A Model of Development of Agricultural Biotechnological Innovations: Patent Policy Analysis.*

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Abstract:
In this paper, peculiarities of the process of development of agricultural biotechnological innovations are considered, in particular the distinction between R&D races for gene discoveries and subsequent competition for developing their marketable applications in the form of genetically modified (GM) crops, the results of which determine the payoffs of discovering a gene. A formal two-stage model is specified and analyzed with regard to how different patent protection regimes and other government policies affect firms' R&D strategies and the welfare realized from an innovation. We find that different policy measures affect the outcomes of the two stages of biotechnological innovation differently, which leaves some ambiguity as to which patent protection regimes might be strictly preferable. However, general direction of policy improvement is identified.

Keywords: agricultural biotechnology, patent protection regimes, innovation, R&D races, genetically modified crops.

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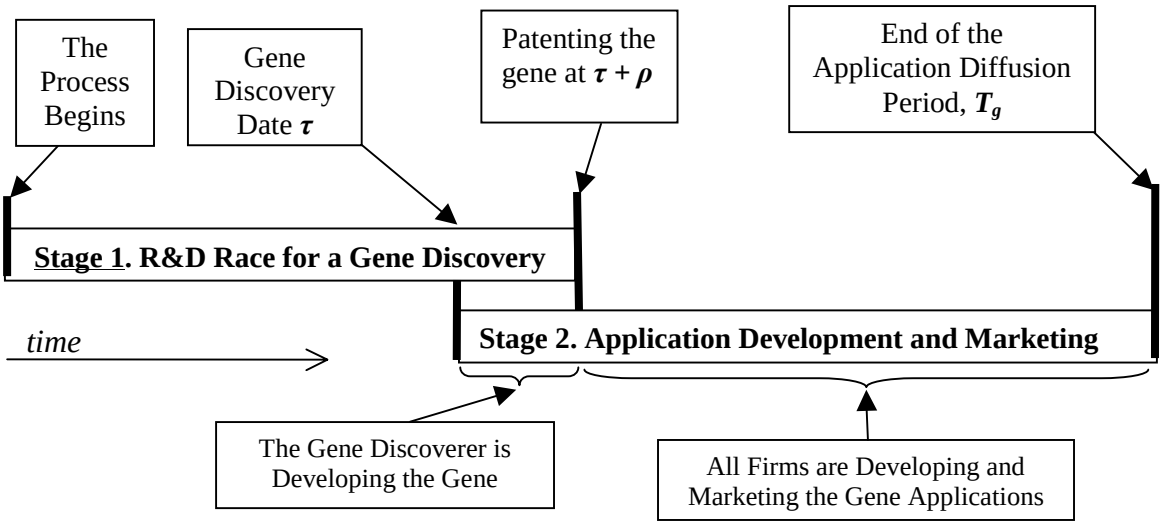
1. The Process of Agricultural Biotechnological Innovations

The purpose of this paper is to provide some insight into the structure and mechanics of the process of development and appropriation of agricultural biotechnological innovations at the current stage of the industry lifecycle (Utterback, 1994, Kalaitzandonakes, 1997, 2000). In particular, we are interested in how different patent protection regimes affect the outcomes of biotechnology R&D and introduction of its applications in agriculture. Despite the fact that biotechnology has been around for a number of years and is an important industry with great potential, considerable ambiguities in the intellectual property rights protection of biotechnological innovations remain, which warrants attention (Brennan *et al.*, 2000).

A stylized structure of the process of agricultural biotechnological innovations is shown in the figure below (based on Brennan *et al.*, 2000, and Harhoff *et al.*, 2001).



The process starts with the first stage, during which firms in the industry compete for the discovery of a particular gene (the so-called basic discovery). A gene discovery usually implies that the gene and its functions are identified, together with the physical ways of separating the gene and its particular traits and inserting them into a target plant's DNA. The firms in the industry may be looking for a particular gene at a time, or for a number of genes. This process is characterized by a considerable degree of uncertainty, as R&D processes are of creative nature, and it is hard to identify what factors or events contribute to the frequency of incidences of successful innovations. The firms' strategies in this stage are investments at

R&D that "buy" them random discovery dates. The investments can be lump-sum and/or flows, and can vary over time depending on the firms' strategic considerations. Obviously, R&D investments and the gene discovery date $\boldsymbol{\tau}$ depend on the rewards the firms expect from it, on the number of firms, nature of competition, and the R&D "cost" function.

A gene discovery in agricultural biotechnology does not, apart from the gene's licensing value, imply any immediate gains, for the value of the gene can be realized only through the development of its marketable applications, *i.e.*, genetically modified (GM) crops with certain traits, which can be either cost-reducing (herbicide or pesticide resistance) or quality enhancing (enhanced vitamin or nutrient content).

It is during the second stage of the process, the gene application development and marketing, that the value of the discovered gene is determined and shared between the firm that originally discovered it (the leading firm) and the rest of the firms in the industry. The analysis in this paper assumes that the same firms that participate in the gene discovery competition are also involved in the application development and introduction, which is a close approximation to reality. During the application development, or diffusion, stage the strategies of the gene discoverer (the leader) and of its rivals differ. As is shown in Sections 3 and 4, the leader often finds it profitable to wait before patenting its discovery, even under the threat of a "re-discovery" by a rival and knowledge spillovers. During this time (defined as $\boldsymbol{\rho}$ in the figure), the leader takes advantage of being the only one who possesses the new information on the gene, working on its applications (*i.e.*, developing different GM crops that utilize the discovered gene's functions). The time of patenting the gene is chosen strategically and depends on the length and scope of patent protection, potential profitability of the applications, licensing opportunities, and the structure of the industry and firm behavior. Under most patent protection regimes, the leader still has some time to develop and market GM crops after patenting. However, when the patent expires, the rest of the firms in the industry start competing for the remaining applications. The diffusion of applications stops at time T_g when all possible applications of the gene have been discovered and marketed.

