquad = \frac{H}{i\,(i+H)}\ \{\pi^e(\cdot)|_{\mu=\mu_{IPR}+\mu_{cost}}\ [1 - exp(-\,i\ T)] + \pi^e(\cdot)|_{\mu=\mu_{cost}}\ exp(-\,i\ T) - \pi_0^e(\cdot)\}.$$

The present value of the *expected* change in producer surplus due to the introduction of the improved input x_1 (ΔPS) is computed as in (2.18) because $[exp(-\,H\ \tau_1)\ H]$ is the probability of the innovation occurring during the interval $(\tau_1,\ \tau_1 + d\tau_1)$.

A similar reasoning can be followed to measure the *expected* change in consumer surplus due to the innovation (ΔCS). That is, define $p_0^e(\cdot)$, $p^e(\cdot)|_{\mu=\mu_{IPR}+\mu_{cost}}$, and $p^e(\cdot)|_{\mu=\mu_{cost}}$ as the equilibrium crop prices before the innovation, after the innovation but under IPR protection, and after expiration of the IPR protection, respectively. Then, if the innovation occurred at time τ_1, the change in consumer surplus per unit of time would be zero until time τ_1, $\int_{p^e(\cdot)|_{\mu=\mu_{IPR}+\mu_{cost}}}^{p_0^e(\cdot)} D(\zeta)\,d\zeta$ from time τ_1 until time $\tau_1 + T$, and $\int_{p^e(\cdot)|_{\mu=\mu_{cost}}}^{p_0^e(\cdot)} D(\zeta)\,d\zeta$ after time $\tau_1 + T$. Discounting and adding up such values yields the change in consumer surplus if the innovation occurred at time τ_1, shown as the term within curly brackets in (2.19):

$$(2.19)\quad \Delta CS = \int_0^\infty \left\{ \int_{\tau_1}^{\tau_1+T} \left[\int_{p^e(\cdot)|_{\mu=\mu_{IPR}+\mu_{cost}}}^{p_0^e(\cdot)} D(\zeta)\,d\zeta \right] exp(-\,i\;\tau_0)\,d\tau_0 \right.$$

$$\left. + \int_{\tau_1+T}^{\infty} \left[\int_{p^e(\cdot)|_{\mu=\mu_{cost}}}^{p_0^e(\cdot)} D(\zeta)\,d\zeta \right] exp(-i\,\tau_0)d\tau_0 \right\} exp(-\,H\;\tau_1)\,H\,d\tau_1,$$

$$(2.19')\qquad = \frac{H}{i\,(i+H)}\ \{[1-exp(-\,i\;T)] \int_{p^e(\cdot)|_{\mu=\mu_{IPR}+\mu_{cost}}}^{p_0^e(\cdot)} D(\zeta)\,d\zeta\ + exp(-\,i\;T) \int_{p^e(\cdot)|_{\mu=\mu_{cost}}}^{p_0^e(\cdot)} D(\zeta)\,d\zeta\ \}.$$

Expression (2.19) takes into account the probabilities associated with the innovation taking place at different times in the future.

Still another welfare measure is the equilibrium aggregate present value of *expected* profits for the R&D industry (*RDS*). This can be computed from (2.20):

$$(2.20)\quad RDS = \int_{\underline{n}}^{\bar{n}} V(k_n^*, l_n^*, H^*, n; \cdot)\ dN(n).$$

That is, *RDS* is calculated by aggregating (2.14) across all R&D firms.

III. Simulation Specification and Parameterization

To illustrate the implications of the model, crop demand is assumed to be isoelastic:

$$(3.1)\quad D(p) = D\,p^{-\varepsilon},$$

where $D > 0$ is a scaling parameter and $\varepsilon > 0$ is the constant elasticity of demand for the crop. The crop production function under the traditional input is postulated to exhibit constant elasticity of substitution between inputs and decreasing returns to scale (so as to yield an upward-sloping crop supply):

$$(3.2)\quad f(x_0, z) = F\,\{[\,a_x^{1/\sigma}\ x_0^{(\sigma-1)/\sigma} + z^{(\sigma-1)/\sigma}]^{\sigma/(\sigma-1)}\}^{\eta/(1+\eta)},$$

where $F > 0$ is a scaling parameter, $\sigma \geq 0$ is the constant elasticity of substitution between inputs x_0 and z, and $\eta > 0$ is the constant elasticity of crop supply. Parameter $a_x > 0$ determines the share of total costs due to input x_0, as the cost share equals $a_x\ w_0^{1-\sigma}/(a_x\ w_0^{1-\sigma} + r^{1-\sigma})$. The farm profit function associated with (3.2) is:

$$(3.3)\quad \pi_0(p, w_0, r) \equiv \eta^{\eta}\,(1+\eta)^{-(1+\eta)}\,F^{1+\eta}\,p^{1+\eta}\,(a_x\ w_0^{1-\sigma} + r^{1-\sigma})^{-\eta/(1-\sigma)}.$$

Technology and profits under the improved input ($g(x_1, z)$ and $\pi_1(p, w_1, r)$, respectively) are straightforward to obtain from (3.2) and (3.3) by noting that $g(x, z) = (\alpha+1)\,f(x, z)$.

