The Impact of Intellectual Property Rights in the Plant/Seed Industry

Tirtha Dhar and Jeremy Foltz*

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Abstract

This work uses changes in intellectual property rights regimes for plants as a way to identify the value and cost to industries and society of the different components of property rights: exclusivity, research exemptions, and revelation of research outcomes. A simple model is described that can account for these differences in company choice of intellectual property versus keeping trade secrets. The data used include observations on multiple crop types over a span of 20+ years across 3 different intellectual property rights regimes. Differences in the replicability of crop types are shown to cause intellectual property rights to have diverse sets of incentives for research and property rights claims.

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Evolution in science such as recent developments in biotechnology creates new challenges for patent regimes, leads to reforms in laws and regulations, and has led to the creation of property rights where none existed before. These new property rights imply new avenues of rents for firms and new types of strategic behavior. In theory, intellectual property rights, by giving inventors monopoly rights to their inventions, provide economic incentives for research and development. In exchange for the monopoly rights inventors reveal the methods behind their invention, which helps further the public good by fostering cumulative invention while imposing a cost on the company from revealing their secrets. This work uses recent changes in the intellectual property laws in the plant and seed industry as well as key agronomic differences between corn and soybeans to analyze firm decision making of whether to patent their technologies or keep trade secrets.

The present exponential growth in biotechnological research is a byproduct of changes in both the technology and the availability of intellectual property rights for living organisms. The new paradigm in biotechnology patenting started after the landmark Supreme Court's 1980 *Diamond v. Chakrabarty* decision that allowed the patenting of life forms. This decision opened the door to the patenting of plants and animals as standard utility patents. In the case of plants certain forms of property rights, for plant seeds the Plant Variety Protection Act (PVPA) and for tubular form plants the Plant Protection Act (PPA), were already in place before the Supreme Court decided this landmark case. The PVPA and PPA, however, granted weaker property rights than utility patents because they allowed researcher and farmer exemptions.

The court decisions and changes in government policies created a menu of choice in plant intellectual property rights for agricultural biotechnology firms. For seeds firms with new research ideas they could either apply for a PVPA or a utility patent or they could apply for both. Such menu choice in intellectual property rights is unique to plants. A theoretical model by Hopenhayn & Mitchell (2001) suggests that a menu approach in patenting with different levels of property rights can lead to strategic patenting behavior by firms leading to socially sub-optimal investments in property rights. Our study will explore this issue of availability of menu choice in plant patenting and its implications for strategic firm behavior in the corn and soybean seed markets.

New property rights also imply increased uncertainty in the interpretation of laws. In such a dynamic scenario where laws and interpretations of them are changing rapidly, firms need to be strategic in their patenting decisions, such that they can extract maximum rents from their rights. Such strategic behavior of firms has been captured in the literature on patent lengths and breadths (for example: Gilbert & Shapiro, 1990). Our goal in this paper is to explore another important aspect of strategic patenting behavior: the implications of patenting rules on the intellectual portfolio choice between patents and trade secrets. We explore this issue using data on patents and other intellectual property rights in the plant/seed industry, which had a strong tradition of using trade secrets to protect its innovations prior to the 1970's.

The chronology of patent law changes allows us to also explore the behavior of biotechnology firms in plants. Chronologically, in the case of plant patents the regulations, litigations and decisions significantly strengthened the property rights available for plants. The following are the most significant decisions and regulation changes on plant patenting: [1] *Diamond v. Chakrabarty* in 1980, [2] *ex-parte Hibberd* in 1985, [3] *J.E.M. Ag Supply v. Pioneer Hi-Bred International* in 2000. We explore strategic behavior of firms in patenting given these events using an event study methodology.

The remainder of this work is divided as follows. The next section presents a brief overview of the salient aspects of intellectual property rights in plants and a description of the market for corn and soybean seeds. This is followed by a review of the economics literature on intellectual property rights. The literature then informs a model of the strategic game played by two firms choosing between intellectual property rights and keeping trade secrets, which is presented in the fourth section. The fifth section tests the analytic model by presenting empirical evidence from data on intellectual property rights in plants from 1981 – 2001. A concluding section follows.

Intellectual Property Rights for Plants

Up until the end of the twentieth century, US utility patent statutes were understood to exclude patents on living organisms. The intellectual property needs/demands of the plant and seed propagation industry led to a number of intellectual property rules to allow intellectual property on plants despite this exclusion. After a series of complaints by nursery owners, the US Congress created the Plant Patent Act (PPA) in 1930 to allow intellectual property protection of asexually propagated plants, which are those that propagate by cuttings rather than seeds. Over the years the court traditions construed this law quite strictly to apply only to asexual propagation and that infringement only occurs from the actual taking of shoots or plant material is proven but cannot be proven merely by genetic similarity (Janis & Kesan, 2001).

