Review of “Property Rights Protection of Biotechnology Innovations”
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Intellectual property rights are sometimes hard to enforce, especially in the case of genetically modified crops which can replicate themselves in the form of seed. The paper examines three regimes for the protection of intellectual property in genetically modified crops: short-term contracts, long-term contracts, and technology protection systems such as terminator genes. The seed company prefers in order: technology protection systems, long-term contracts, and short-term contracts. The farmers prefer in order: long-term contracts, short-term contracts, technology protection systems. High monitoring costs for the seed company may switch social economic preference to long-term contracts from short-term contracts, and society does not like technology protection systems.

Perhaps more important than the results specific to this model is the methodology used by the authors in approaching the problem. Many prior models around the protection of intellectual property only use one period, i.e. agents are not required to first purchase the protected materials before they can copy. The introduction of the second period introduces a dynamic effect into the model which allows it to more closely represent reality. For example, to produce a pirated copy of a good, one must first have acquired the good. In a one period model, this purchase then pirate dynamic cannot be accurately portrayed.

Background

Once human-designed organisms created through genetic modification became patentable, the problem arose of how to protect that intellectual property (IP) in the use of products based on that patent. One example is that of an agricultural seed company protecting its genetically modified seed from illegal propagation by farmers who buy that seed. Patent protection would be available for, for example, Roundup-ready soybeans, which produces plants that are immune to the effects of the pesticide Roundup. That pesticide can be sprayed directly on the crop without damaging the crop but it kills weeds in the field. Under the terms of sale of the initial seed purchase of the patented genetically modified organism (GMO) seed, farmers would not be allowed to save seed at harvest for planting in the next year, the way that farmers might for traditional agricultural products. If, in violation of that purchase contract, farmers save seed at harvest for later planting, these farmers are said to be pirating that seed. Such pirating is stealing the intellectual property of the patented GMO. A pure protection mechanism would be to make the progeny seed sterile, by creating a terminator gene in the soybean plant so that progeny seed would not germinate. The authors evaluate possible contract mechanism designs against the pure terminator gene protection to see which produces the least cost contract for the company and the highest economic welfare for the farmers. They use a game-theoretic, two-period model to do this evaluation and prove their results analytically.

In game theory, this economic construct is known as a principal-agent problem. The principal is the company and the agents are the farmers. The objective of the company is to get the farmers to do what the company wants them to do: purchase the seed and respect the intellectual property contained within that seed by purchasing seed each planting season. The problem arises because the principal cannot observe individual agent behavior and so cannot know if each individual farmer is in compliance. Monitoring by the company of all individual farmers would be prohibitively expensive. Given that the company cannot exhaustively monitor farmers, the easiest way to motivate the farmers to act is to align the farmer’s incentives with the company’s incentives via the sales contract. The sales contract must establish a penalty if the farmer is caught saving seed and there must be some positive probability that the farmer will be caught. From the company’s perspective, it must balance the penalty and probability of being caught against what it would lose in profits if the farmer gets away with pirating. The company wants to minimize its cost and still maintain its IP protection, as well as design a contract that motivates the desired behavior in the famers.

Farmers (agents) are postulated to be players of three types: those who will never pirate and always buy seed, those who will always pirate after their first seed purchase, and those in-between who will make the pirating decision based on what their individual profit from pirating might be. The farmers know their type, the company does not know, and cannot determine it before the initial sale. This paper evaluates two different contracts mechanisms and a biologically imposed solution technology protection system (TPS) using a terminator gene to protect the company’s intellectual property rights.

Each player (company and farmers) has incomplete information about the others. The company does not know which farmer is which type, and the farmers do not know the extent of the monitoring that the company will do in search of pirates. Each player will try to maximize their expected profit. The paper identified three different possible sales structures: short-term contracts, which the paper indicates is what are currently used, long-term contracts, and the TPS. Each of these are described generally in the following way: a long-term contract lasts for more than one growing season, a short-term contract lasts for one growing season, and TPS prevents pirating of seed by rendering the harvested seed from the crop infertile, unable to produce a plant in the next season. The model is a two-period model, meaning that the game has two “rounds,” thus each player is allowed two decisions (one per round). Furthermore, a player’s decision in the first round will affect what decisions the player may make in the second round. In all the models, the company can choose the price of the GM seed in each round, and the company chooses how much to spend to search for pirates. In the first round, the farmers must decide between buying GM seed or traditional seed (which they can legally save some of at harvest to plant in the next year). In the second round, again, the farmers must decide between buying GM seed or traditional seed. In the short-term contract model, if a farmer bought GM seed in the first round, he can pirate the seed for the second round. However, there is a certain chance that the farmer will be caught pirating and pay a fine to the company. Under long-term contracts, the farmer has no decision to make in the second period as the contracts cover both periods.

