Valuation of International Patent Rights for Agricultural Biotechnology: A Real Options Approach*

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Abstract:
Uncertainty of returns from marketing is an extremely important factor affecting the diffusion of a wide range of genetically modified (GM) crops worldwide. Biotech companies face complicated choices in making decisions about whether to enter agricultural markets in different countries with their agricultural products. In this paper, we model these choices as a real option problem of entry decision solved at a micro-level by individual firms. The model is aggregated in order to reflect the heterogeneity of different genetic events, as well as different markets, in terms of their profitability. The solution to the model produces distributions of entry probabilities as functions of the functional forms (and parameter values) that govern the evolution of stochastic returns from marketing. These proportions are then compared to the actual data on incidences of biotech firms entering foreign markets with different GM crops, and conclusions about the distribution of their patent values, evolution of returns, and efficiency of local IPR protection are drawn.

Keywords: patent values, agricultural biotechnology, real options, numerical simulation.

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INTRODUCTION

Genetically modified crops can be marketed in many countries. The biotech companies that hold stocks of patented genetically modified crops (genetic events) face the choice of entering these markets. Entering a particular market brings a flow of uncertain revenues (not necessarily positive), but is also associated with substantial entry costs. The costs of entry involve building the storage and retail capacities, getting approval and possibly local patent protection, and obtaining the producer acceptance and establishing customer loyalty via developing public relations and conducting advertising campaigns. Thus, before entering a particular foreign market, the owners of the rights to GM crops must weigh the costs and benefits of such a decision. This involves not only comparing the entry costs with the expected PV of the future returns, but also accounting for the option value of *not* entering the market, which should be significant given the uncertainties associated with bioengineered products. Not entering a market at any particular time gives a firm the benefit of waiting until new information arrives (*i.e.*, new benefits or hazards of a GM crop may be discovered, the consumer acceptance may change, or a more viable GM crop may appear). The firm can then revise the expected values of costs and returns and thus make a more informed decision.

The option value of delaying entry into particular markets is by no means negligible. The future safety and profitability of GM crops is highly uncertain - consider the notoriously inconclusive empirical research on the profitability of the Roundup-Ready soybeans and Bt corn in the US, not to mention the more controversial and less widespread genetic modifications introduced elsewhere, like those of rice or papaya. As is well known, an option value increases in both the volatility of the (returns from) underlying asset and time to expiration[1]. When the uncertainty of the returns is significant and a firm believes that bits of information that will clarify the situation are to arrive in the near future, the option value of not entering a particular market presently may be large enough to cover the expected present returns from entering a market. This situation bears a striking resemblance to an American call option on a dividend paying stock or asset.[2] Exercising the option (effectively making a purchase) means acquisition of the stream of stochastic future returns, but giving up the opportunity not to exercise it. Not

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[1] However, the option value can never be greater than the value of the underlying asset.
[2] In the realm of real options, it is analogous to an option to defer investment.

exercising the option implies giving up the current dividends but preserving the option value. Entering a market is equivalent to exercising an option because it implies commitment in the form of the sunk costs of entry (i.e., getting regulatory approvals, obtaining customer and producer loyalty, establishing production capacities or licensing to local seed companies, etc.), which is equivalent to the exercise price, and becoming entitled to a stream of returns from marketing. An alternative way to specify the model would be to introduce compound options in the form of an additional option to abandon a market if it turns out to be unprofitable. For now, we do not explicitly consider the abandonment option in order to keep things less complicated and also because the precedents of pulling out of GM seed markets are rare and the costs of abandonment are unclear[3].