The hazard rate function of R&D firm n is represented by a Cobb-Douglas technology with decreasing returns to scale:

$$(3.4)\quad h(k, l; n) = A(n)\ k^{\kappa_K}\ \ l^{\kappa_L}\ ,$$

where $A(n)$ is a firm-specific scaling parameter, and $\kappa_K > 0$ and $\kappa_L > 0$ are constants such that $\kappa_K + \kappa_L < 1$. The optimal hazard rate associated with (3.4) is:

$$(3.5) \quad h_n^*(H) \;=\; A(n)^{1/(1-\kappa_K-\kappa_L)} \; \underline{\kappa} \; v(\cdot)^{(\kappa_K+\kappa_L)/(1-\kappa_K-\kappa_L)} \; (i+H)^{\kappa_K/(\kappa_K+\kappa_L-1)},$$

where $\underline{\kappa} \equiv (\kappa_K+\kappa_L)^{(\kappa_K+\kappa_L)/(1-\kappa_K-\kappa_L)} \left[(\kappa_K/\kappa_L)^{\kappa_L/(\kappa_K+\kappa_L)} + (\kappa_L/\kappa_K)^{\kappa_K/(\kappa_K+\kappa_L)} \right]^{(\kappa_K+\kappa_L)/(\kappa_K+\kappa_L-1)}$.

Given (3.5) and (2.15), the equilibrium aggregate hazard rate is obtained by solving numerically for H^e the implicit equation (3.6):

$$(3.6) \quad H^e - \AA\, \underline{\kappa}\, v(\cdot)^{(\kappa_K+\kappa_L)/(1-\kappa_K-\kappa_L)} \; (i+H^e)^{\kappa_K/(\kappa_K+\kappa_L-1)} = 0,$$

where $\AA \equiv \int_{\underline{n}}^{\bar{n}} A(n)^{1/(1-\kappa_K-\kappa_L)} \, dN(n)$. The solution to (3.6) must satisfy $0 \le H^e \le 1$ because the equilibrium hazard rate is a probability. Upon solving for H^e in (3.6), the aggregate equilibrium lump-sum investment and recurrent costs can be calculated from (3.7) and (3.8), respectively:

$$(3.7) \quad K^e = \AA\, \underline{\kappa}\, \kappa_K \; v(\cdot)^{1/(1-\kappa_K-\kappa_L)} \; (i+H^e)^{(\kappa_L-1)/(1-\kappa_K-\kappa_L)},$$

$$(3.8) \quad L^e = \AA\, \underline{\kappa}\, \kappa_L \; v(\cdot)^{1/(1-\kappa_K-\kappa_L)} \; (i+H^e)^{\kappa_K/(\kappa_K+\kappa_L-1)}.$$

Interestingly, the functional form chosen for the hazard rate function (3.4) obviates the need to specify the scaling function $A(n)$ and the distribution function of R&D firms $N(n)$ to solve for the R&D industry equilibrium. As it can be seen from (3.6), (3.7), and (3.8), all of the R&D industry equilibrium figures only depend on parameter $\AA$, as this parameter summarizes all of the information required about the functions $A(n)$ and $N(n)$.

Despite the apparent complexity of the model, simulations can be performed with as few as eleven parameters. These are the elasticities of supply (η), demand (ε), and input substitution (σ), the cost share attributable to traditional seed (determined by a_x), the length of time during which property rights are enforced (T), the interest rate (i), the strength of the IPR regime (μ_{IPR} and μ_{cost}), the expected improvement in seed productivity (α), and the productivity of "labor" and capital in the R&D process (κ_L and κ_K). Other parameters of the model can conveniently be normalized to unity; these are the price of other inputs (r), the cost of producing old seed (c_0) and new seed (c_1), and the scaling parameters in the demand, output, and hazard rate functions (D, F, and $Å$, respectively).

Comprehensive sensitivity analyses of alternative parameterizations were performed. In the interest of space, only the most realistic and insightful scenarios are reported below. For the purpose of reporting results, the parameterization chosen for the benchmark scenario was η = 1.5, $\varepsilon = 0.5$, $\sigma = 0.3$, cost share = 10%, T = 17 years, i = 10% per year, $\mu_{cost} = 0$, α = 20%, and $\kappa_K = \kappa_L = 0.3$. Simulations were conducted by varying μ_{IPR} -- and therefore appropriability μ -- over a very large range of feasible values.

IV. Results and Discussion

Figures 2 and 3 show the present value of the expected change in total surplus (i.e., for the farm, consumer, and R&D sectors) using a range of demand and supply elasticities.[13] Sensitivity results for different elasticities of substitution (σ) and expected yield impact (α) show a very similar pattern, though with different absolute levels of welfare changes. All of the results in Figures 2 and 3 show changes in welfare increasing up to a maximum point, and then declining before flattening out. In all instances, the expected change in welfare is positive regardless of the level of appropriability, but there is clearly an “optimum” level of appropriability that maximizes the welfare change. This optimum level is typically in the range between $\mu = 1$ and $\mu = 2$,[14] and is surprisingly resilient to changes in model parameters other than the productivity of "labor" and capital in the R&D process (κ_L and κ_K). The change in surplus rises with the appropriability level up to the maximum point as more research increases the rate of yield growth, and it

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[13] The reported surplus changes can be put in perspective by comparing them with the *present value* of consumer expenditures if improved seeds were not introduced at all. The latter values range from 6.44 (for $\varepsilon = 3$) through 12.82 (for $\varepsilon = 0.5$) for the scenarios depicted in Figure 2, and from 11.63 (for $\eta = 5$) through 13.25 (for $\eta = 1$) for the scenarios shown in Figure 3. (Note that total initial surplus cannot be used as a benchmark for comparative purposes because the isoelastic demand function (3.1) yields an infinite consumer surplus when $\varepsilon \leq 1$.)