Each of the players is assumed to be perfectly rational and forward thinking. Each farmer values GM seed differently, and this value is assumed to be uniformly distributed on the unit interval. This value derives from a farmer’s potential benefit (profit) from the use of GM seed. A farmer’s value of GM seed is referred to as the farmer’s type, and is private to the farmer.

The paper evaluates each of the different contract types in two ways: profit for the company and general social economic welfare. As might be expected, the TPS model shows the greatest profit for the company because it allows the company to create a perfect monopoly and no monitoring costs are needed. The TPS model shows the lowest general welfare gain, however. The long-term contract model shows the second most profits for the company, with the short-term contract model showing the smallest profits. When monitoring costs are high, the long-term contract results in higher social welfare, and when they are low, the short-term contract is superior.

Model

The mathematics of the paper are presented in the solution of the model and as a set of propositions and proofs. The outlines of each proof are in the appendices and appear to be carefully done and laid out. The model is executed as a constrained optimization: an economic welfare function constrained by player participation constraints that determine which farmers will do what under each contract type. A separate model is solved for each contract type and for the TPS. The model is solved through use of backward induction, by initially solving for the second period in terms of first-period decision variables and exogenous variables, and then solving for those first-period variables in terms of only the exogenous first-period variables. This is a common solution method for game theoretic, multi-period models.

The solution to the model for the short-term contract is developed. There are four classifications of farmers (one for each possible combination of moves): H, M, L, T. Farmers of type H are high-return farmers and always buy GM seed. Farmers of type M are medium-return farmers and buy GM seed in the first period, but pirate GM seed in the second. Farmers of type L are low-return farmers and buy traditional seed in the first period, but buy GM seed in the second period (the price of GM seed falls in the second period). Farmers of type T are traditional farmers and always buy traditional seed. The notation to stand for the yield a farmer receives from using GM seed is θ_i, where $\theta \epsilon [0,1]$. The subscript $i \ \epsilon \ \{H, M, L, T\}$ refers to the type of farmer. Moreover, we only consider the lowest return obtained by farmers of a certain type. So θ_H is the lowest return obtained by farmers of type H. Likewise, θ_M is the lowest return obtained by farmers of type M, etc. As a condition for the model, $0 \leq \theta_L \leq \theta_M \leq \theta_H \leq 1$, with θ_T implicitly smaller than θ_L and normalized to zero. Therefore, for the optimized values of θ, i.e. θ^*, we require $\theta_L^* \leq \theta_M^* \leq \theta_H^*$. The conditions for which this occurs are laid out in Lemma 1 of the paper, discussed after the model's solution. The price of the GM seed is P_t, where $t \ \epsilon \ \{1,2\}$ refers to the period. Thus, the net return for the marginal farmer of type i is $\theta_i - P_t$.

To address pirating conditions, postulate that a farmer purchases GM seed in period 1 and then he may pirate seed from his harvest in period 1 to plant in period 2. Because the yield of pirated seed is not always as high as the original, pirated yield of GM seed is given by $\alpha\theta$, where $\alpha \ \epsilon \ [0,1]$. However, if a farmer pirates, there is a probability that he will be caught by the monitoring program run by the company, denoted by ψ, where $\psi \ \epsilon \ [0,1]$. If the farmer is caught, then he must pay a fine of $\lambda > 0$ to the GM company. Note that ψ and λ are properties of the game decided before play commences, and therefore cannot be affected by the players. Monitoring the farmers cost the GM company a flat fee $k > 0$. Then, to find the expected value of pirating GM seed, recall that expected value is given by the probability of an outcome multiplied by the value of that outcome, summed over all possible outcomes. Thus, the expected value of pirating GM seed is given by $(1-\psi)\alpha\theta - \psi\lambda$. To prevent a farmer from pirating, it is necessary that the expected value of pirating be less than the value from buying GM seed, i.e. that $(1-\psi)\alpha\theta - \psi\lambda \leq \theta - P_2$.