In the model presented in this paper, we assume that the biotech companies will enter a particular market only if the expected discounted value of future net returns conditional on the information currently at their disposal is greater than the value of the option to delay marketing the product. An optimal sequential policy for the agent has the form of an optimal entry rule that determines whether to enter a market at time *t* depending on the information currently available, *i.e.,* whether to incur the entry costs and secure a stream of uncertain returns. If the decision not to enter is taken, the agent is getting a net current profit of zero but keeps the option to wait until the next period, when new information becomes available that will refine the expectation of the future returns. On the aggregate level, the proportion of the products that enter a foreign market at any age *t* is the proportion that satisfies the entry criteria at this age but did not satisfy them at *t-1*. The entry proportion at each age is a function of the value of the model's parameter vector, which consists mainly of the coefficients of the distribution functions that describe the heterogeneity of the initial product values and their evolution over time. The data provide the actual proportions of products that enter foreign markets. Loosely speaking, the problem is to determine the optimal entry rule and find the values of the model's parameters that make the entry proportions implied (generated) by the model as close as possible to the actually observed ones.

Formally, we are looking for specifying an discrete stochastic model of optimal entry (call it optimal commitment) in order to derive the implications of this model on aggregate

[3] An additional complication of pulling out of a GM seed market is effectively giving up the property rights on the crop there: once a crop has been "diffused" but the market was abandoned, producers would be free to re-plant the GM seeds if it is privately profitable.

behavior and to estimate the model's parameters using aggregate data on how many GM crops enter foreign markets each year. So far, the best approximation we found for this has been the GM crop approval data that contains the dates of different genetic events of particular crops being approved for environmental safety, food, feed, and marketing in different countries. While this may not be the best indicator of entering a foreign market, these are the most complete and detailed data we found so far. Our hypothesis is that, assuming that costs of entering a particular foreign market are approximately the same for a certain class of GM crops (or proportional to the market size), the timing and frequency of their approvals indicate their relative values (and therefore the distribution of these values). Most generally speaking, the sooner the crop enters a market after it is patented, the more valuable it is. The distribution of incidences of entry, together with economically justifiable assumptions about the distribution and evolution of stochastic returns from marketing, defines the distribution of relative values of different genetic events (GM crops). It should be noted that, without some "anchor" value, it is impossible to get the ordinal patent/GM crop values, but knowing their distribution, *i.e.,* relative values, can also be of value. While this does not answer all the questions, these results help identify the proportion of the patents that actually cover the R&D expenses of biotech companies and shed light on the profitability of GM crops in different world regions. The difference of this model from the other R&D models is that it does not require information that is unavailable in the majority of cases. In addition, instead of deriving the results from making assumptions about the R&D production and cost functions, the model makes assumptions about the stochastic returns from marketing the R&D products (*i.e.,* the processes that generate them). The correctness of these assumptions can be verified by comparing the samples generated by the model to the actual data. Besides, the model does not treat mere patent counts as indicators of R&D profitability – something that has been the "Achilles' heel" of the R&D literature. If compared to a simple NPV rule of entering a foreign market, other things being equal, the real option model would predict relatively late entry into different markets, particularly in the early stages of product lives when information is scarce. Later on, however, the real option model would predict a higher proportion of entries, particularly as patents approach their expiration dates.

In the analysis of patent values, the discrete choice optimal stochastic control models have only been used in the analysis of optimal patent renewal data and applied to the countries where the obligatory patent renewal rules exist (*i.e.,* Germany, France, and the Norway)[4]. Under the patent renewal rule mechanism, a patentee has to pay an annual renewal fee in order to keep the patent in force. Knowledge of the renewal fee schedules and having very extensive aggregate data on all patent cohorts (by year of patenting) in a country makes the task of evaluating the distribution and average magnitude of patent values quite accomplishable. In particular, the simulations performed by Pakes (1986) showed a very close fit to the actual aggregate data on French and German patent renewal behavior and highlighted the differences between the two countries (i*.e.,* patent offices' claim approval behavior and the intensity with which the inventors explore the marketability of their products). Similar models have also been used in dealing with other issues, such as job matching, sequential binary choice models for birth sequences of married women, etc. It should be mentioned that, though the discrete optimal stochastic control techniques have a wide range of applications and provide rich interpretation of data, they share one common disadvantage. Both the estimation technique and the simulation/estimation results heavily depend on the details of the stochastic specification and, because of the complexity of the estimation problem, it is difficult to determine the robustness of the conclusions to the stochastic assumptions chosen. The only way to offset this shortcoming is to be very careful and informed in the model's construction, so that the specifications are as close to economic reality (are as economically justified) as possible.