In 1970 Congress created the Plant Variety Protection Act (PVPA) which allowed intellectual property protection of plants propagated by seeds. While similar to utility patent statutes, the PVPA has a research exemption and a farmer use exemption. The research exemption allows the use of PVP protected seeds in research, while the farmer exemption allows farmers to replants from PVP protected seeds he grew the previous year, "bin-run seeds". It does, however, exclude the farmer selling those seeds to other farmers, a practice commonly called "brown-bag seeds". Most studies of the effects of the PVPA (see e.g., Butler & Marion, 1985; and Lesser & Mutschler, 2002) have concluded that the introduction of this type of intellectual property right did not induce a significant increase in the amount of research conducted by the industry.

In 1980, the Supreme Court stepped into the fray with its 5 to 4 decision on *Diamond v. Chakrabarty*, which held that genetically modified bacteria could be patented within the scope of the US patent statutes. This decision, which was the linchpin to the explosion of biotechnology patents in the late 1980's and 1990's, was not clarified as being applicable to plants until 1985 when in *ex-parte Hibberd*, a utility patent application for a type of corn seed, the patent office's board of appeals concluded that Chakrabarty did apply to plants. Note that utility patent statutes have higher levels of standards for novelty and utility than the PVPA and have neither a farmer or researcher exemption, such that farmers cannot "bin-run" seeds with utility patents and researchers cannot use them without license. But on the other hand, because of the US patent office infrastructure in publicizing utility patent application contents is better than that used for PVPs, the utility patents provide much more exact information for the public domain.

Given these changes, plant seed producers had after 1985 two methods to protect their intellectual property a PVP and a plant utility patent (PUP) and could even apply for protection on both property rights. The issue of joint protection using both PVP and PUP was resolved in December 2001 by the Supreme Court decision *J.E.M. Ag Supply Inc. v. Pioneer Hi-Bred Int'l Inc.* which held that concurrent protection under the PVPA and the utility patent statutes was fine.

This history of intellectual property rights has created a number of different regimes for plant seed producers. The first regime which lasted until 1970 had no available intellectual property except for keeping company secrets. In this period corn seed producers developed closely guarded "closed pedigree" seeds that only partially protected their germplasm from use by rivals. After 1970 they had the option of applying for PVPs for their seed varieties. In 1985 utility patents were added to the intellectual property rights portfolio, but with some uncertainty as to their validity when concurrent with a PVP. In 2001 this uncertainty was resolved with plant/seed firms able to use a full menu of choices to protect their technologies: i) trade secrets kept in hybrids, ii) PVP certificates, iii) utility patents, and iv) some combination of these three methods.

The Corn and Soybean Seed Markets:

Corn and soybeans represent the two most important crops in the US seed market with the 2001 corn crop being worth $19 billion and the 2001 soybean crop worth $12 billion (U.S. Department of Agriculture, 2002). Not surprisingly a large portion of the private research dollars for seed development are in these seeds and have been the major crops to receive intellectual property protection with just under 1/3 of all the PVPs issued out of the hundreds of crops eligible have been for either corn or soybean varieties. The corn and soybean markets are both dominated by the same two firms Monsanto and Pioneer/Dupont which in 1997 accounted for 56% of the corn seed sales and 38% of the soybean seed sales (Hayenga, 1998).

While these two seed products are globally similar, some key differences in corn and soybean agronomics and markets imply different firm strategies with respect to research and development as well as marketing strategy. These key differences imply different values to the possible menu of firm strategies with respect to intellectual property rights. Such differences may lead to different firm strategies and market equilibriums as presented in the theoretical model presented below..

A key agronomic difference between corn and soybeans is that corn hybrids if replanted the following year with saved seed will not produce reasonable yields while soybeans will produce approximately the same yield when replanted. Thus soybeans have more durable good properties than corn for which new seed needs to be purchased every year. Anecdotal evidence suggests the soybean seeds sold in the market cover no more than three quarters of the national acres with the remainder planted in saved seed. Thus the overall size of the corn market is much larger and farmers make decisions about seeds each year rather than perhaps every other year.

This every year demand for hybrid corn seed as well has the larger overall size of the corn acreage planted has meant that more research dollars have gone into corn research than soy. In addition greater marketing and advertising efforts as well as brand/variety proliferation is present in corn seed than in soybeans. In part because of these higher levels of technological change, marketing, and variety proliferation farmers tend to change their corn seed variety every 2 years while in soybeans the turnover is every 4 or 5 years. Thus the effective life of a soybean variety from a company's point of view is about twice as long as that of a corn seed variety.