We believe that the novelty of our model setup is in the fact that we specify the process of agricultural biotechnological R&D as a two-stage process, with the first stage determining the industry leader and the likely gene patent holder, and the second determining

the payoffs from appropriating the market value of the gene's applications (GM crops). We recognize that the two stages are of a different nature, yet are ultimately related, as one determines the incentives and intensity of participation in the other. We also recognize that, in most cases, private payoffs from innovative activity do not coincide with the social benefits from it, as society generally does not care which firms benefit from an innovation or how the benefits are distributed among them. Generally, society benefits from the fastest possible introduction of as many innovations and their applications as possible. In case of agricultural biotechnology, society would be interested in maximizing the discounted value of all applications associated with a particular gene: $\max \sum_{1}^{d} v_i (1+r)^{-(\tau+t_i)}$, where v_i is the discounted value of an i^{th} application at the time of its introduction and t_i is the time of its market introduction since the gene discovery. Disaggregating the process into two stages, the dual goal becomes minimizing the time it takes to discover a gene and maximizing welfare from the introduction of its applications.

Governments have a set of tools they use in order to influence the outcomes of innovative R&D activities. We identify different levels of intellectual property rights protection and antitrust policy as the most common ones. Patent protection is guaranteed by the patent law (in particular, patent length and scope) and antitrust policy in the biotechnology R&D industry is exercised mainly as selective approval of mergers and acquisitions and regulation of entry barriers.

Considering the nature of the agricultural biotechnology R&D process identified above, it is of interest to question how these different regulating policies might affect the outcomes of the patent race and application development stages, and what their aggregate results are. We use different models from the economics of innovation literature to analyze the effect of policies on the two stages. Our preliminary findings are that some policies and their combinations can have conflicting effects on the two stages, *i.e.*, improve on one but worsen the outcome of the other. However, the analysis, while presenting some ambiguities, defines a certain ranking of different patent protection regimes and antitrust policies in terms of their social desirability.

Section 2 of the paper contains a brief description of the gene discovery R&D race and an analysis of policy effects on this process. Section 3 considers the gene application development and introduction stage (drawing on Matutes, Regibeau, and Rockett, 1996).

Different patent protection regimes are considered, their effects on the firms' behavior and welfare implications are analyzed, and the results are compared with those from the gene discovery R&D race. Section 4 provides the summary of the preliminary findings and suggested extensions of the model.

2. Gene Discovery R&D Race

The process of discovery of a basic innovation always involves uncertainty. Out of the voluminous literature on patent (R&D) races, we have chosen Lee and Wilde's (1980) model, which is a modification of the Loury's (1979) model relating innovation process to market structure, as the most obvious way to illustrate the mechanics of the process.

An R&D industry is assumed to consist of N identical firms playing a non-cooperative Nash game of racing for the discovery of a single gene. Discovering a gene implies identifying its functions, finding a way to separate it and to alter it. Racing for a single gene can be justified by assuming that the gene is believed to have the greatest potential number of lucrative marketable applications, which makes non-cooperative pursuit of its discovery more worthwhile than coordinating firms' efforts and pursuing different discoveries at once.

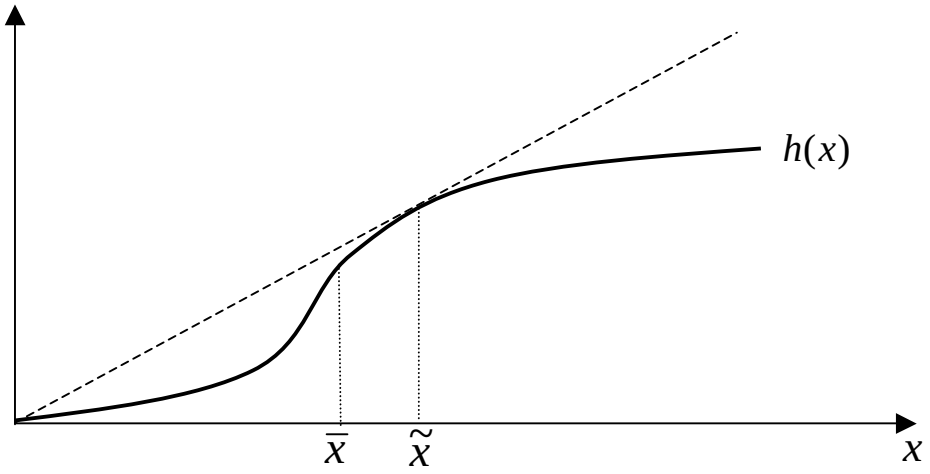
The first firm that makes the discovery is assumed to be awarded a reward of V^A, which is determined by how many marketable applications this firm can appropriate. The firms' strategies are described by a fixed cost investment F and a flow of per period investments x_i that continue until one of the firms stumbles upon the discovery. These investments purchase this firm a random discovery date $\tau(x_i)$ that is assumed to be exponentially distributed:

$$pr[\tau(x_i) \le t] = 1 - e^{-h(x_i)t},$$

which implies that the expected introduction time is

$$E[\tau(x_i)] = 1/h(x_i),$$

where $h(x_i)$ is equivalent to a "cost" of R&D and exhibits some initial increasing returns, which determines a long-run industry structure with finite number of firms (natural oligopoly):



Defining the date of discovery by firm *i's* rivals as $\bar{\tau}(x_i) = \min_{j \neq i}\{\tau_j(x_j)\}$ and probability of this happening before time *t* as $\Pr(\bar{\tau}_i \leq t) = 1 - e^{a_i}$, where $a_i = \sum_{j \neq i} h(x_j)$ is a constant instantaneous probability of introduction by the rivals, the expected benefit to a representative firm from investing in the R&D is

$$E[B] = \int_0^\infty \Pr(\hat{\tau}_i = t)\left\{\int_0^t \Pr(\tau = s) V^A e^{-sr} ds\right\} dt = \frac{V^A h}{a + h + r},$$

and the expected costs are

$$E[C] = \int_0^\infty \left\{\int_0^t x e^{-rs} ds\right\} \Pr(\hat{\tau}_i = t \_ or \_ \tau_i = t) dt + F = \frac{x}{a + h + r} + F,$$

making the expected profit from participation in the gene discovery R&D race

$$E[\pi] = E[B] - E[C] = \frac{V^A - x}{a + h + r} - F.$$

An analysis of the optimization conditions and comparative statics leads to the following conclusions:

- an increase in the number of firms in the industry leads to an earlier discovery date: $dE[\tau(N)]/dN < 0$.
- an increase in the number of firms decreases expected profits: $dE[\hat{\pi}]/dN < 0$.
- given a certain stability condition, the equilibrium individual firm investment increases in the number of firms (size of the industry): $d\hat{x}/dN > 0$. This is the opposite of the Loury's result ($d\hat{x}/dN < 0$), which is a consequence of the difference in investment specification – Loury only assumed a lump-sum investment.