DESCRIPTION OF THE MODEL

The model that we use employs the Markov assumption, namely it assumes that the distribution of the next period's return conditional on current information depends only on current returns and the parameters of the problem. The model is essentially a search model: each year the firms that hold patents on GM crops gather information about their economic viability in different countries (or world regions) and explore the ways in which these crops can benefit the producers and/or consumers. Three outcomes of this search are possible: one is that this search does not provide any new information; another is that the crops can never be profitably exploited, and yet another one is that information is uncovered indicating that the returns will increase in subsequent years. The conditional distribution of outcomes, should they occur, is non-stationary

[4] See Pakes (1986), Schankerman (1984), Pakes and Schankerman (1994), Lanjouw (1996, 1998).

over time, which allows for the possibility that the patent holders explore the most promising alternatives first. In addition, we assume that patent protection is finite (i.e., that there is a statutory limit to patent lives), so that the model has a finite horizon.

Given these assumptions, it is possible to obtain an explicit solution for the optimal entry rule as a function of the parameters of the Markov process and the age of the patent, which should simplify estimation of the real-life aggregate data. On the other hand, the model presents some difficulties with respect to calculation of aggregate entry probabilities. To allow for heterogeneity, we assume that there is a distribution of initial returns among patents, which is modified over time as the agents uncover more profitable ways of exploiting their patented ideas. The distribution of returns at each age does not have an analytic form and, therefore, neither do the entry probabilities. (Pakes uses a simulated frequency approach). Below is a formal description of the discrete choice optimal stochastic control model of market entry.

A biotech firm has *N* patents on GM crops (genetic events of particular crops). There are many firms (several actually), but this is irrelevant to the model, as it is not about competition. Each crop is protected by a patent of length *L* (the patent can be broader than just one event, in which case several crops are protected by the same patent). The firm is deciding whether to enter a new market with each of the products (possibly a market in a foreign country). The returns from marketing in this country (r_t) evolve according to a stochastic process (details later), and entering the market requires a considerable one-time sunk cost, *C* (related to capacity building, getting approvals, customer loyalty, producer acceptance, etc.). One can assume that the entry cost is declining due to the gradual lowering of the regulatory barriers and increasing consumer and producer acceptance.

The situation is very similar to an American call option: the firm has an option to "buy" marketing its new product in a foreign country at the price of the sunk entry cost (C_t). The option's maturity is *L*, and the time to expiration is *L-t*. The *value* of the option to enter the foreign market with stochastic returns at any particular time *t* is

$$V(t) = \max\left\{ \underbrace{\beta E[V(t+1) \mid \Omega_t]}_{do\_not\_enter\_at\_t}, \_ \underbrace{E\left[\sum_{i=0}^{L-t} \beta^i r_{t+i} \mid \Omega_t\right] - C_t}_{enter\_at\_t} \right\} \qquad (*)$$

The first term in the brackets is effectively the option value: it shows what the firm gets if it decides not to enter the foreign market, *i.e.* the discounted value of the patent in the next period.[5] The second term is what the firm gets if it decides to exercise the option at t and enters the foreign market. In this case, it gets a PV of the flow of per period returns until the patent's expiration, r_{t+i} ($i = 0, L - t$) conditional on the current information, Ω_t, minus the sunk entry costs, C_t.[6]

Given the distributional assumptions about the returns are specified, equation (*) can be solved recursively for two variables: cutoff values $\bar{r}_t$ and proportions of products entering the market π_t. For each t, there exists a unique return (cutoff value), $\bar{r}_t$, such that the option is exercised (entry occurs) if the actual current return $r_t > \bar{r}_t$. Alternatively, the option is *not* exercised if $r_t < \bar{r}_t$. Knowing the cutoff values ($\bar{r}_t$'s as functions of the distributional parameters and t) permits calculation of the shares of patented products (call them different GM crops), π_t's, that will be marketed at each t.