[14] The expected level of annual yield growth with an appropriability level of $\mu = 1.5$ and T = 17 years is around 3.5%.

Figure 2. Present value of expected change in total surplus as a function of appropriability level (μ), for different demand elasticities (ε).

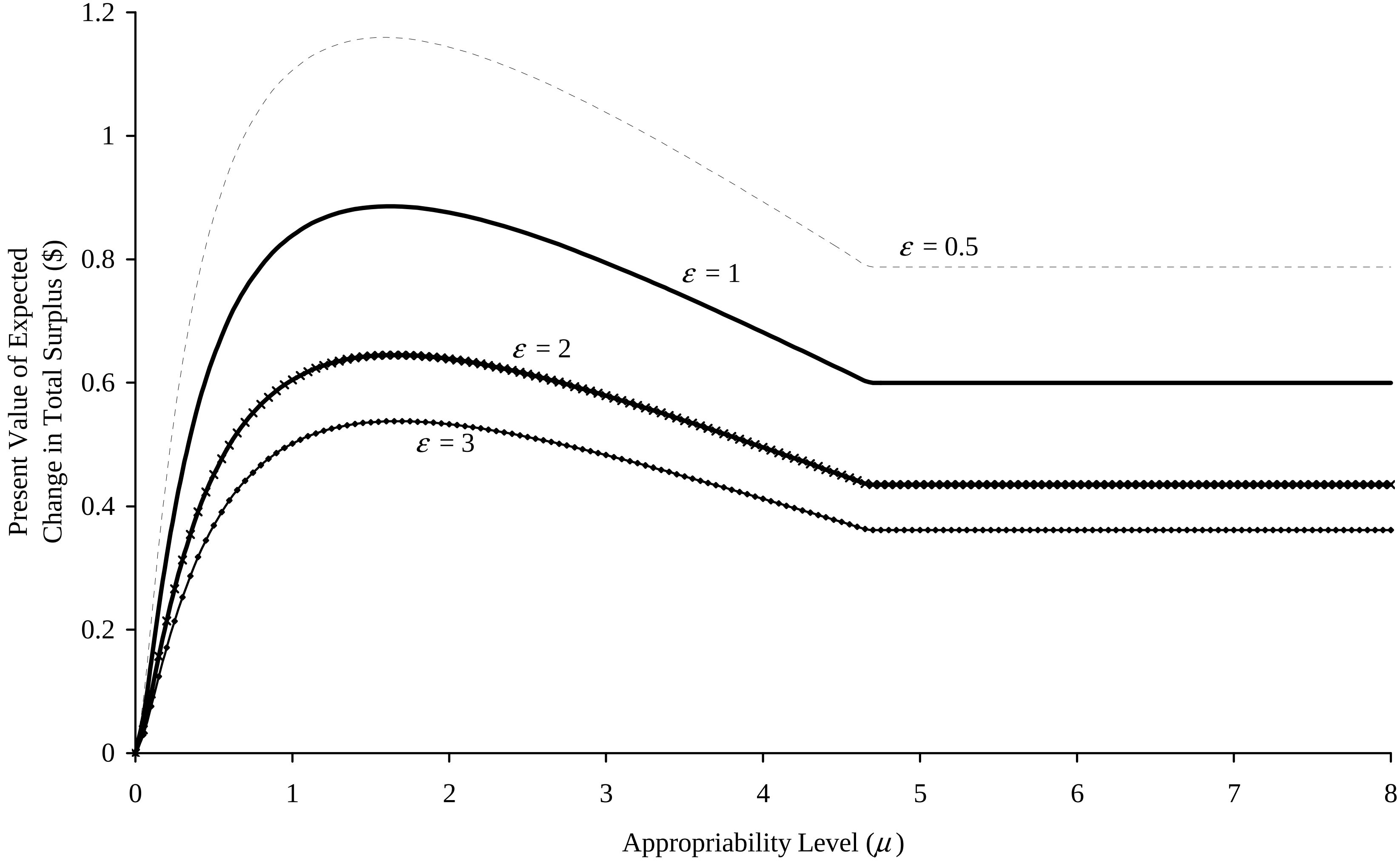
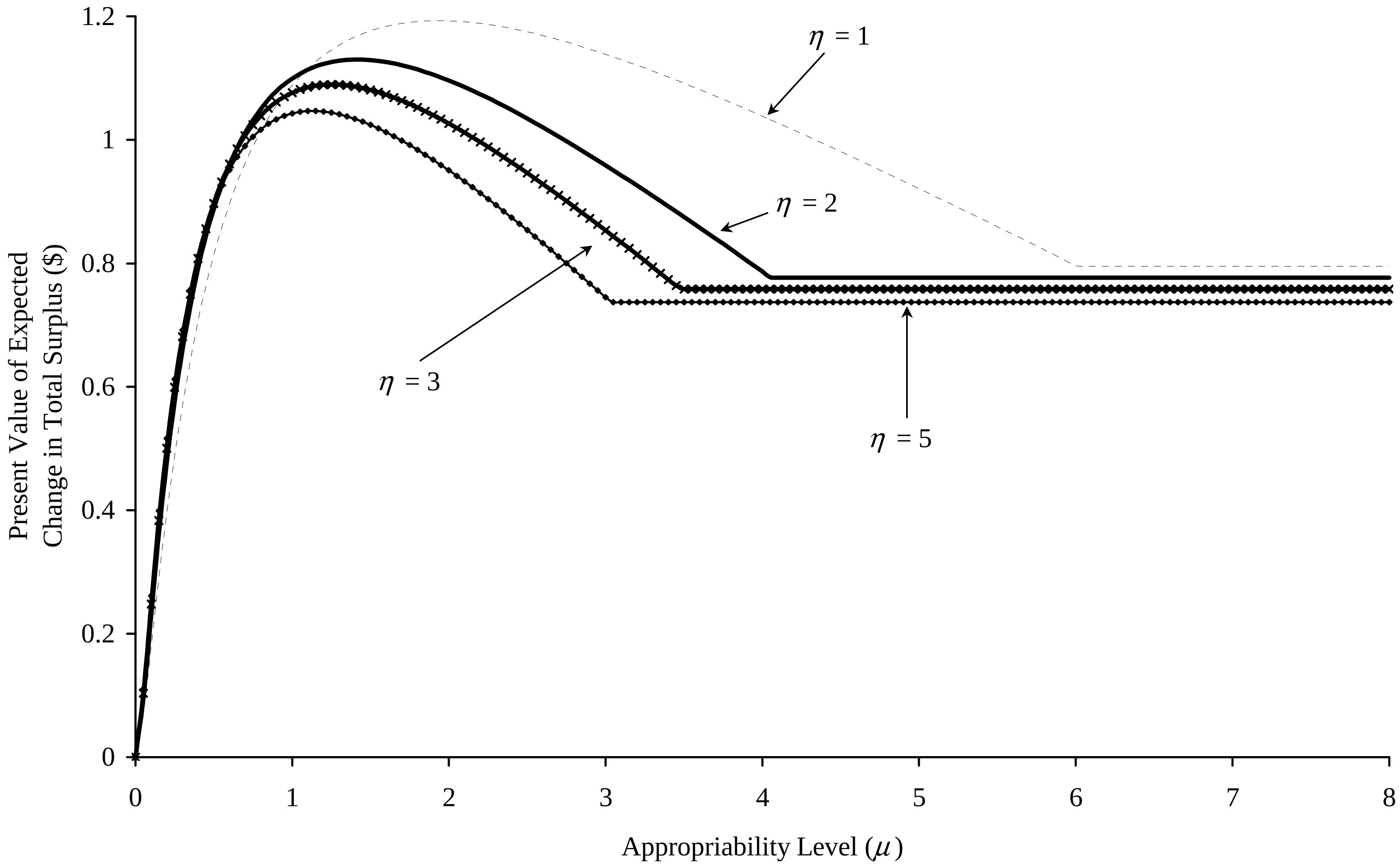