It is also obvious that an increase in the reward from the discovery, V^A, increases individual firm R&D investment and, therefore, results in earlier introduction. This is a very important observation, as the value of V^A is determined at the gene application development stage of the innovation process. This stage represents an altogether different game which, as we show in the next section, is influenced by the gene and application patent protection regimes (appropriability), firm behavior and, to some degree, antitrust policy.

3. Application Development and Introduction Stage

After the gene discovery, the gene's potential value has to be appropriated. In agricultural biotechnology, this happens through development and marketing of the gene's applications, or genetic modifications of agricultural crops (different traits corresponding to the gene's functions, like herbicide resistance or enhanced nutrient content, can be developed in different crops). There is much less uncertainty involved in the process of application development, which implies that the firms in the industry can more or less precisely estimate the total number of applications that can be developed from the newly discovered gene and time it takes to develop an application.

In the model presented below (following Matutes *et al.*, 1996), these facts are accommodated by the following assumptions:

- a total of d marketable applications can be developed from the gene, d is known with certainty;
- the applications are developed by a single firm with a fixed speed of one at a time;
- ρ defines the time after the gene discovery at which the information on the gene discovery, and the ρ applications developed by that time by the discoverer, is revealed through the patent grant and the introduction of the applications. T_g defines the gene diffusion time – the time it takes for all possible gene applications to be developed and introduced in markets;
- before the first application is introduced by the original gene discoverer, *i.e.*, before the gene is patented, the rivals can not get hold of the information that would enable them to start developing their own applications. However, it takes an introduction of a single application to provide the rivals with sufficient information about the gene to

enable them to develop all the other applications and introduce them in the absence of intellectual property rights (IPR) protection.

- the markets for applications are assumed to be independent of each other, and marketing of each application yields a discounted flow of profits v_a.
- firms do not work on the same applications, *i.e.*, there is no coordination problem. This assumption is relaxed later on.
- the penalties for patent infringement are sufficiently high to discourage rivals from it.

In the absence of rivalry, the gene discoverer would develop and introduce all the d applications itself, one at a time. With rivalry, the leading firm's behavior depends on the type and level of gene patent protection provided by patent law. In the absence of any intellectual property rights and under most protection regimes, the leading firm has an incentive to wait for a period of ρ before introducing ρ applications developed during this period. Doing this allows it to secure discounted profits from them before *(N-1)* rivals start developing $d - \rho$ remaining applications.

It should be mentioned that there is always a threat that one or more of the rival firms will also stumble upon the basic discovery during the waiting period ρ. According to the specification of the gene R&D race, this threat is represented by a constant exogenous instantaneous probability of "re-discovery". If pursuing the basic research is very inexpensive in comparison to the application development, rival firms may choose to continue investing in it in hope of discovering the same gene before the leading firm patents it and enjoys temporary monopoly on (some of) the applications. Under any protection regime, a rival firm discovering the gene at time $\lambda > \tau$ can only benefit from it by becoming an industry leader if it patents it *before* $\tau+\rho$. In the absence of IPR protection, a rival firm discovering a gene at time λ can only benefit from it if it discovers it *before* $\tau+\rho$ thereby securing $\tau+\rho-\lambda$ applications before all the firms start racing for them. Obviously, firms are still racing for the basic discovery during the period before τ and $\tau+\rho$, as they still do not know that the discovery has already been made[1]. These considerations obviously complicate the analysis. However, due to the exogenous and constant nature of the probability of "re-discovery" we, for the time being, ignore it in the analysis of the application development

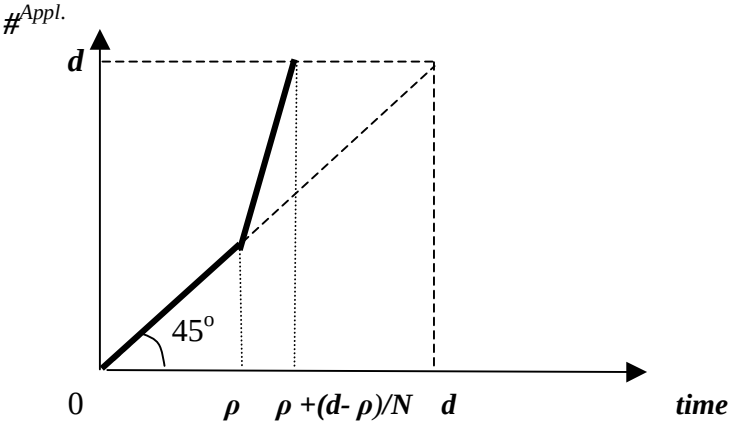
[1] An alternative assumption would be that everybody learns the news about the basic discovery as soon as it is made, but imitation is not possible.

and introduction by assuming the cost of basic R&D to be high enough to prevent rivals from continuing this research. Clearly, the presence of a constant exogenous threat of re-discovery during the "secret" stage of application development shortens ρ but leaves the ordinal results of the analysis unchanged[2].

Below, following Matutes *et al.*, (1996), we consider three basic patent protection regimes and their subtypes, analyze their welfare implications, and discuss their relative (dis)advantages in the framework of the agbiotechnology innovation process.