Given the availability of empirical data on the number of GM crops that enter markets in different countries over several years, the simulation results can be compared to the actual proportions in several ways and conclusions drawn.

Below we suggest the distributional assumptions of the model and try to justify them on empirical grounds.

- When the invention is made (*i.e.*, the option appears), we have a known *initial returns distribution*. The initial returns (r_1) are lognormally distributed with a mean of μ and variance σ_R:

  $$\log(r_1) \sim \eta(\mu, \sigma_R). \quad (1)$$

  This distribution is properly skewed, which reflects the fact that the bulk of the innovations (genetic events) are not as profitable as the few that lie on the far right.
- The *evolution* of the returns is a Markov process (this goes without saying ☺). The information set Ω_t thus consists of the current return, r_t, and the current time, t. The conditional distribution of r_{t+1} is:

[5] Note that the option value is non-negative, even the future returns turn out to be negative.
[6] A possible extension is to introduce another option – an abandonment option of exiting the market after entering if the returns are really bad, but this would complicate the analysis.

$$r_{t+1} = \begin{cases} 0 & with\_probability\_\exp(-\theta r_t) \\ \max\{\delta r_t, z\} & with\_probability\_1-\exp(-\theta r_t) \end{cases} \quad (2)$$

where the density of z:

$q_t(z) = \sigma_t^{-1} \exp(-(\gamma + z)/\sigma_t)$,

and $\sigma_t = \phi^{t-1}\sigma$, for $t=1,\dots, L-1$.

In addition, $\delta \leq 1$ and $\phi \leq 1$.

This process has the following economic interpretation. At each age, patent holders (biotech firms) gather information on and explore the ways of improving their crops marketability and safety in order to increase the profits. Three outcomes of this process are possible:

1) It is found that the crop can never be profitably exploited (something quite common among GM crops). This event occurs with probability $\exp(-\theta r_t)$ - note that it occurs with smaller probability the larger are the current (estimated) returns from marketing the product, r_t. In this case, the product never enters the market (technically, 0 is an absorbing state, as $\exp(-\theta r_t \mid r_t = 0) = 1$) and a single realization of zero return is an absorbing state. The option value on this product is zero as well.
2) No new information discovered, this search does not provide any new information, in which case the current returns decay at the rate of $\delta \leq 1$, which can be attributed to obsolescence due to arrival of better substitutes (as an illustration, consider the number of patented herbicide resistant versions of soybeans and cotton). In this case, entry is not likely, but a decrease in the entry costs may still trigger it.
3) Information is uncovered indicating that the returns will differ from the returns expected before the new information became available (say, the environmental safety concerns have been raised or lowered, IPR protection has been improved or worsened, or the producers have recognized or rejected the convenience of growing a crop). The new return depends on the precise realization of z, which is specified as a random variable with a two parameter exponential distribution. z is greater than zero with probability $\exp(-\gamma/\sigma_t)$ (new information does not necessarily indicate positive returns – consider the Taco Bell Bt corn incident) and density that declines at a constant rate σ_t thereafter. $\phi \leq 0$ allows for the possibility that the probability of the returns will increase declines

over time, or for the possibility that the patentees lay their hands on the most relevant and important information first.

The stochastic process above generates the distribution of $r_2, r_3, \ldots$ from the original distribution of r_1 (defined by the parameters μ and σ_R) and the parameters $(\theta, \gamma, \sigma, \delta, \phi)$.

This process a solution for the sequence of the cutoff values that determine the entry decision, $\{\bar{r}_t\}_{t=1}^{L}$, as a function of the parameters of the model. The distribution of the initial returns, the stochastic process generating the subsequent returns, and the entry tule defined by the sequence of cutoff values determine the <u>unconditional</u> distribution of returns at each age that depends only on the parameters of the model,

$1 - F(r,t) = \Pr\left[r_t \geq r, r_{t-1} \geq \bar{r}_{t-1}, \ldots, r_2 \geq \bar{r}_2, r_1 \geq \bar{r}_1\right].$

The proportion of GM patent holders who enter at age t is the proportion with current returns above $\bar{r}_t$, but with the previous period returns below $\bar{r}_{t-1}$, which can be written as

$\pi_t = F(\bar{r}_t, t) - F(\bar{r}_{t-1}, t-1)$.