The Economics Literature

This work fits in a now large literature that seeks to understand the effects of changes in regulations and research technologies on the rate of innovation and patenting. Kortum and Lerner (1997) investigate whether the tremendous growth in US patents starting in the early 1980's can be attributed to rule changes that strengthened patents or to increases in innovation. They conclude that the "jump" in patent production is due to innovation and improvements in the management of research rather than to changes in patenting laws. Hall and Ziedonis (2001) in contrast found that changes in patent laws had a significant impact in patenting strategies of firms in semiconductor industries and led to `patent portfolio races' among capital-intensive firms, but it also facilitated entry by specialized design firms. These findings imply that stronger patenting rules are likely to lead to more strategic behavior by firms, but not necessarily more innovation. Using Japanese patent data before and after the 1988 patent reforms Sakakibara and Branstetter (2001) find no evidence to link the stronger patent rights with increased R&D investment or innovation.

A number of observers of patenting, particularly in the biological sciences, have suggested that patenting rules and overlapping claims have generated a "patent thicket" that has impeded innovation and made the R&D process more costly (Rai, 2001; Rai, 1999). Rai (2001) for example, argues that broad patents especially on upstream platform technologies represent a threat to competition and the cumulative process of innovation in the biopharmaceutical industry. A 2002 court ruling in *Madey v. Duke University* greatly contracts the research exemption rules on US patents especially for universities making this patent thicket potentially more of a problem.

Such concerns of a patent thicket have raised questions as to whether there might be reasons to legislate a greater research exemption in US patenting laws. Does intellectual property with a research exemption have sufficient value to companies that it can foster innovation? Or does the research exemption make imitation too easy and reduce the value of intellectual property to zero? The plant science industry provides a useful place to test the effects of such a research exemption since among the multiple types of intellectual property available to companies in the plant sciences industry are ones that have a research exemption (Plant Patents and Plant Variety Protection Certificates).

While much of the theoretical literature has focused on varying rules within the realm of intellectual property rights (patent length, breadth, etc.), recent empirical evidence has pointed to the importance of company secrets in company strategies. Cohen, Nelson, & Walsh, (2000) for example, find that firms in the 1990's were likely to rely more heavily on company secrets than were firms in the 1980's. This type of empirical evidence is not well described by current models of patenting, since they typically ignore the option to keep a company secret rather than apply for a patent. An exception is the model of firm R&D strategies put forth by Denicolo & Franzoni (2004) in which firms choose whether to patent or keep a trade secret based on the returns from patenting and their probability of losing a trade secret. We use ideas from that model in order to capture how the changing intellectual property regimes in plants might affect firm choices of whether to choose apply for property rights, PVP or utility patents, or to keep trade secrets.

Such choices between company secrets and intellectual property are particularly salient in the plant science industry where "closed pedigree" plant breeding in corn hybrids was developed in the 1940's and 1950's to respond to the lack of intellectual property rights in plant seeds. From the 1950’s to the 1970’s the trade secrets contained in hybrids were the only property rights available to corn breeders. In other crops, such as wheat, sunflowers, and soybeans, hybrid technology was not available as a method of keeping a trade secret. With the Plant Variety Protection Act and subsequent court rulings, seed companies gained access to a full panoply of intellectual property much greater than in other industries. This change in property rights as well as the differences between crops can be used to identify the value of different property rights.

A Model of Firm IP Strategy

In this section we examine a firm’s ex-ante decision problem to apply for any form of intellectual property rights through patents or to keep trade secret. For the purposes of this exercise we abstract from the differences between PVPA and utility patent property rights, but one should note that it is the differences in rules that will drive the value of intellectual property rights with respect to trade secrets.

Let there be two firms competing in a market to produce a seed to sell to a set of farmers. The firms can choose between keeping a trade secret and seeking intellectual property rights, a patent, on their technology. We assume two symmetric firms that each has a piece of R&D research output that they wish to either patent or keep as a trade secret. We assume that the probability of success in the patent application process is independent for each firm. As a result the probability of success of a patent application from firm 1 does not impact the probability of success of firm 2. If both the firms are approved for a patent then they share the total monopoly rent equally, if they both keep trade secrets they also share the market rent equally. The profit from a patent and a trade secret will differ due to differences their costs and benefits, which are described below. When one chooses a patent and the other a secret the majority of the rent accrues to the patent holder.

In matrix form the game can be stated as:[1]

		Firm j	
		Patent	**Trade Secret**
Firm i	**Patent**	$\Pi_i\{pt,pt\}, \Pi_j\{pt,pt\}$	$\Pi_i\{pt,s\}, \Pi_j\{pt,s\}$
	Trade Secret	$\Pi_i\{s,pt\}, \Pi_j\{s,pt\}$	$\Pi_i\{s,s\}, \Pi_j\{s,s\}$

Where $\Pi_i\{pt,pt\}$ is the monopoly returns from firm *i* having a patent and sharing the market with firm *j* and $\Pi\{s,s\}$ are the returns from both firms keeping a trade secret. When one firm chooses a patent and the other a trade secret they have asymmetric returns $\Pi_i\{s,pt\}, \Pi_j\{s,pt\},$ which provides monopoly returns to the firm that owns a patent while the trade secret owner receives zero returns.