3.1. No patent protection

In the absence of patent protection on the discovered gene, the leading firm has an incentive to wait a period of time ρ before introducing the ρ applications developed during this time, thereby securing early returns from them. After this, all N firms compete for the remaining applications developing them at a speed of $(d - \rho)/N$. The leading firm thus faces a tradeoff between waiting in order to secure more applications and the cost of delaying introduction of the applications it has developed. The diffusion pattern is shown in the figure below:



Total discounted profit to the leading firm is:

$V_A = v_a\left(\rho e^{-\rho r} + \int_{\rho}^{(d+(N-1)\rho)/N} e^{-rt}dt\right)$, the F.O.C. being,

$\partial V_A / \partial \rho = v_a e^{-rt}\left[(N - N^{-1})e^{-r(d-\rho)/N} - \rho r\right] = 0$.

Assuming an interior solution, it can be shown that the profit function of the leading firm is single peaked. Let ρ^* define the optimal waiting time: $V^*_A = V_A(\rho^*)$. By differentiating

[2] Also, under the "first to invent" system, independent discovery would not prevent the earlier inventor from obtaining the patent.

the first order condition, it can be shown that ρ^* is increasing in the number of competitors an decreasing in *r*, which can partially reflect the rate at which an application becomes obsolete. Private payoff to the discoverer is decreasing in the number of competitors.

Defining the discounted social surplus associated with one application as W_0, the social welfare associated with the discovered gene not protected by a patent is:

$$W = W_0\left(\rho e^{-\rho r} + N\int_{\rho}^{(d+(N-1)\rho)/N} e^{-rt}dt\right).$$

Substituting the first-order conditions into the welfare expression and differentiating with respect to *N*, one obtains

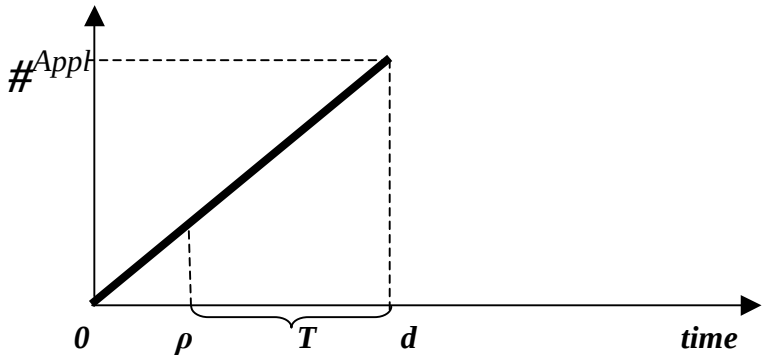
$$\partial W/\partial N = W_0 e^{-\rho r}\begin{Bmatrix}(1/r)e^{-r(d-\rho)/N}(d+(N-1)\rho/N \\ -(1/r)+\rho)+(r-N+(N-1)e^{-r(d-\rho)/N}\end{Bmatrix} \begin{matrix}> \\ \\ <\end{matrix} 0$$

Using numerical computations, Matutes *et al.* show that the diffusion welfare increases with the number of firms for small *N*, as higher *N* speeds up the diffusion after the leader introduces its ρ applications, and decreases for large *N*, as higher *N* also delays the optimal introduction time. Therefore, intense rivalry under no patent protection is not always preferable. This makes antitrust policy, the only tool available to the government under no patent protection, an ambiguous tool. Increasing *N* by, say, encouraging entry, reduces the private payoff from the gene appropriation to the discoverer and thus discourages investment in the gene discovery R&D process, thereby making it longer. However, an increase in N speeds up the application diffusion process, making the net effect on welfare unclear.

3.2. Length protection

Under the length regime, the discoverer of the gene is granted an exclusive right of introducing applications during a period of *T after* patenting the gene. Depending on the relationship between *T*, ρ, and *d*, several cases are possible:

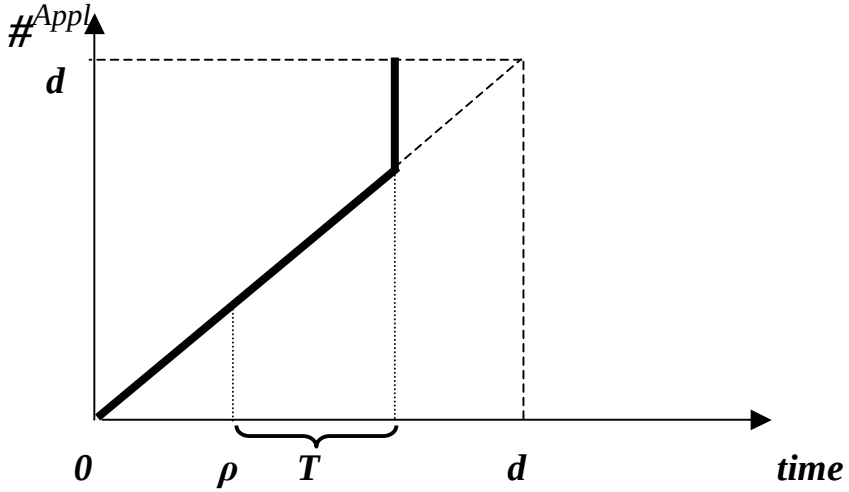
Case 1: long patent - $\rho + T \geq d$



Under such a long patent protection, the leader appropriates all the applications.

Case 2: short patent - $\rho + T < d$

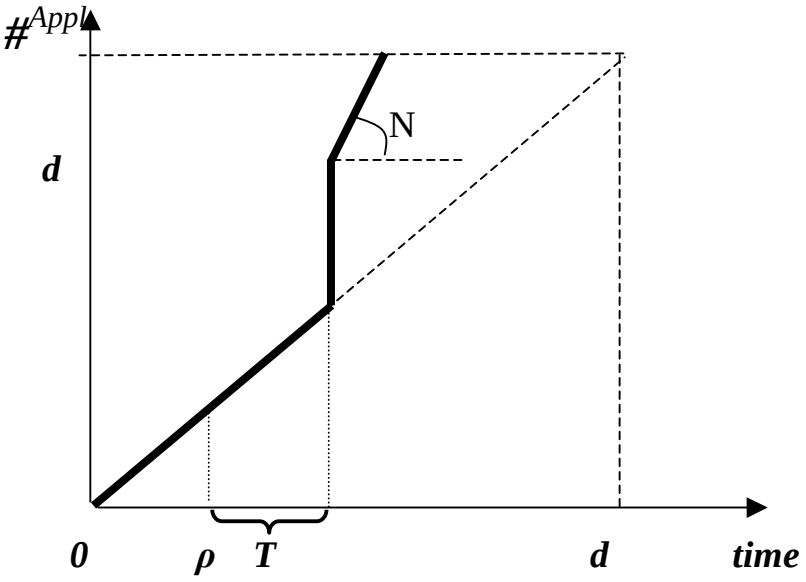
Subcase 2.1: $\rho + NT \geq d$



Here, the marginal benefit of waiting is the discounted value of the last application developed before the patent expires. Optimal waiting period, ρ_2^*, is thus a decreasing function of the patent length *T*.