π_t thus also depends only on the vector of the parameters of the model (*i.e.,* by $w = (\mu, \sigma_R, \theta, \gamma, \sigma, \delta, \phi)$).

With these definitions, the likelihood of a particular value of the parameter vector conditional on the actual (observed) data is

$l(w) = \sum_j \sum_t n(j,t) \log(\pi(j,t,w))$,

where $n(j,t)$ denotes the number of approvals of patents granted at time j and t years after patenting.

The distributional specifications for the stochastic returns are by no means final – these were chosen as most economically and empirically justifiable given the industry facts we have at the moment. Different distributional specifications are certainly possible (including continuous ones) and should be favored if they are considered to reflect the actual situation in the GM crop markets better (one suggestion would be to make the entry costs stochastic but with a declining mean). We would like to point out once more that the distributional specifications for the stochastic returns and there evolution are essential for this model, and probably are even more important than the parameter values. The reason is that it is these specifications, together with the parameter values, that give rise to particular patterns of entry that should be compared to their real life counterparts, so in effect one must test the validity of the functional forms as well as their parameters. The need to be as flexible as possible in the distributional assumptions also explains why the model is solved numerically.

This model can be solved recursively using numerical methods. The simplest way to proceed is to generate the population of the initial returns and their evolution over time (using either repeated Monte Carlo sampling or better Gaussian quadrature nodes). Then, the program should solve the problem recursively, starting at the terminal (patent expiration) date, for whether entry is optimal for a given current realization of *r*.[7] The solution is a sequence of the cutoff values, $\{\bar{r}_t\}_{t=1}^{L}$, that specify whether a firm should enter given it gets a return r_t (*i.e.,* enter if $r_t \geq \bar{r}_t$ and do not if otherwise). This sequence then determines the entry proportions for each age, $\{\pi(t)\}_{t=1}^{L}$, all being dependent on the parameters (and functional specifications) only.

The maximum likelihood estimation of the parameter vector *w* from the actual entry data is more computationally burdensome, as it requires the use of nested fixed point estimation. However, Matlab routines for similar problems have been are available and would require but a few adjustments to be suited for this particular problem.

[7] If this problem is to have a *real* real options setup (contingent claims analysis), there is a potential issue of finding the right twin security (*i.e.*, with perfectly correlated returns) that would be used to determine the required rate of return. This rate of return is then used to derive the so-called adjusted risk-neutral probabilities, defined as p=[(1+r)-d]/(u-d) in the real options literature, that allow expected values to be discounted at the risk-free rate. This eliminates the common mistake of comparing projects with flexibility to the "naked" projects that allow for no flexibility. In the absence of such a twin security, one can derive the required rate of return by assuming that risk of entering a particular market is a function of average market risks. Otherwise, one must use actual probabilities of future returns, and problem becomes more like a decision tree analysis (DTA), which is basically equivalent to the real options but leads to overestimation of the option value.

DATA DESCRIPTION AND ANALYSIS

In search for the data that would most adequately reflect the decisions of biotech companies to enter foreign and domestic markets with particular patented genetic events (GM crops), we did not find any sources that would provide the exact identifiable market entry dates. In fact, an entry into a market is not a one-time event, as it takes time to establish capacities, contract retailers, get approvals, and otherwise prepare the ground. However, there might be certain events that are likely to indicate that the entry commitment has been made (*i.e.,* the option has been exercised).

One of such events is getting a GM crop approved for production and/or consumption in a certain country. A particular significance of an approval comes from the fact that we are dealing with genetically engineered food/feed, hence the thoroughness with which every marketable genetic event is examined before granting it an approval. Had the subject of approval been less controversial, the approval procedure would be of much less significance, but the GM crops have been considered unsafe for consumption and unpredictably dangerous to the environment for long enough to warrant special attention.