[1] For expositional purpose we also present parts of the detailed analytical model in the appendix.

There are two interesting Nash equilibrium from the perspective of the empirical evidence presented below: the two diagonal elements of the matrix (Trade Secret, Trade Secret) and (Patent, Patent). Given the very low returns for trade secret owners on the off-diagonal, these are also the least likely equilibriums given reasonable parameterizations of the other values. The trade secret/trade secret equilibrium characterizes an industry such as the plant/seed industry in the period before the advent of the Plant Variety Protection Act, while the patent/patent characterizes an industry such as the biotechnology part of the plant/seed industry in the last decade. Whether the equilibrium is at (Trade Secret, Trade Secret) or (Patent, Patent) will be a function of the relative value and costs of patents versus trade secrets.

The elements of the value of property rights are determined by the strength of the property rights, their enforceability, and the length of time that they hold sway. Thus a trade secret is only as valuable as the firm's ability to keep it a secret and a patent's value only as good as a firm's ability to enforce it. In addition decisions to choose intellectual property rights will be in part driven by how long they can be enforced, while decisions to keep trade secrets will be a function of the expected length of time before a rival can legally steal, copy, or reverse engineer the technology. Also relevant to the value of intellectual property is the speed of technological change in the industry. In industries with rapid change, such as in software, the effective length of intellectual property protection is bounded by the length of time before the product becomes obsolete, which may be as little as two years. Thus one is more likely to see the (Trade Secret, Trade Secret) equilibrium in industries with high levels of technological change.

The elements of the costs of intellectual property and trade secrets to a firm come from two elements: 1) the probability that the information in the technology will be revealed, and 2) the cost of obtaining the intellectual property rights. We focus primarily on the first cost as being the most important to the outcome of the firm's choices. Each type of property right will have its own probability of being revealed to a rival. Patents because of their public disclosure necessarily reveal some of the technology, although a part of that revelation is protected. PVPs in addition to having the same level of public revelation as utility patents allow further public disclosure of the technology to rivals, by having a research exemption.

The theory presented above suggests the following relationship between the features of the intellectual property and the technology and the equilibrium outcomes likely to be observed in the market.

High revelation loss probabilities in IP: When there are high probabilities of revelation losses in patenting, firms are more likely to keep trade secrets than apply for intellectual property rights. Thus under the PVP only regime the trade secret equilibrium is more likely than under the utility patent regime.

Timing: A longer shelf life for a technology is likely to lead to greater reliance on patents than on trade secrets. Thus we should expect more trade secrets in corn than in soybeans.

Probability of losing a trade secret: As the probability of losing a trade secret goes up, firm are more likely to choose intellectual property. Thus for seeds where hybrids do not exist such as soybeans and wheat, one is much more likely to see the use of intellectual property rights than in seeds such as corn where hybrids are possible.

These predictions are considered below using empirical evidence from firm choices of intellectual property in the plant/seed industry with a particular focus on corn and soybean intellectual property rights.

Empirical Evidence

We start the empirical analysis by demonstrating the tremendous growth in intellectual property rights in the plant/seed industry. Figure 1 shows the growth in intellectual property rights in plants including plant patents, plant variety protection certificates, and plant utility patents from 1976 to 2001. There is clearly dramatic and steady growth overall during this time period with 1,496 intellectual property grants for plants in 2001 being more than 11 times the 128 granted in 1976. While this was a period of some growth in research expenditure in these industries, the rapid growth of intellectual property is strongly suggestive of the increase in property rights being strategic behavior rather than reflective of an inducement of new research. This gives some support to the view of intellectual property rights put forth by Hall and Ziedonis (2001), that it induces strategic behavior rather than actual research and innovation.

In order to demonstrate how the different property rights in plants have grown over time, figure 2 shows the growth in PVPs and PUPs. One can see that after an initial spurt in PVP grants, the levels held relatively constant until another increase at the end of the 1990's. PUP grants, non-existent before the court rulings in 1985 did not really start to take off until the mid 1990's at which point they experienced a growth spurt which ended in 1999 with some retrenchment. The graph shows no evidence that these two types of intellectual property were substitutes, it rather suggests that they might be complements or at best unrelated to each other. This might be the case if firms were in fact using each of these different property rights regimes for different items or seeds.

In order to disaggregate the demand for the different types of property rights, figure 3 shows the growth of intellectual property rights in corn and soybeans showing both PUPs and PVPs. One sees immediately that soybean PVPs were applied for and granted soon after the new intellectual property rights became available in 1970. Meanwhile in corn there were no corn PVPs until the early 1980's at which point they started to grow rapidly to the level of soybean PVPs. This suggests two of the key relationships described above between intellectual property rights values and strength and company strategy. In particular the evidence suggests that the shorter time horizon and greater ability to keep a trade secret for corn made applying for PVPs less attractive than keeping trade secrets. Meanwhile the low probability of keeping a trade secret in soybeans due to the lack of hybrid technology meant that PVPs were favored for soybeans over trade secrets.