Figure 3. Present value of expected change in total surplus as a function of appropriability level (μ), for different supply elasticities (η).



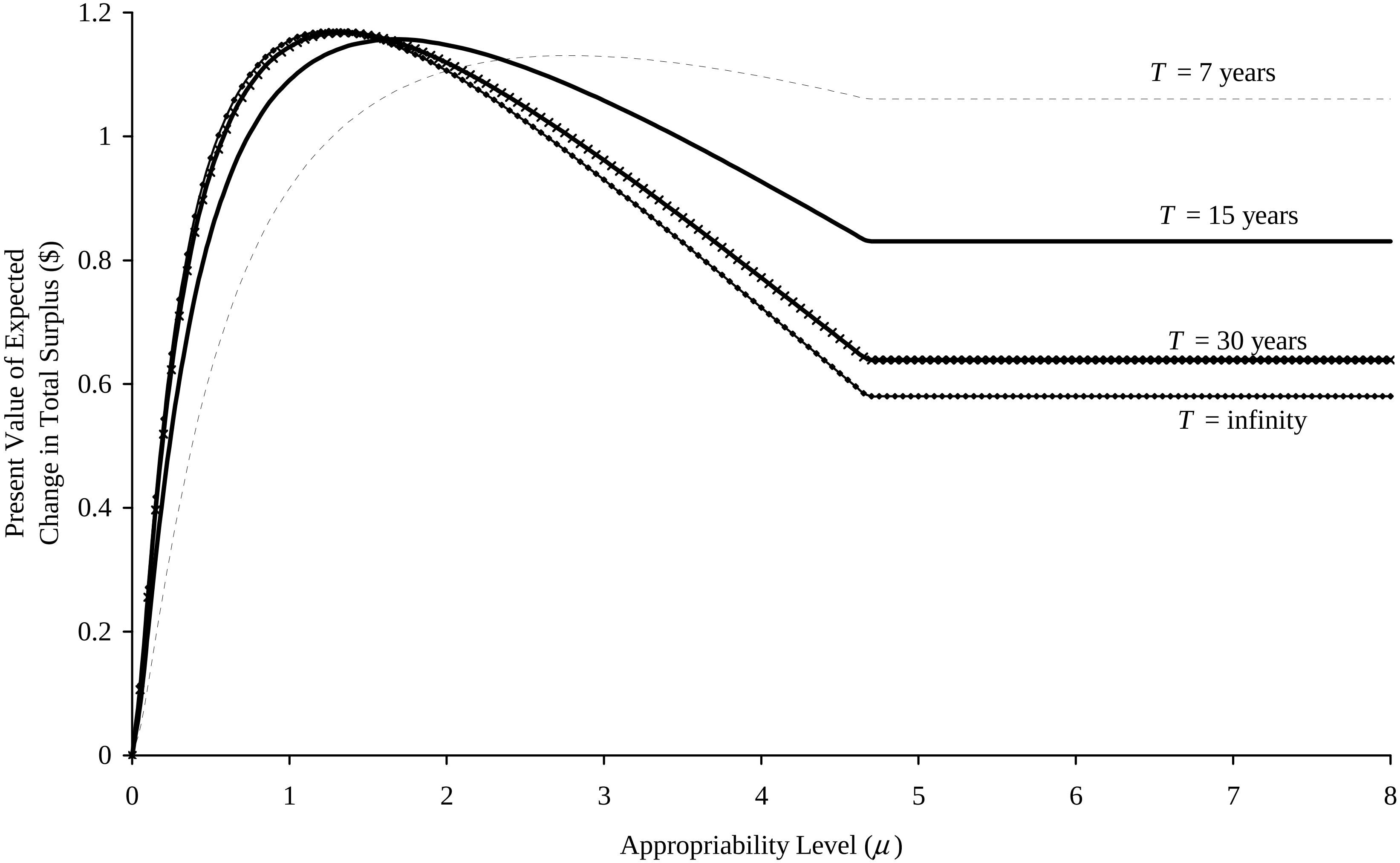
declines after this point as deadweight losses associated with the exercise of market power are introduced. The decline in welfare halts when the price on the improved seed rises to a level where farmers become indifferent between adopting it and using unimproved hybrids/varieties. Rather than lose these customers, seed companies optimally charge a lower price for seed than their monopoly situation would dictate if there were no substitutes. The ability of producers to chose between hybrids/varieties dramatically limits the ability of the seed company to behave as a monopolist. For this reason, the seed company never sets marginal cost equal to the marginal revenue of the demand curve that would exist in the absence of the farmer's ability to choose the unimproved hybrid/variety.

The *level* of the total expected welfare change is sensitive to the parameterization of the model. When crop demand is inelastic (as might occur if exports are not significant or close substitutes are not available), farmers lose regardless of the other parameter values. However, consumer surplus *rises* as crop demand becomes more inelastic, and the sum of producer and consumer surplus also rises because consumer gains outweigh producer losses. This can be seen in Figure 2. Figure 2 also shows that the optimum appropriability level is very insensitive to the size of the elasticity crop demand and reaches its maximum value at around $\mu = 1.6$. The sensitivity of the results to changes in the farm supply elasticity (η) is depicted in Figure 3. This graph reveals that a smaller farm supply response increases the optimal appropriability level, and reduces the rate at which welfare is reduced to the right of this point.

Figure 4 shows how results change as we modify the length of the protection period (T). The optimal appropriability level decreases with the length of the protection period. This makes sense because R&D companies would need smaller incentives to conduct research if they can capture benefits for a longer period.

The results for an infinite protection period to the right of an appropriability level of $\mu = 4.7$ are those that would exist if GURTs were used to replace legal protections. These results suggest that GURTs would result in a small positive impact, but they also show that the optimal appropriability level is far lower than that which would exist under GURTs (i.e. welfare

Figure 4. Present value of expected change in total surplus as a function of appropriability level (μ), for different lengths of IPR protection (T).



increases as the appropriability level falls below $\mu = 4.7$), and that the welfare impact of reducing the appropriability level to this optimal point is substantial.

Figure 5 shows the present value of the expected change in total surplus as a function of both the appropriability level and the protection period. Here the societal tradeoff between the length of protection and the level of protection becomes very clear. At low levels of appropriability welfare increases monotically in the protection period, whereas at higher levels of appropriability there is an optimum protection period of about $T = 5$ years. The expected change in total welfare falls when the protection period is greater than $T = 5$ years because price premiums last longer, thereby depriving consumers of the benefits associated with the eventual removal of IPR protection. There is no corresponding increase in R&D at these protection levels because firms are constrained by producer choice rather than by the level of IPR appropriability.