There is significant evidence that suggests that the process of approval of GM crops and/or food in any particular country is both costly and lengthy (perhaps, with the exception of the US and particularly Canada). It usually takes up to several years to get a crop (event) approved, and the approval process demands constant attention and injection of resources on behalf of the applicant. It is hard to imagine that dealing with other aspects of entry can take that long. Thus, while an approval date can certainly be a noisy indicator of entry date we, for now, assume that this particular event is coincidental with entry.

The data we use comes from a Canadian non-profit initiative called Essential Biosafety (which is currently funded primarily by the Monsanto company). The purpose of the initiative is to provide "information resource and educational tool to meet the needs of scientists, regulatory personnel, policy makers, and others interested in the environmental and food safety of GM plants". The Essential Biosafety webpage gives access to a comprehensive, veritable, and constantly updated GM crop database that contains precisely the newest and quite detailed information on all the existing *events* (*i.e.,* traits infused into/imposed on certain crops via genetic modification). In particular, the database provides data on the approval of all these events in different countries. Unfortunately, these data do not contain any other economic indicators (which probably is symptomatic of the general lack thereof).

A cursory examination of the data on GM crops that have been developed so far reveals that, to date, 78 events of 17 crops have been patented. The most widely "genetically altered" crops are:

- corn (maize): 22 events, 9 of which provide resistance to a European Corn borer, 19 provide resistance to various herbicides, and one is resistant to the corn root worm (some events actually give combined pest/herbicide resistance).
- Argentine Canola: 15 events, 12 of which are herbicide tolerant, and the rest have modified seed fatty acid content and male sterility.
- Soybean: 7 events altogether, 5 of which have herbicide tolerance, and 2 have modified seed fatty acid content.
- Cotton: 7 events, 3 of which provide pest resistance, and 5 herbicide resistance. [8]

The rest of GM crops include carnation (3), chicory (1), flax/linseed (1), melon (1), papaya (1), polish canola (2), potato (4), rice (2), squash (2), sugar beet (2), tobacco (1), tomato (6), and wheat (1).[9] The main crop developers are Aventis Cropscience, Du Pont, Monsanto, Syngenta Seeds, Pioneer Hi-Bred International Inc., and Astra-Zeneca.

The approval time-span encompasses the years 1994 through 2002. Unfortunately, the database does not contain the patenting dates, so we gathered the dates of patenting from elsewhere. In cases where the patenting dates were not available, we assumed them to be coincidental with the date of first approval, which always happened in the US, so that there is a high chance that the approval and patenting indeed happened at the same time. It should be mentioned that there are different types of approval listed in the data set: environmental, food, feed, and marketing. Unfortunately, the marketing approval was granted only to a negligible fraction of events, and there is no detailed explanation what these different types of approvals actually mean. We thus consider an event to be approved if it receives both environmental and food and/or feed approvals.

[8] It is a pity that the authors do not have expertise in molecular biology and agronomy to judge on the relative merits of these events.

[9] It is probably indicative the prevailing herbicide tolerant trait is that that of glyphosate tolerance – something pioneered and proven popular by the RR soybeans has been attempted in many other plants.

Ideally, we would like to have data rich enough to define a pattern of entry for every country and, most importantly, for every patent cohort (*i.e.,* the group of patents granted at the same time). However, though currently there exist as many 78 approved events, they are scattered among countries, so there is not enough data for a proper econometric analysis.[10] We thus resort to examination of worldwide and regional approval data (which by assumption identifies entry) and, for now, consider frequencies of approvals rather than their proportions.