Solving for the marginal low-value farmer, or the farmer who is indifferent between buying GM seed in the second period and pirating seed from the first period, means that $\theta_L = P_2^{ST} = [\,1-(1-\ \psi)\alpha]\theta_H +\ \psi\lambda$.

To solve the model, formulate the company's (principal's) profit for the second period

$$\Pi_2 = \int_{\theta_H}^{1} P_2^{ST}\ d\theta + \int_{\theta_L}^{\theta_M} P_2^{ST}\ d\theta + \int_{\theta_M}^{\theta_H} \psi\lambda\, d\theta - k$$

The first two integrals are the profit from selling GM seed to the two farmer types who buy seed in the second period and the last integral is the penalties obtained from catching pirates minus the cost of monitoring. Integrating and substituting for P_2^{ST} gives the expression for profits to maximize over the value θ_H:

$$max_{\theta_H} \, [(1-(1-\psi)\alpha)\theta_H + \psi\lambda][1-\theta_H+\theta_M-\theta_L] + \psi\lambda(\theta_H-\theta_M) - k.$$

Substituting in $\theta_L = P_2^{ST} = [\,1-(1-\psi)\alpha]\theta_H + \psi\lambda$ gives profits as a function of θ_H and θ_M :

$$max_{\theta_H} \, (1-\theta_H)[(1-(1-\psi)\alpha)\theta_H + \psi\lambda][\theta_M - (1-(1-\psi)\alpha)\theta_H - \psi\lambda]$$
$$[\,(\,1-(1-\psi)\alpha)\theta_H + \psi\lambda] + (\theta_H-\theta_M)\psi\lambda - k.$$

The lowest return to a farmer who buys GM seed in the first period, θ_M, is determined in the first period and so is set for the second period. Thus, profit can be maximized with respect to θ_H . Solving the first-order condition (FOC) for θ_H gives:

$$\theta_H = \frac{1-2\psi\lambda+\theta_M}{2(2-(1-\psi)\alpha}$$

Substituting in gives second period price for the short-term contract as:

$$P_2^{ST} = \theta_L = \frac{1-\alpha+\alpha\psi+2\psi\lambda+\theta_M(1-(1-\psi)\alpha)}{2(2-(1-\psi)\alpha)}.$$

To solve for the first period variables, the company profit is stated in terms of the present value of first period profit from seed sales in the first period and discounted, previously optimized (*), second period profit:

$$\Pi = \int_{\theta_M}^{1} P_1^{ST} \, d\theta \; + \; \delta \, \Pi_s^{ST*}$$

If $\alpha = 1$ (progeny seed are the same quality as original seed), then the equilibrium values for the variables are found by integrating and maximizing the total profit with respect to θ_M. That is the process of backward induction. The resulting expressions are complicated and Lemma 1 in the paper is derived as the necessary condition on the variables in the model.

Lemma 1

A sufficient condition for $\theta_L^* \leq \theta_M^* \leq \theta_H^*$ is

$$1 + (-1-\delta-4\lambda)\psi + (-2+3\lambda\delta-4\lambda)\psi^2 + (4\lambda\delta+2\delta)\psi^3 > 0$$

and this occurs when $\psi\epsilon[0, 0.1581], \delta\epsilon[0,1], \lambda\epsilon[0,1]$.

The weak point of the paper is that the propositions rest on Lemma 1, which is a numeric relationship. Thus, the propositions and their proofs are all conditional on this numeric relationship. This makes the paper weaker than it would be if that condition was unnecessary.

Proof of Proposition 5

The proof of Proposition 5 is illustrative of the approach to proofs taken in this paper. Proposition 5 states that the short-term contract price for period 1 is greater than or equal to the TPS technology seed price, which is greater than or equal to the short-term contract price in period 2. The authors consider the price differences and prove the relationships by proving positive price differences. Since the price difference expressions are not simple, they first must be simplified and then the numerical values from Lemma 1 applied. When that is done, the expressions are evaluated and the relationships found to be as indicated. The proof consists of showing that the expression for the price difference is positive over the domain of the variables within the expression. The authors outline their proof in Appendix D of the paper.