All of the results presented so far assume that the policy maker values the welfare of producers, consumers and the R&D firms equally. This assumption contradicts some of the political economy literature that suggests different welfare weights for different groups (Rausser and Freebairn). Figure 6 shows some results that incorporate these political economy considerations. The vertical axis shows only the sum of the present value of expected changes in consumer and farm surpluses, i.e., it attaches a weight of zero to the R&D firms. The horizontal axis shows only the present value of the expected change in surplus of the R&D firms. The graph shows how different levels of appropriability impact on these two welfare measures for a 17-year protection period (the one that is currently in use in the U.S.) and an infinite protection period.[15] The most interesting result in the 17-year line Figure 6 is that there is a wide range of appropriability levels ($\mu \in (0, 1.2)$) over which the interests of both groups are complementary. Increased appropriability in this region increases the surplus of the R&D firms *and* increases the welfare of the rest of society. The results also suggest that over a different range of appropriability ($\mu \in (1.2, 4.7)$), increases in the welfare of R&D firms comes at the expense of

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[15] The curve is drawn by changing the level of appropriability from $\mu = 0$ to $\mu = \infty$, while leaving all of the other parameter values constant. In the graph, appropriability increases monotonically from left to right.

Figure 5. Present value of expected change in total surplus as a function of appropriability levels (μ) and length of IPR protection (T).

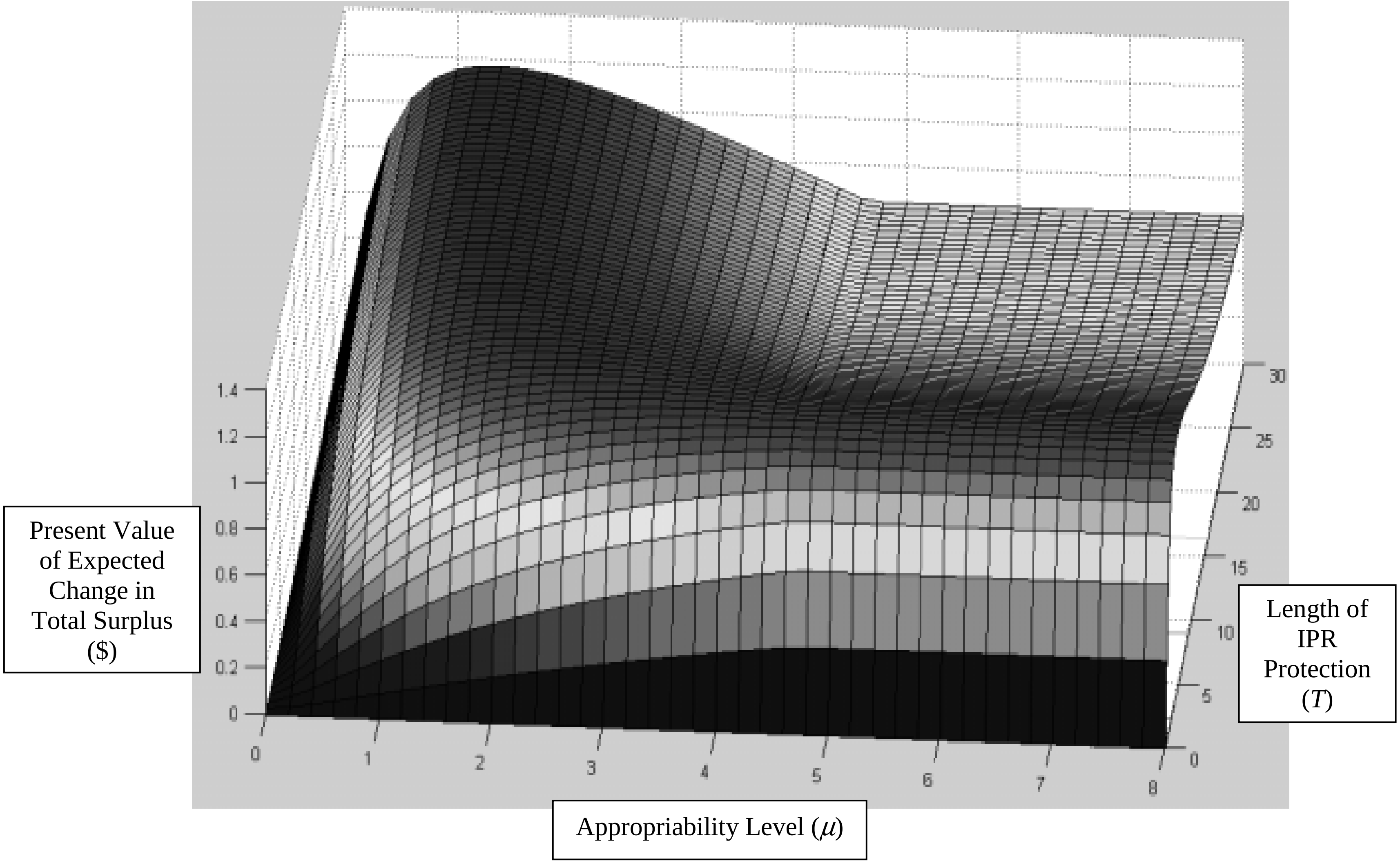
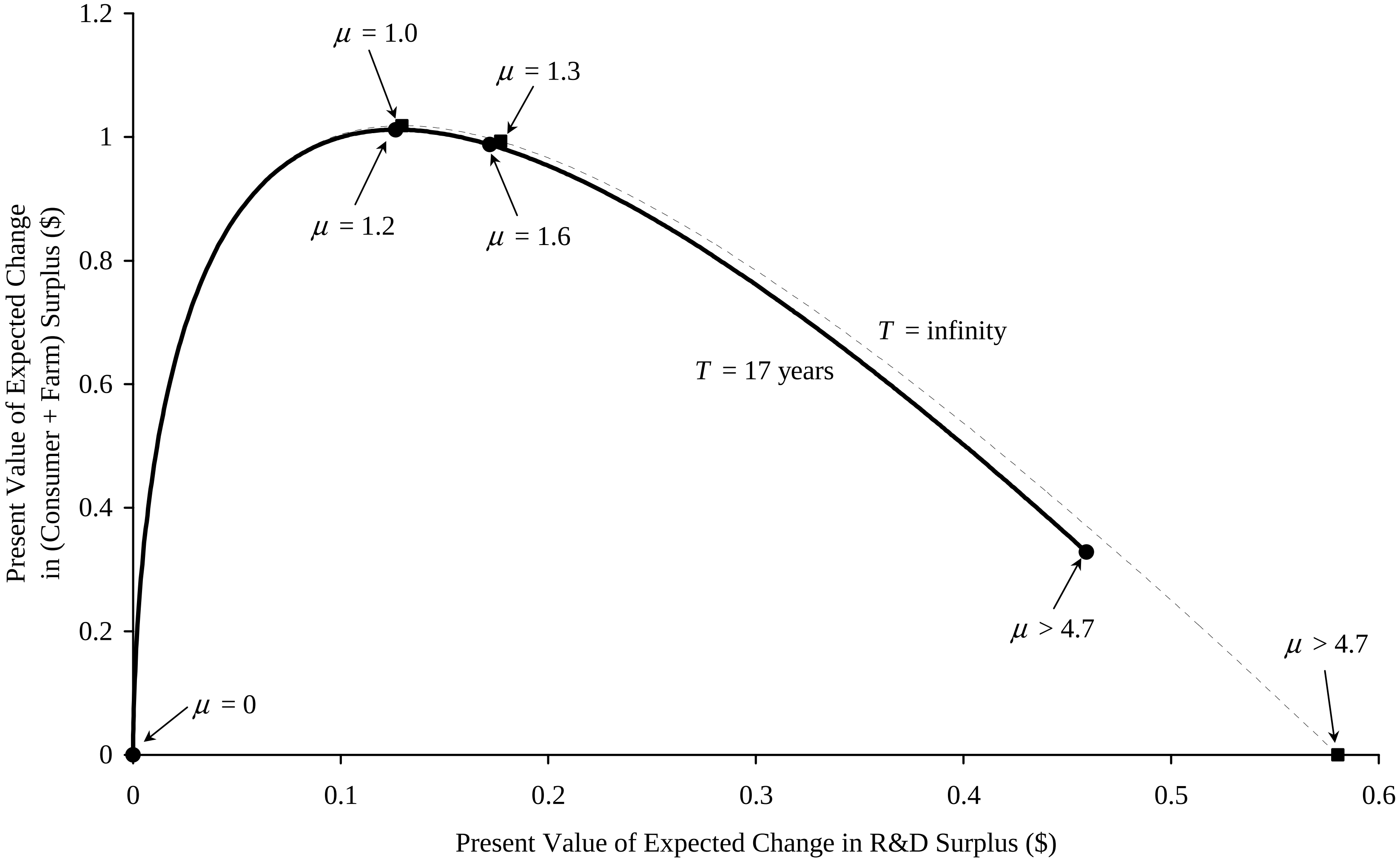