Subcase 2.2: $\rho + NT < d$

Here, the leading firm faces the same tradeoff as with no protection: the benefits of waiting in order to secure more applications *vs.* the cost of delaying introduction of the applications it has developed. The optimal waiting period is thus also the same $\rho_3^* = \rho$.



The leader's optimization problem under length protection is thus

$$V_A = v_a\left(\rho e^{-\rho r} + \int_{\rho}^{\max\{\min(\overbrace{d}^{\rho+T\geq d},\ \overbrace{\rho+T}^{\rho+NT\geq d}),\overbrace{[d+(N-1)\rho]/N}^{\rho+NT<d}\}} e^{-rt}\,dt \right),$$

the appropriate first order conditions being:

Case 1: $\rho + T > d$

$\partial V_A / \partial \rho = -\rho r e^{-\rho r} = 0$;

Subcase 2.1: $\rho + T < d$ and $\rho + NT \geq d$

$\partial V_A / \partial \rho = e^{-\rho r}(e^{-rT} - \rho r) = 0$;

Subcase 2.2: $\rho + NT < d$

$\partial V_A / \partial \rho = e^{-\rho r}[(1-1/N)e^{-r(d-\rho)/N} - \rho r) = 0$.

The technical solution to this problem is quite complicated due to the functional forms involved and the discontinuity of the payoff functions. As Matutes *et al.* show, there exists a patent protection period T^* such that, for every $T > T^*$, the leading firm finds it optimal to wait until $\rho + T = d$. There also exists length T^{**} such that for all T's that are $T^{**} \leq T < T^*$, privately optimal waiting period is less than d-T, so that the leader introduces only a fraction of the applications waiting for $\rho^* = e^{-rT}/r$. For even lower lengths of patent protection ($T<T^{**}$), the tradeoffs between accumulating applications and introducing them,

i.e. patenting the gene, become mixed and the leader either chooses the long "no-protection" waiting period or a shorter $\rho^* = e^{-rT}/r$.

Length protection provides the government with a policy tool – patent length *T*, which is to be used in order to speed up the application development and introduction process (the diffusion of applications). Assuming that applications already developed by the time of the gene patent application cannot be denied patenting, it can be shown from the first order conditions that length protection always delays the date of introduction of the last applications: $\rho(T) + T \geq \rho(0)$ and $d(\rho(T) + T)/dT > 0$. Therefore, length protection is only useful when it can speed up the patenting date $\rho(T)$ significantly. Matutes *et al.* show that this can be achieved only by setting *T* equal to *0, d,* or within [*A, T**], where $T^{**} \leq A < T^*$. Clearly, gene patent length *T=d* dominates all the other values in the neighborhood by making the leader patent immediately and introduce all the applications as soon as they are developed (*T<d* inflicts a waiting period of *d-T*, which is undesirable). Values of *T* in between *0* and *A* result in longer delays, making *T=0* preferable within this interval. However, depending on the parameter specifications, $T \in [A, T^*]$ may be preferable to *T = 0* or *d*.

Several properties of the length patent protection can be specified. It is obvious that, for all *T*'s higher than zero, the private return to the discoverer is higher than under no protection. The diffusion time, $\underline{T_g}$, is always shorter than with no protection, hence higher welfare from the gene appropriation. By performing numerical computations in order to find welfare maximizing patent length, Matutes *et al.* determine that optimal *T* and diffusion welfare are (discontinuously) non-decreasing in the number of firms.

These results clearly indicate that length protection is strictly superior to no IPRs within the framework of a two-stage process of agbiotechnological innovation. Not only does it increase the diffusion welfare, but it also speeds up the gene discovery process by (weakly) increasing private payoff from gene appropriation. Besides, antitrust policy is now likely to be an unambiguous tool, as increasing the number of firms speeds up the gene discovery race, and also increases optimal *T* and thus the discoverer's private payoff, thus providing even more incentive to invest in gene R&D. An increase in *N* also increases diffusion welfare.

3.3. Scope protection

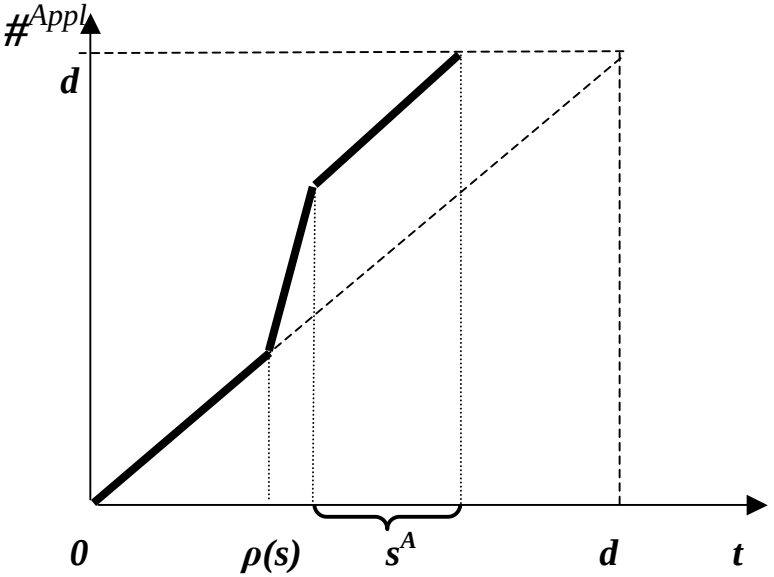
Under length protection, a patent guarantees the firm a given number of applications for an arbitrarily long (possibly infinite) period of time. This definition can be related to legal practice. Patent applications are filed with the Patent Office. The core of an application is a set of claims about the innovation that can range from very specific to very general. Obviously, more general claims, if granted, correspond to greater protection than more specific ones. Approval of the claims by the Patent Office involves considerable discretion which, together with infringement suites that are likely to be filed after the patent is granted, defines the scope of patent protection. Another interpretation of the scope protection is a "license to hunt" for applications in a broad field, which is granted on the basis of demonstrated usefulness of a product or process. While these procedures can not define the scope with considerable degree of precision, the model assumes that the there exists a policy instrument available to the government that defines the number of applications granted to a patent holder, $\boldsymbol{s}$. Alternatively, the firms could be assumed to form expectations as to which applications would be protected.