Figure 3 also shows the relative importance of corn and soybean varieties among PUPs, demonstrating that in the early years corn PUPs were the dominant type of PUP. Corn shows a growth spurt starting in the early 1990's and retrenchment after 1999. Soybean PUPs lagged a few years behind corn varieties, but follow a similar pattern to those of corn though at a lower overall level. The high uptake rate of corn utility patents suggests that utility patents had strengths over trade secrets even with the high rate of technological change in corn. This significant advantage of utility patents over plant variety protection suggests that an intellectual property with a research exemption may entail too much revelation loss and be worth relatively little to firms.

Finally, the figures show that the introduction of stronger property rights in plants after the ex-parte Hibbard decision of 1985 caused an increase in both PVPA and utility patent property rights in plants. Some of this increase clearly comes from the uncertainty in which would be the strongest form of property, but some may also represent strategic behavior by companies. Some evidence of property rights uncertainty as the driving force behind the increases in property rights protection comes from the drop in PVPA applications after the *JEM Ag Supply* decision implied that anything that could receive a PVPA could also receive a utility patent.

Conclusions:

This work has analyzed changes in intellectual property rights in plants using both economic theory and empirical data. We find evidence that the changes in intellectual property rights in plants had significant effects on firm strategies as to which type of property rights they chose. The utility patent had the greatest effect, suggesting that PVPs were a lesser form of intellectual property. The evidence with respect to corn and soybeans also shows the importance of understanding the differences in R&D and technology types when analyzing firm strategies and the effects of intellectual property.

We also find that contrary to widely held expectations, utility patents in plants did not make plant variety protection obsolete. On the contrary, the number of PVP's and PUP's seems to increase at tandem, suggesting the decision processes of firms to apply for different types of property rights were complex and strategic. We identified some of the potential strategic variables affecting this decision process, namely, revelation cost, and effective patent lengths. Empirical findings also conform to the idea of patent thickets, where as firms applied for both types of patent protections to avoid any loss due to rejection of any of the application.

Our work makes a start both theoretically and empirically in recognizing the important strategic role of revelation loss in firm strategies of choice of intellectual property rights or trade secrets. There are, however, many more issues that deserve further investigation. For example, it is probable that the extent of revelation loss varies by the product category and the dynamics of R&D within an industry. In such cases patent and property rights law might need to be amended to take into account the different revelation losses from patenting in different industries. Another possible solution might be to provide a menu of property rights similar to that existent in plants so that innovating firms can choose between the extent of property rights and loss from revelation from the patenting process.

While this work has demonstrated how changes in rules and laws can impact the strategic choices within the plant industry, neither we nor the existing empirical literature have not measured the welfare effects of all these new laws and Supreme Court decisions on farmers and consumers. Larger numbers of claims of property rights do not imply farmers and consumers gained from more property rights for the seed firms. In the future we plan to direct our research toward estimating the social welfare impact of new property rights in plants.