More specifically, the proof proceeds from several relationships given in the paper:

$0 \leq \lambda \leq 1$	penalty λ is between zero and one by definition
$0 \leq \delta \leq 1$	discount factor is between zero and one by definition
$0 \leq \psi \leq 0.1581$	probability of being caught pirating from Lemma 1

Proposition 5 proves that the optimal (denoted by *) values of short-term prices for periods 1 and 2 bound the price for the TPS seeds. In other words: $P_1^{ST*} \geq P^{T*} \geq P_2^{ST*}$

$P^{T*} = 1/2$ from Proposition 4

$$P_1^{ST*} = \frac{2 + 4\psi + (2 - 4\delta - 4\delta\lambda - \delta^2)\psi^2 + (-4\delta - 4\lambda\delta + 3\lambda\delta^2)\psi^3 + (2\delta^2 + 4\lambda\delta^2)\psi^4}{(1 + \psi)(4 + (4 - 3\delta)\psi - 4\delta\,\psi^2)}$$

from equation (11) in the paper.

$$P_2^{ST*} = \frac{(3 + 4\lambda)\psi + (3 - 2\delta + 4\lambda - 3\lambda\delta)\psi^2 + (-3\delta - 4\lambda\delta)\psi^3}{(1 + \psi)(4 + (4 - 3\delta)\psi - 4\delta\psi^2)}$$

from equation (10) in the paper.

Finding a common denominator and expanding yields:

$$P_1^{ST*} = \frac{2[2 + 4\psi + (2 - 4\delta - 4\,\delta\lambda - \delta^2)\psi^2 + (-4\delta - 4\lambda\delta + 3\lambda\delta^2)\psi^3 + (2\delta^2 + 4\lambda\delta^2)\psi^4]}{2(1 + \psi)(4 + (4 - 3\delta)\psi - 4\delta\psi^2)}$$

$$P^{T*} = \frac{(1 + \psi)(4 + (4 - 3\delta)\psi - 4\delta\psi^2)}{2(1 + \psi)(4 + (4 - 3\delta)\psi - 4\delta\psi^2)}$$

$$P_2^{ST*} = \frac{2[(3 + 4\lambda)\psi + (3 - 2\delta + 4\lambda - 3\lambda\delta)\psi^2 + (-3\delta - 4\lambda\delta)\psi^3]}{2(1 + \psi)(4 + (4 - 3\delta)\psi - 4\delta\psi^2)}$$

Consider the denominator. If it is always positive, since it is the same for all three fractions, it can be removed without affecting the direction of the derived inequalities. The variable λ does not appear in the denominator. The expression is linear and monotonically decreasing in δ. At maximum δ = 1, the expression is positive. At δ = 0, it is also positive and therefore positive for all δ. Over the domain of ψ, the expression is positive. Thus, the denominator can be dropped without affecting the direction of the derived inequalities and only the relationship among the numerators is left to consider.

Gathering terms on ψ, the inequality we are trying to prove is equivalent to:

$$4 + 8\psi + (4 - 8\delta - 8\delta\lambda - 2\delta^2)\psi^2 + (-8\delta - 8\lambda\delta + 6\lambda\delta^2)\psi^3 + (4\delta^2 + 8\lambda\delta^2)\psi^4$$
$$\geq 4 + (8 - 3\delta)\psi + (4 - 7\delta)\psi^2 - 4\delta\psi^3$$
$$\geq (6 + 8\lambda)\psi + (6 - 4\delta + 8\lambda - 6\lambda\delta)\psi^2 + (-6\delta - 8\lambda\delta)\psi^3$$

The authors consider each inequality separately in Appendix D. First, they consider $P^{T*} \geq P_2^{ST*}$ or $P^{T*} - P_2^{ST*} \geq 0$. That difference is

$$4 + (2 - 3\delta - 8\lambda)\psi + (-2 - 3\delta - 8\lambda + 6\lambda\delta)\psi^2 + (2\delta + 8\lambda\delta)\psi^3$$

This is equation D1 in the article. To evaluate that this expression is always positive, one can take the first derivatives with respect to δ and λ. These derivatives are

$\frac{\partial}{\partial\lambda} = -8\psi + (-8 + 6\delta)\psi^2 + 8\delta\psi^3$ and $\frac{\partial}{\partial\delta} = -3\psi + (-3 + 6\lambda)\psi^2 + (2 + 8\lambda)\psi^3$