A very broad scope is identical to total protection of a gene and therefore to indefinite length protection. A range of narrower scopes can be interpreted in the context of the leniency of the claim review by the Patent Office and patent enforcement by the courts. Scope protection can have two forms:

- Additional scope protection, $\boldsymbol{s^A}$, means that the applications already developed by the patent applicant by the time of filing to the Patent Office do not count as part of the scope granted. Under this regime, the leading firm that waits for a period of ρ before patenting gets $\rho + \boldsymbol{s^A}$ applications.
- Inclusive scope protection, $\boldsymbol{s^I}$, means that the applications developed before patenting count as part of the scope. The discoverer gets $\max(\rho, s^I)$ applications.

The two scope regimes are briefly considered below.

Additional number of applications s^A. The figure below shows the diffusion pattern under additional scope protection.



Once the patent is obtained, the leading firm competes with the rivals for $d-(\rho+s^A)$ applications until $\rho+(d-\rho-s^A)/N$, and then develops and introduces s^A applications granted by the patent, completing the diffusion by $d+(N-1)\rho-s^A)/N+s^A$. For the diffusion process to have enough time to unfold, the length of protection for the s^A applications should be $T>\min[(\rho+s^A)+(d-(\rho+s^A))/N, d]$. The leader's decision problem is therefore

$$\max v^a\left\{\rho e^{-\rho r}+\int_{\rho}^{\min[(\rho+s^A)+(d-(\rho+s^A))/N,\,d]} e^{-\rho r}dt\right\}$$

The tradeoff that the leading firm now faces is between the marginal benefits of waiting before patenting, which secures more applications, and the costs of delaying introduction of the s^A applications granted by the scope. An increase in s^A emphasizes the costs, and thus decreases the waiting period ρ.

It is obvious that, compared to no protection, additional scope decreases the initial wait but prolongs the application diffusion time. Comparing scope and length protection, it is also easy to see that, if the leader was to develop s^A applications immediately after patenting, additional scope of s^A would be equivalent to length protection of $T= s^A$. However, competition following patenting immediately increases diffusion welfare because the leader

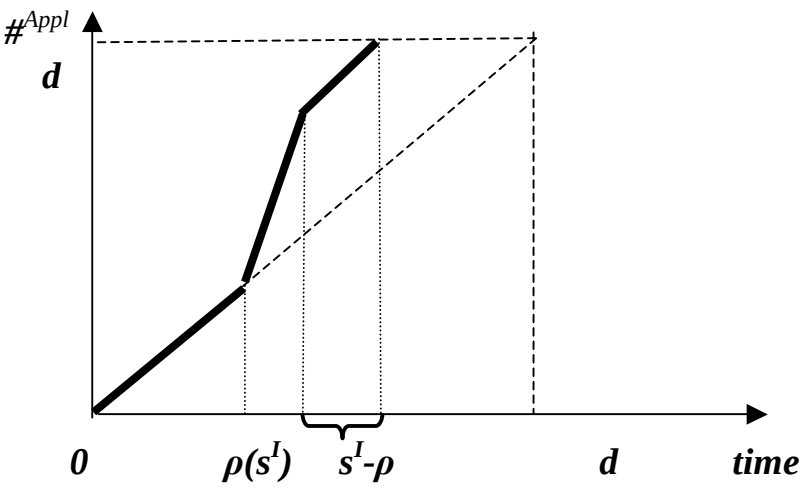
is forced to compete with the rivals first, $d-(\rho+ s^A)$ applications are introduced earlier, which makes additional scope protection preferable to length protection.

Formally analyzing the properties of this problem, Matutes *et al.* conclude that diffusion welfare is higher under the optimal additional scope than under either 1) no protection or 2) optimal length protection or 3) any combination of length and additional scope protection. The date of patenting, $\rho(s^A)$, is decreasing in s and is smaller than the optimal patenting date with no protection, $\rho(0)$. The total diffusion time increases with the scope s^A.

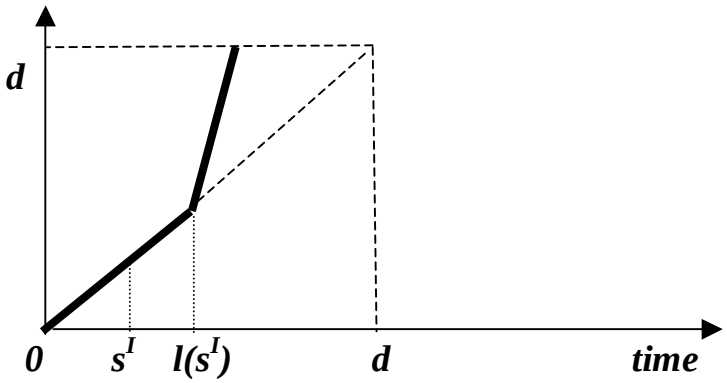
It can also be shown that optimal additional scope protection provides the gene discoverer with higher rewards than the length or no protection, and that an increase in the number of firms in the industry shortens the diffusion process but reduces the private payoff. This suggests that the additional scope protection is overall likely to be preferable to the length protection, which has been shown to be strictly preferable to no protection. However, additional scope protection leaves the antitrust policy affecting the number of firms an ambiguous tool for increasing the social returns from an innovation, as increasing N, apart from encouraging the gene discovery R&D process and speeding up application diffusion, decreases the private payoff to the discoverer and thus discourages R&D activities.