Table 1 contains the number of approvals by country and by time measured by the number of years since the event's patenting.[11] Clearly, the US and Canada have a great lead in the number of approvals, which should be attributed mainly to the fact that all the common obstacles to GM crop introduction are much less severe there.[12] In particular, the entry costs there are likely to be very small in comparison to the expected returns. The regulatory approval is likely to take less time and resources, and the respect for intellectual property rights on patented innovations is much more pronounced in these countries (i.e., there is virtually no uncontrolled diffusion by illegally replanting GM seeds without paying for them). In addition, consumer attitudes are more accommodating, and producers are more receptive to agricultural innovations. But, most importantly, there is much less uncertainty of the returns from marketing the GM crops, and therefore the value of the option to defer entry is not as large as elsewhere, hence the early approval. On the other hand, it is precisely the ease of approval that might make the data on countries like US and Canada less meaningful in the context of our model in the sense that approval there is less likely to imply entry.

These concerns aside, the entry proportions approximated by the national approval data give rise to some interesting observations. Figure 1 shows the frequency of approvals worldwide plotted against the time in between patenting and approval of an event. This time reflects how long a patentee waited after he effectively acquired an option to enter a (foreign) market before exercising it (the time the option was held before it was exercised).

[10] The overwhelming majority of approvals still happen in the US and Canada.
[11] The economic rationale behind our reasoning justifies measuring approval/entry dates only by the time since patenting and not by the calendar time.
[12] We were surprised to see the only GM trait of papaya (nutrient enhancement) being approved for environment and consumption only in the US and Canada and nowhere else.

Table 1.

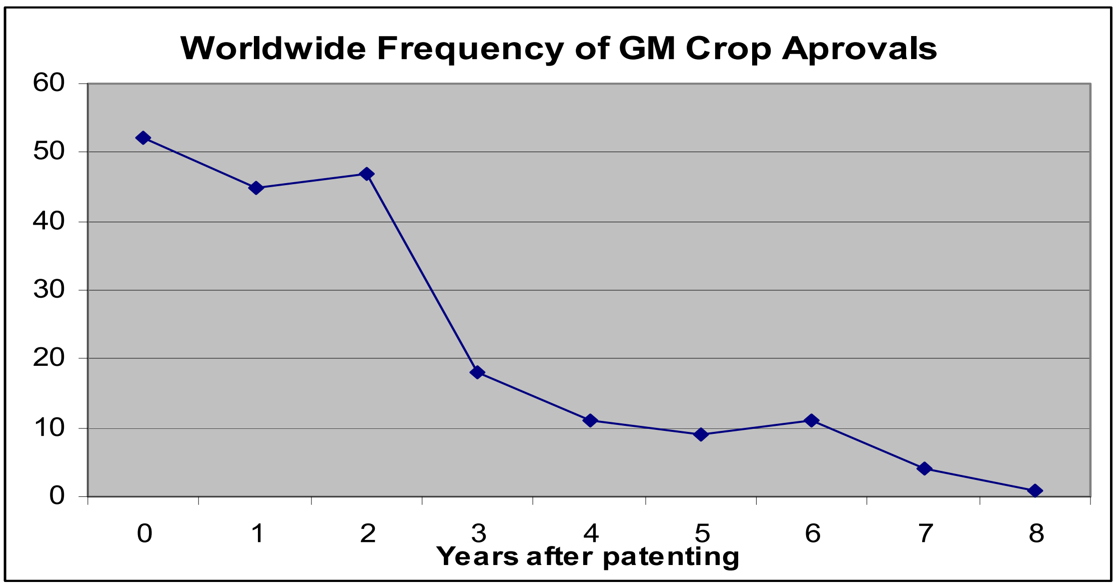
Approval date (years after patenting)	0	1	2	3	4	5	6	7	8	
COUNTRY										
Argentina			2	3		1	1			**7**
Australia	1	1	1	3	3	6	3	1	1	**20**
Brazil					1					**1**
Canada	16	18	11	4	3			1		**53**
China			1							**1**
Czech Republic								1		**1**
European Union		1	5	3						**9**
Japan	2	10	15	2	2	1	2			**34**
Korea							3			**3**
Mexico			2	1						**3**
Netherlands			2							**2**
Philippines							1			**1**
Russia						1				**1**
South Africa		1	1					1		**3**
Switzerland			2		1					**3**
United Kingdom										**0**
United States	33	14	5	2			1			**55**
Uruguay					1					**1**
TOTAL	**52**	**45**	**47**	**18**	**11**	**9**	**11**	**4**	**1**	**198**