Both are negative over the domain of ψ, indicating that the difference is decreasing in both variables. Thus, the difference can be evaluated at the maximum of λ and δ to get a minimum difference as a function of ψ. At δ = λ = 1, the difference becomes $4 - 9\psi - 7\psi^2 + 10\psi^3$. Over the domain of ψ = [0, 0.1581], this difference is always positive. Thus, we have proven that if the conditions for Lemma 1 are met, then:

$$P^{T*} \geq P_2^{ST*}$$

The second difference, $P_1^{ST*} - P^{T*}$, is

$$3\delta\psi + (-\delta - 2\delta^2 - 8\delta\lambda)\psi^2 + (-4\delta - 8\delta\lambda + 6\lambda\delta^2)\psi^3 + (4\delta^2 + 8\lambda\delta^2)\psi^4$$

This compares to equation D2 in the article. The first derivatives of this expression are

$\frac{\partial}{\partial\delta} = 3\psi + (-1 - 8\lambda - 4\delta)\psi^2 + (-4 - 8\lambda + 12\lambda\delta)\psi^3 + 8\delta^2\psi^4$ and
$\frac{\partial}{\partial\lambda} = -8\delta\psi^2 + (-8\delta + 6\delta^2)\psi^3 + 8\delta^2\psi^4$.

The first is positive, while the second is negative, which means that the difference is monotonically decreasing in λ and increasing in δ. To understand the behavior of this inequality with respect to the variables, because the derivative can be clearly signed, it is only necessary to explore the four possible corners of the domains of δ and λ. These are [λ, δ] = [(0, 0), (0, 1), (1, 0), (1,1)].
For [λ, δ] = [0, 0], the difference becomes 0, as there is no additive constant.
For [λ, δ] = [0, 1], the difference becomes $3\psi - 3\psi^2 - 4\psi^3 + 4\psi^4$. Over the domain of ψ, this expression will be positive or 0.

For [λ, δ] = [1, 0], the difference becomes 0.
For [λ, δ] = [1, 1], the numerator becomes $3\psi - 11\psi^2 - 10\psi^3 + 12\,\psi^4$. Over the domain of ψ, this expression is positive or 0.
Thus, for this second price difference, it is demonstrated that is it positive or zero over the domains of all the variables. Thus, we have that:

$$P_1^{ST*} \geq P^{T*}$$

And by extension:

$$P_1^{ST*} \geq P^{T*} \geq P_2^{ST*}$$

This concludes the proof.

Conclusion

One extension of this paper would be to look into proving the propositions without Lemma 1 or proving Lemma 1 analytically, as opposed to using a numeric approximation method. A second would be to look into extending this into a more general multi-period model, but it is easy to see that the complexity of solutions, and even the setup, is greatly increased by addition of even one period. The authors suggest inclusion of a "gray" market, or commercial piracy where farmers could sell the seed they keep (pirate) at harvest.

The authors have used these methods to evaluate contract mechanism designs that might yield good profits for the company and motivate buyers (farmers) to behave in a way that is good for them (gives them maximum profit), good for the company (gives them maximum profit) and good for society (produces maximum social economic welfare). The importance of the paper is not in the specifics of this situation, but in the demonstration of how models like this can be used to optimize sales contract design within market situations. As intellectual property and the protection of it gets more complex, these kinds of models and evaluations can assist.

The paper had been cited by others investigating the economics of intellectual property and its protections in agricultural systems and beyond. These kinds of models would allow consideration of how various contract types, well beyond those two considered here, would impact company profits, farmer profits, and the tendency of farmers to pirate. Beyond agriculture, these kinds of models are used to investigate software and music pirating (the authors cite a number of software pirating one-period papers), and could be used to examine other kinds of piracy in video games, and even online streaming. In any industry-product combination where the company has imperfect monitoring, this kind of model can be used and these authors have shown clearly how the analysis can proceed to gain useful results. Beyond companies making these products, these results can be useful to regulators and policy makers to evaluate the need for regulation, for criminal and/or civil penalties, and for consideration of how piracy will affect these industries.

D.M. Burton, H.A. Love, G. Ozertan, and C.R. Taylor, Property Rights Protection of Biotechnology Innovations, Journal of Economics & Management Strategy, **14**(2005), 779-812.