Figure 6. Tradeoff between present value of expected changes in (consumer + farm) surplus and present value of R&D surplus.



the rest of society. With a 17-year protection period, policy makers who attached a weight of zero to the welfare of R&D firms would choose an appropriability level of $\mu = 1.2$ while those who attach equal weights to all three groups would choose an appropriability level of $\mu = 1.6$.[16] With a 17-year protection period, points associated with $\mu < 1.2$ reduce total welfare and can be ruled out regardless of the policy makers' relative preference for the two groups. On the other hand, the only possible justification for $\mu > 1.6$ is a greater weight for the welfare of R&D firms than for the welfare of consumers and farmers.

With GURT technology we have an infinite protection period, and there is a level of appropriability of $\mu = 4.7$ at which the sum of consumer and farm surpluses is zero. Although this level may be considered unrealistically high, it does help explain why the early discussions regarding this technology were so negative.

The difference between the 17-year line and the infinite time line at the higher levels of appropriability shows the present value of the welfare benefits that accrue after the protection period. These can be substantial.

It is possible to change the optimal level of appropriability by adjusting the productivity of both "labor" and capital in the R&D process (κ_L and κ_K). As the productivity of these inputs falls, the optimal level of appropriability also falls. Therefore, we have chosen these values both to reflect the productivity we have seen in this sector (Huffman and Evenson) and at as small a level as can be justified by the literature.

IV.1. What is the Appropriability Level in the U.S. Seed Industry?

To assess the simulated results vis-à-vis real-world appropriability levels, it is worth noting that the magnitude of μ in a particular market can be estimated from the marginal production costs for seed (excluding R&D expenditures) and the sales price for that seed. For example, the U.S. Securities and Exchange Commission Form 10 K for Pioneer Hi-Bred International, Inc. for

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[16] The slope of the 17-year curve depicted in Figure 6 equals minus one at $\mu = 1.6$. Hence, at that point the welfare of one group can be increased by $1 only if the welfare of the other group is reduced by the same amount.