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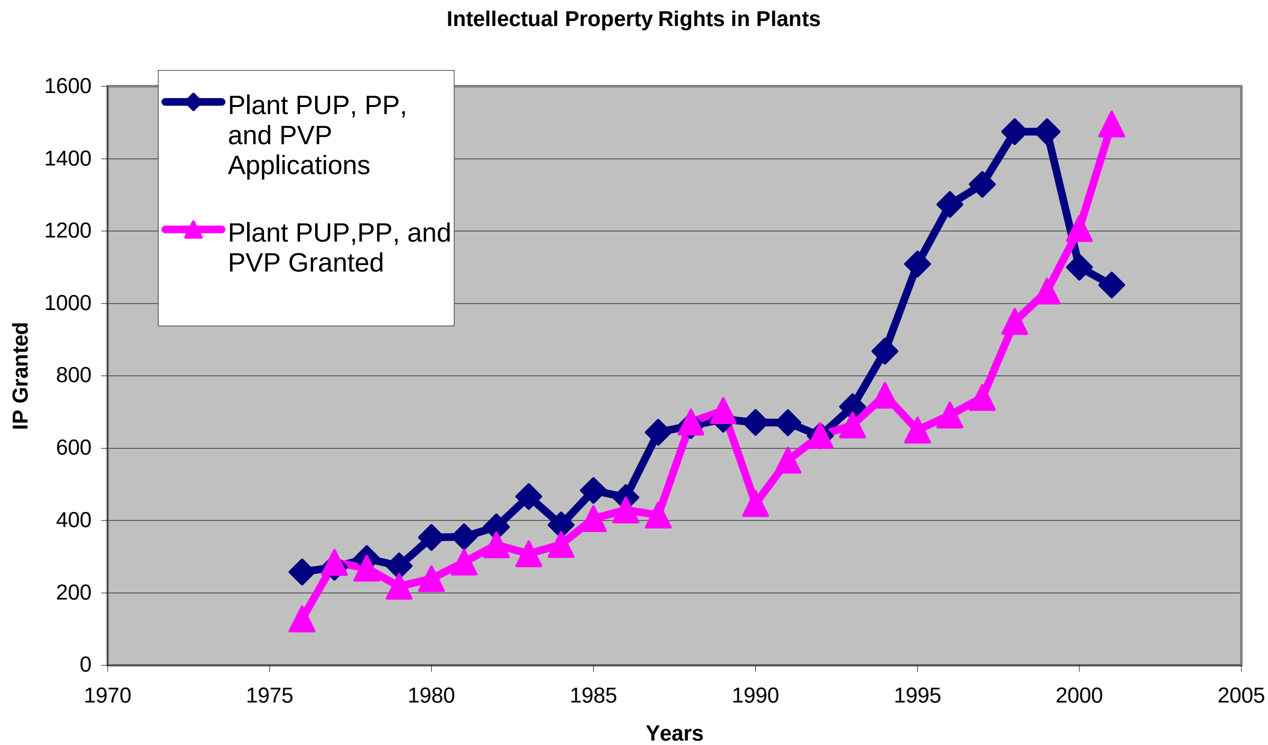
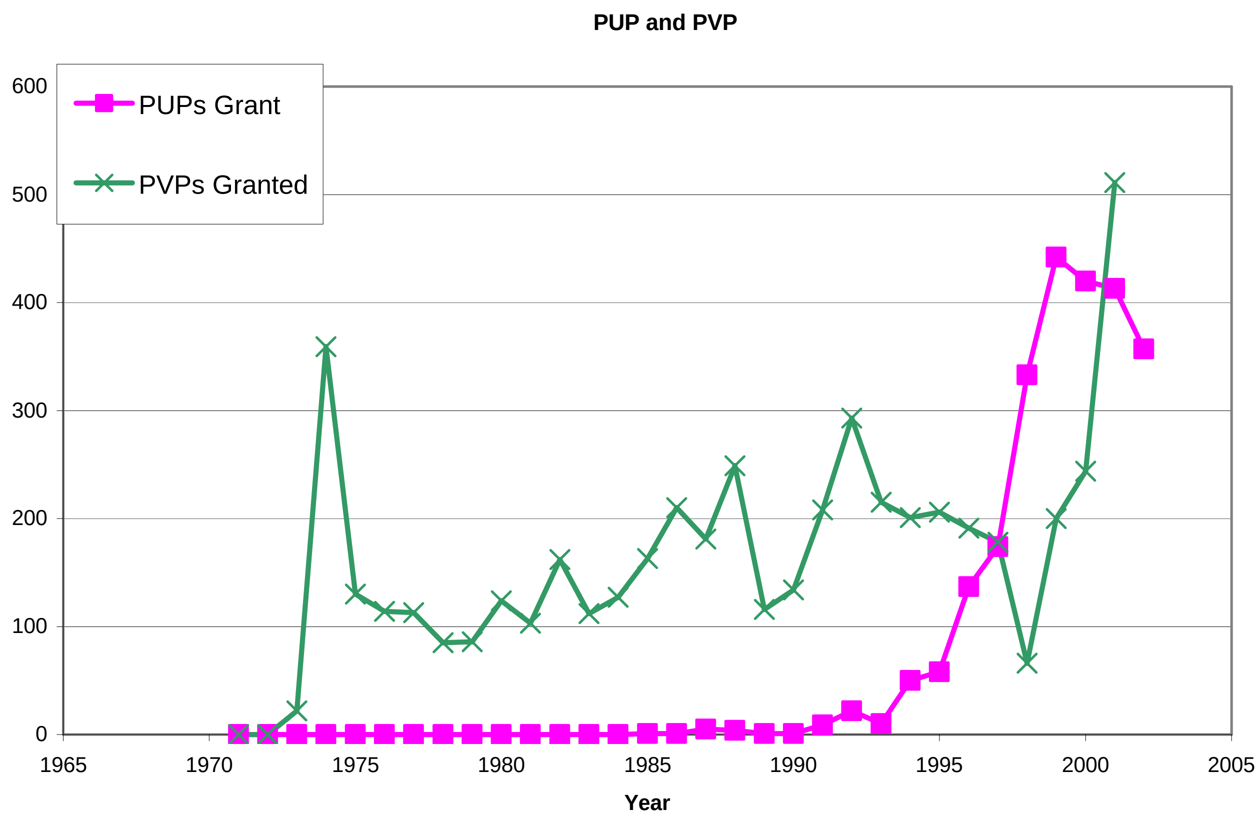
Figure 1