Inclusive number of applications s^I. This regime is consistent with the restrictions on pre-filing activities that exist in the patent law, for example, the statutory bar in section 102(b) of the Patent Act "is intended to motivate the inventor to apply for a patent soon after invention" (Miller and Davis, 1983). Depending on the breadth of the scope, two cases can arise:

Case 1: $\rho < s^I$. The pre-patent period is followed by competition for $d-(\rho+s^I)$ applications, followed by developing the remaining $s^I-\rho(s^I)$ applications single-handedly by the leader.



Case 2: $\rho > s^I$. The applications granted by the patent are all "used up" before patenting.



For the inclusive protection to be unaffected by the length of application protection, the length of protection of the s^I applications must be no shorter than $[d + (N-1)s^I]/N$. The leader's payoff is:

$$V^A(s^I) = \max v^a \left\{ \rho e^{-\rho r} + \int_{\rho}^{[d+(N-1)\max(\rho, s^I)]/N} e^{-\rho r} dt \right\}.$$

Comparing this payoff function with the one under no protection, it is clear that, when $\rho > s^I$, the two payoffs *and* waiting periods are identical. If $\rho < s^I$, the marginal benefit of waiting is clearly negative, as it does not increase the number of applications the leader can appropriate but only delays the introduction of some of them. Therefore, immediate patenting is optimal in this case. Formal analysis by Matutes *et al.* shows that welfare can be improved

over the case of no patent protection only by an $\boldsymbol{s^I}$ that induces immediate patenting by the gene discoverer. Moreover, considering the application development stage in isolation, socially optimal $\boldsymbol{s^I}$ must be small enough to ensure the patentee's payoff is minimal (equal to the no protection payoff). This ensures immediate patenting, and guarantees that the $\boldsymbol{s^{I*}}$ is smaller than the waiting period under no protection.

This makes application diffusion welfare under inclusive scope protection superior to all the other protection regimes considered here and their combinations. However, additional scope protection leaves the owner of the basic innovation with minimal payoff (equal to no protection), which discourages R&D investment in fundamental gene research. This argument does not lose its validity even if different firms specialize in gene discovery and application development, for the payoffs that the latter get would still determine the value of the gene license.

Another interesting result of the analysis of inclusive patent protection is that the optimal scope increases with the number of firms in the industry which, in most cases, implies higher private payoff to the gene discoverer. This makes antitrust policy an unambiguous tool that can be used in combination with the inclusive scope protection. Increasing the number of firms, say, by disapproving mergers and acquisitions, shortens the gene discovery date *and* increases the incentive to invest by increasing the payoff from discovering the gene, V^A. These results make additional scope protection appear to be a policy tool that is superior to all the other gene patent protection regimes considered here.

4. Summary of Results and Extension Suggestions

The analysis above, while presenting some ambiguities, defines a preliminary ranking of different patent protection regimes in terms of their effect on the social welfare realized from the process of agricultural biotechnological innovation as depicted in the Section 1. A table below, using somewhat loose terminology, summarizes our preliminary findings.

General direction of policy improvement ⟶ Tie?

	No Protection	**Length Protection**	**Additional Scope Protection**	**Inclusive Scope Protection**
Private payoff to the discoverer	Low	Higher	Highest	Low
Gene discovery date	Late	Earlier	Early	Ambiguous
Diffusion time/welfare	Long/ Lowest	A little faster/ A bit higher	Faster/ Higher	Fastest/ Highest
Total time to gene utilization	Longest	A little shorter	Shorter	Ambiguous but Petty Short
Effect of increase in *N*	Ambiguous: Shortens basic R&D Bad for diffusion	Unambiguous: Good for basic R&D and for diffusion	Ambiguous: Ambiguous for basic R&D Good for diffusion	Unambiguous: Good for basic R&D Good for diffusion

The absence of gene patent protection is clearly inferior to all the other regimes. The application diffusion time is the longest, meaning smallest diffusion welfare, and the private payoff to the gene discoverer is the lowest, meaning the weakest incentives for the gene discovery R&D race participation and long discovery time. A small private payoff from appropriation may also result in a dropout of firms from the industry, which makes matters even worse.

Antitrust policy that affects the number of firms in the industry has a very ambiguous effect on the process and, therefore, can not be used for improvement. Diffusion welfare increases with the number of firms for small N (as an increase in N speeds up the diffusion after the leader introduces its ρ applications), and decreases for large N (as increasing N also delays the optimal introduction time). Therefore, intense rivalry under no patent protection is not always preferable. This makes antitrust policy, the only tool available to the government under no patent protection have ambiguous effect. Increasing N by, say, encouraging entry, reduces the private payoff from the gene appropriation to the discoverer and thus discourages investment in the gene discovery R&D process, thereby making it longer. However, an

increase in N may speed up the application diffusion process, making net welfare effect unclear.

Under length patent protection, private payoff to the discoverer is always higher than under no protection. The diffusion time, T_g, is always shorter than with no protection, hence higher welfare from the gene appropriation. Optimal patent length *T* and diffusion welfare are non-decreasing in the number of firms. This clearly indicates that length protection is strictly superior to no IPRs within the framework of a two-stage process of agricultural biotechnological innovation. Not only does it increase diffusion welfare, but it also speeds up the gene discovery process by increasing the discoverer's private payoff from the gene appropriation. Besides, antitrust policy is now likely to be an unambiguous tool, as increasing the number of firms speeds up the gene discovery race by toughening the competition and also by increasing the optimal *T* and thus the discoverer's private payoff, thus providing even more incentive to invest in gene R&D. An increase in *N* also increases the diffusion welfare.