1998 (p. 90) breaks out costs and margins for North American seed corn operations. The price per unit sold in 1996 and 1997 respectively was \$75.0 and \$78.9.[17] The production cost of each unit sold can be calculated as \$52.2 in 1996 and \$55.7 in 1997. However, this production cost included R&D expenditures of \$6.2 in 1996 and \$7.5 in 1997. Subtracting these R&D expenditures from production costs provides estimates of marginal production cost of \$46.0 in 1996 and \$48.2 in 1997. Comparing market prices received with this marginal production cost suggests a measure of $\mu = 0.63$ in 1996 and $\mu = 0.64$ in 1997, given the chosen normalization of unitary marginal costs ($c_1 = 1$).[18] These figures are relevant because Pioneer Hi-Bred International is by far the largest producer of hybrid seed corn in the U.S., with a market share in the North American hybrid seed corn market approaching 40%.

We conducted a similar analysis for DeKalb Seed Company and found measures of μ of 0.44 in 1997 and 0.35 in 1998. To compare with firms outside the seed industry, we looked at available data from leading firms in other industries with heavy emphasis in R&D, such as computers (Intel Corporation and Microsoft) and pharmaceuticals (Pfizer and Eli Lilly). Intel had a μ of 1.05 in 1997 and 0.66 in 1998, and by 2002 Intel's μ had fallen to 0.49. Microsoft had a μ of 1.60 in 1997, 1.88 in 1998, and 1.68 in 2002, with an average μ of 1.94 over the six-year period from 1997 through 2002. Eli Lilly and Pfizer had appropriability levels that varied between a low of $\mu = 0.67$ for Pfizer in 1998 and $\mu = 1.15$ for Eli Lilly in 2001. The average for these two drug companies over the six-year period from 1997 through 2002 was $\mu = 0.80$ for Pfizer and $\mu = 0.98$ for Eli Lilly. It would be interesting to calculate optimal appropriability levels using a model that described the industry and market structure that drug and computer companies operate in. For now, all we can say is that appropriability levels in the U.S. seed corn industry appear to be lower than those that exist in other sectors where intellectual property rights are important and protected.

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[17] Each unit consists of 80,000 kernels.

[18] This calculation implicitly assumes that the limiting pricing factor for w_1 in (2.9) is $\mu + c_1$.

An interesting experiment is to ask what level of productivity of labor and capital would be needed to justify the appropriability level of around $\mu = 0.6$ that we see in the U.S. seed corn market. To achieve this one needs productivity measures of $\kappa_L < 0.15$ and $\kappa_K < 0.15$ simultaneously. These values are unrealistically small (Huffman and Evenson).

The above results suggest that the appropriability level that exists in this sector is probably lower than the social optimum. Yet the hybrid seed corn market in the U.S. represents an extreme in terms of appropriability. This is true because hybrid seed lines are difficult to copy and because U.S. property rights are strong. This comparison suggests that appropriability levels for other sectors of the seed market where appropriability levels are weak (e.g., open pollinated crops such as wheat and soybeans in the U.S., and all crops in countries with poor property right protection) are far lower than the social optimum. So long as this situation is in place, public research will be essential to offset the lack of sufficient private incentives.

V. Conclusions

This paper proposes and utilizes a model that assumes optimal behavior and equilibrium in the private sector R&D market, the market for seeds and the market for grains. To the best of our knowledge, this is the first attempt to allow for simultaneous equilibrium in all three of these markets.

The model allows us to calculate the impact on producer and consumer surplus of changes in plant variety protection (or intellectual property rights (IPRs)). The model can be used to measure the impact of R&D during the period for which protection is granted *and* in the period after which this protection is removed. Despite the apparent complexity of the model, relatively few parameters are required for purposes of simulation and most of these can readily be found in the literature. Results confirm a well-known result that producers generally lose from innovations whenever the own-price elasticity of crop demand is less that one.[19] However,

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[19] Although on average producer welfare is lost, producers who are early adopters of the new technology tend to gain from it.

increased benefits to consumers outweigh producer losses and total welfare increases in IPR appropriability over a wide range.

We present simulations that show that there is an optimal level of IPR appropriability for seeds, and that this level is not particularly sensitive to parameters of the model other than the R&D productivity of the seed industry. We also show that there is a range of appropriability levels where the interests of consumers and producers (taken together) are complementary to the interests of R&D firms. There is also a range of appropriability levels where the welfare of producers and consumers (taken together) can be increased only at the expense of the welfare R&D firms.

These results may explain some of the acrimony that has accompanied the debate about the patenting of plant genes and the genetic use-restriction technologies (GURTs). Seed firms typically view all increases in IPR appropriability as welfare increasing, and our results confirm that assumption. But those that represent consumers and producers can correctly point out that there is at the upper range of IPR appropriability over which the welfare of R&D firms comes at the expense of the rest of society, and that total welfare can sometimes be increased by reducing the level of IPR appropriability. Our results suggest that the optimum level of IPR appropriability is greater than that which existed in the North American seed corn market in 1996 and 1997, but that it is lower than would exist if GURTs were to become widely used.

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