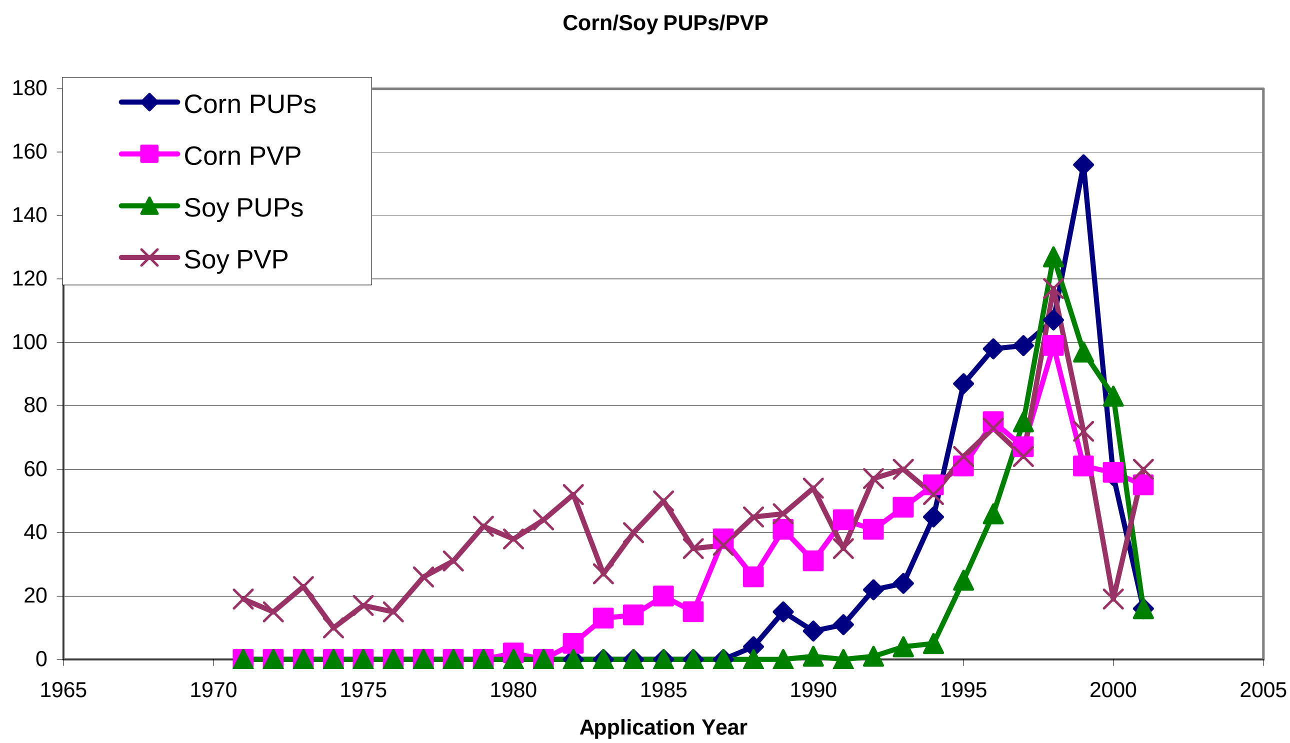
Intellectual Property Rights in Plants
Plant PUP, PP, and PVP Applications
Plant PUP,PP, and PVP Granted
IP Granted
1600
1400
1200
1000
800
600
400
200
0
1970
1975
1980
1985
1990
1995
2000
2005
Years

Figure 2



PUP and PVP
PUPs Grant
PVPs Granted
600
500
400
300
200
100
0
1965
1970
1975
1980
1985
1990
1995
2000
2005
Year

Figure 3



Corn/Soy PUPs/PVP
Corn PUPs
Corn PVP
Soy PUPs
Soy PVP
180
160
140
120
100
80
60
40
20
0
1965
1970
1975
1980
1985
1990
1995
2000
2005
Application Year

1 Appendix

1.1 Desciption of the Game

We first examine a firm's ex-ante decision problem to apply for any form of property rights through patents or to keep trade secret. Compared to recent work in the literature our model makes the following innovation. We allow that the probability that a patent is granted is less than one. We also allow there to be a revelation loss from the patent application process. The motivation for this assumption comes from the fact that in a patent application a firm needs to reveal the methods behind the innovation. As a result whether the firm's patent is accepted or not, the firm faces a potential loss from this revelation. When comparing strategies of patenting with different length or scope, this revelation loss is constant, but when comparing patents to trade secrets the revelation loss could be important.