Under additional scope protection, the leader waits for a longer time before patenting, which increases the application diffusion time and private payoffs, contributing to shorter gene discovery time. Diffusion welfare, however, is clearly superior to no protection, optimal length protection, or any combination of length and additional scope protection. Optimal additional scope protection also provides the gene discoverer with higher rewards than the length or no protection. This suggests that additional scope protection is overall likely to be preferable to the length protection, which has been shown to be strictly preferable to no protection. However, additional scope protection leaves antitrust policy an ambiguous policy tool, for an increase in the number of firms in the industry shortens the diffusion process (good) but reduces the private payoff (bad).

Inclusive scope protection is clearly the best regime for maximizing diffusion welfare, as it induces immediate patenting and ensures the fastest diffusion. In this respect, it is also superior to all combinations of the protection regimes considered. However, additional scope protection leaves the owner of the basic innovation with minimal payoff (equal to what she gets under no protection), which discourages R&D investment in fundamental gene research. This argument does not lose its validity even if different firms specialize in gene discovery and application development, for the payoffs that the latter get would still determine the value of the gene license. The optimal inclusive scope increases with the

number of firms in the industry, which in most cases implies higher private payoff to the gene discoverer. This makes antitrust policy a tool with an unambiguous effect under inclusive scope protection. Increasing the number of firms by, for instance, disapproving mergers and acquisitions, shortens the gene discovery time *and* increases the incentive to invest by increasing the payoff from discovering the gene, V^A.

Thus, while inclusive scope protection is definitely the best choice for maximizing the application diffusion welfare, it might be no better than the additional scope protection due to the fact that the latter provides higher payoff to the gene discoverer. However, according to our preliminary analysis, it is clear that scope protection as a welfare maximizing tool dominates no or length protection. In the light of these findings, it would be interesting to look at the differences in patent law between the U.S. and the EU and identify them according to length and scope classification, or a combination of different types of these.

Some possible extensions to the model are as follows:

Patent protection of applications. Rather than treating the benefits from the gene applications as exogenous values, application patent protection can be used to endogenize them. It is worth noting that scope protection of applications is possible only if, apart from having a market value, the applications themselves spur further innovations, possibly improved applications. In agricultural biotechnology, this could be the case if it were possible to "stack" already developed traits in a single plant like, for example, a draught resistant rice with enhanced vitamin A content and storage characteristics instead of three separate types of GM rice. So far, no such trend has been observed in the agricultural biotechnology. Assuming such a possibility away leaves only length (T_a) as a tool for patent protection of applications, making private benefits and welfare from an application functions of T_a.

Specific functional forms for $v_a(T_a)$ can capture different market idiosyncrasies without affecting the results of the application development model, as $v_a(T_a)$ and $W_0(T_a)$ are only multiplicative factors in the profit and welfare functions. Assuming $\partial v_a / \partial T_A > 0$ and $\partial W_0 / \partial T_A < 0$, due to monopoly distortion, the tradeoff in setting the duration of application patent protection is between the two effects of shortening it. Shortening an application patent life to the level that brings minimal reward to the application developer (the one under no patent protection) maximizes the diffusion welfare (from the gene application development),

at the same time undermining the incentives for gene discovery. If the application length protection is set before the gene R&D race begins, it might be optimal to sacrifice a part of the current welfare in order to encourage and speed up the pursuit of gene discovery.

An interesting complication arises if the requirement that gene and application protection lengths must be of the same length is imposed[3]. As the scope protection implies certain patent length as well, this constraint can lead to deadweight losses only if the specified patent length is too short to allow the optimal scope protection work at its best.

Overall, patent protection of applications is an extremely important consideration for the analysis of agricultural biotechnological innovations. If the process of application development is stochastic and the firm coordination is imperfect, the issues of pre-emptive patenting and capacity investment in the form of vertical or horizontal integration come to the fore (see, for example, Gilbert and Newbery, 1982). Unfortunately, the setup of the models dealing with pre-emptive patenting strategies is hardly compatible with the one considered in this article. Currently, we are working on a simulation of an application patenting game with stochastic elements, the results of which may be interesting in explaining the current trends in the industry.

Licensing and horizontal integration. In the context of biotechnological innovations, it makes sense to explore the incentives for horizontal integration as a way to expand the leader's capacity by gaining access to that of the rivals. To the extent that horizontal integration in the framework of this model is a substitute for licensing, the two are equivalent.

Different licensing models usually specify the following market structures. An independent researcher (single innovation company) who does not have rivals, develops an innovation that it can license to a number of strictly manufacturing companies in a downstream industry. The firms in the downstream industry are assumed to either be competitive or an oligopoly. There is a different strain of literature that considers joint ventures by the producing firms established for developing and patenting innovations that give the joint venture participants an edge over the non-participants. The members of the joint venture thus face a tradeoff between licensing an innovation to non-members and benefiting from it themselves. Yet another branch of the voluminous licensing literature

[3] Matutes *et al.* point out that, under the new World Trade Organization rules, all patents are of the same length.

considers setups in which firms in an industry possess both R&D and production facilities, but differ from each other in terms of R&D and production costs efficiency.

In the model considered here, firms are identical and gene applications can be licensed by the leading firm to the rivals. With at least some patent protection, licensing is a feasible means of expanding the leader's development capacity. If the leading firm can extract all the surplus from the licensees, it would be socially optimal to grant the leader a gene patent of infinite length and scope, since this would ensure immediate patenting and the fastest diffusion period. However, if full surplus extraction is not possible, the leader's incentive to delay patenting remains (albeit reduced), and the ranking of protection regimes remains the same. Vertical integration, however, is not equivalent to licensing, and usually represents an opportunity to increase the payoffs from marketing individual applications. In agricultural biotechnology, vertical integration typically takes place between the R&D and seed or herbicide distribution companies.

Perfect coordination. The plausible assumption of perfect coordination can be replaced by an assumption of a probability p that another firm happens to introduce the same application with $v^- < v^a$ being the discounted profits of each of the firms. This makes the expected value of introducing an application equal to $pv^- + (1-p)v^a$, which does not affect the Matutes *et al.* model's results, as the application value is only a multiplicative factor in the leader's payoff function. However, scope protection regimes are likely to reduce the probability of duplication, which makes them even more favorable.

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