1.2 Benefits under different regimes:

Let the social benefit of a product innovation be described by:

$$SB = \int_0^\infty be^{-rt}dt = \frac{b}{r}. \tag{1}$$

Here we assume that the per period benefit of innovation is b, the rate of discount is r, and t is the time period. We also assume that this benefit accrues to the whole society over an infinite horizon. Innovating firms receive some portion of this social benefit, the exact value of which depends on whether they apply for a patent or keep a trade secret. The benefit from a trade secret to a firm will be based on a hazard rate z , of losing the trade secret. So the benefit from a secret is expressed as:

$$FB_s = \int_0^\infty ue^{-(z+r)t}dt = \frac{b}{z+r} = \frac{r}{z+r}SB = \gamma(z)SB. \tag{2}$$

The benefit for the firms in patenting will be received for a finite time period (patent length, T). In addition the patent application process reveals some trade secrets and may or may not lead to a successful application. We assume that the revelation loss is a fraction of the benefits from keeping trade secrets. So, the benefit for the firm for successful application can be stated as:

$$FB_{pt}^A = \int_0^T be^{-rt}dt = \left(1 - e^{rT}\right)\frac{b}{r} = \delta^T SB - lFB_S, \tag{3}$$

where $0 < l < 1$ is the revelation loss. This can also be expressed as:

$$FB_{pt}^A = SB\left(\delta^T - l\gamma\right). \tag{4}$$

On the other hand the failure of an application leads to a loss of:

$$FB_{pt}^R = -l\gamma SB. \tag{5}$$

1.3 Ex-Ante Probability

As mentioned before we assume that the any firm's application for patent may get rejected. As a result, the expected pay-off will be based on the probability of success and failure. Let the probability of success for a patent application be p. Such that the firm receives FB_{pt}^A with probability $p$and FB_{pt}^R with probability

$1 - p$.

1.4 The patent game with two firms

We assume symmetric firms and that they have the R&D research output, innovation, necessary for a patent or a trade secret. The probability of success in the application process is independent for each firm. As a result the probability of success of firm 1 does not impact the probability of success of firm 2. And if both the firms gets approved then they share the total monopoly rent equally. In matrix form the game can be stated as:

		Firm j	
		Property Rights	Trade Secret
Firm i	Property Rights	$\Pi_i^{pt,pt}$, $\Pi_j^{pt,pt}$	$\Pi_i^{pt,s}$, $\Pi_j^{pt,s}$
	Trade Secret	$\Pi_i^{s,pt}$, $\Pi_j^{s,pt}$	$\Pi_i^{s,s}$, $\Pi_j^{s,s}$

So, the expected payoff can be stated as:

1. Expected payoff of each firm when both firms choose to patent:

$$\Pi_i^{pt,pt} = p(1-p)FB_{pt}^{A} + (1-p)FB_{pt}^{R} + p^2\left(\frac{FB_{pt}^{A}}{2} + \frac{FB_{pt}^{R}}{2}\right). \tag{6}$$

This can also be stated as:

$$\Pi_i^{pt,pt} = SB\left[p(1-p)\left(\delta^T - \gamma l\right) - (1-p)l\gamma + p^2\left(\frac{\delta^T}{2} - l\gamma\right)\right]. \tag{7}$$

2. Expected payoff of firm i when firm i chooses patent and firm j chooses trade secret:

$$\Pi_i^{pt,s} = pFB_{pt}^{A} + (1-p)FB_{pt}^{R}. \tag{8}$$

Similarly we can simplify the expression as:

$$\Pi_i^{pt,s} = SB\left[p\left(\delta^T - \gamma l\right) - (1-p)\,\gamma l\right]. \tag{9}$$

3. Expected payoff of firm i when firm i chooses trade secret and firm j chooses patent:

$$\Pi_i^{s,pt} = (1-p)\,\frac{FB_s}{2} + pFB_{pt}^{R}. \tag{10}$$

This expression here can be expressed as:

$$\Pi_i^{s,pt} = SB\left[(1-p)\,\frac{\gamma}{2} - pl\gamma\right]. \tag{11}$$

4. Expected payoff when both the firms decide to keep a trade secret:

$$\Pi_i^{s,s} = \frac{FB_s}{2} = SB\frac{\gamma}{2} \tag{12}$$

Now to explore pure strategy Nash equilibrium (PNE) there are two interesting Nash equilibrium from the perspective of our research. They are [(Patent, Patent): PNE_1] and [(Trade Secret, Trade Secret): PNE_2]. In this symmetric game for PNE_1 the following condition should hold:

$$\Pi_i^{P,P} \geqslant \Pi_i^{TS,P} \tag{13}$$

and for PNE_2 the condition will be:

$$\Pi_i^{TS,TS} \geqslant \Pi_i^{P,TS} \tag{14}$$

And under reasonable approximations of the discount rate it is also easy to show that the PNE_1 and PNE_2 are the dominant strategy Nash equilibrium.