Clearly, there is a downward trend in the approval frequency, indicating that most of the events (genetic modifications of crops) occur soon after patenting. However, the figure does not indicate immediate approval and market entry (except for the US and Canada).[13] The approvals happening some time after an opportunity to enter markets appears is indicative of an positive option value of this opportunity (a call-like option to defer investment). In other words, there is uncertainty in the markets for GM crops, and therefore any flexibility in decision making presents economic agents with a non-negative option value (the right but not the obligation) and makes many of them wait for new information to arrive in order to be able to estimate the

[13] While getting an approval might not necessarily mean entry, an entry into a market definitely implies an approval (*i.e.,* an approval is a necessary condition for entry).

expected returns more precisely and make better decisions. Generally speaking, had there been no uncertainty, the agents would make a decision either to enter immediately or never to enter. Another consistency with the real options approach shows up in the fact that, though the frequency of approvals declines with the patent age (which can be attributed to declining returns due to substitution and other obsolescence effects and because of declining entry costs), the decline is significantly less steep (more gradual) at later ages. This is because, as the patents' time to expiration declines, so does the option value, which provide an additional incentive to enter.

Figure 1.



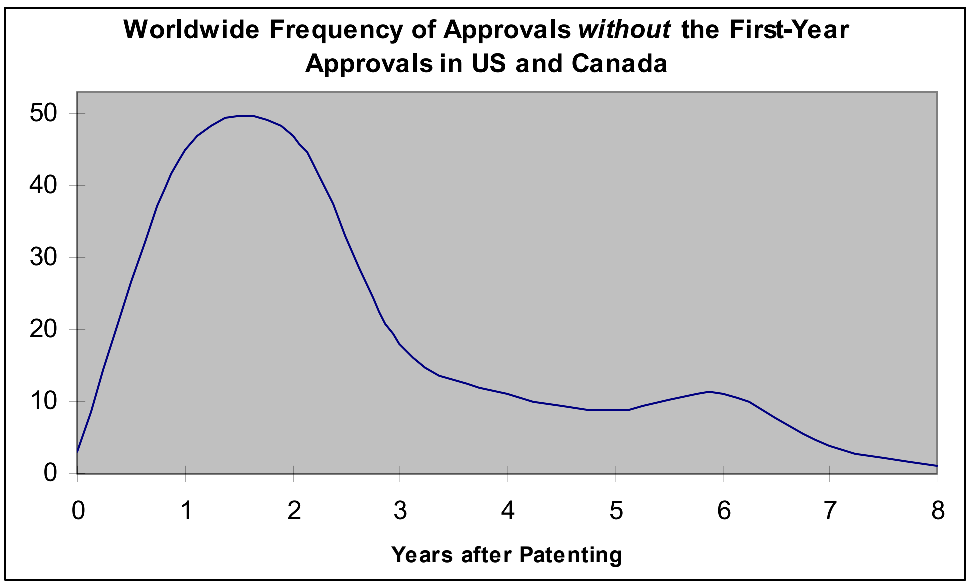
While we do not have exact information on the length of the patents that protect these genetic events (many are patented in different countries), it is comparable with the time span in Figure 1. The downward trend is much less noticeable in the early ages of the patent lives. As a matter of fact, approvals peak again around the patent age of 2, which most likely accounts for many patent holders being willing to defer entry (note that there is no universal exogenous influence - the frequencies show approvals at the same *patent age*, not at the same calendar time).

Our observations can be refined in two ways:

- One is by eliminating the US and Canadian approvals from the sample as they are less likely to indicate entry because of the relatively trouble-free approval. Figure 2 below shows the predictable result: only the second peak in approvals remains around the age of 2 years, since which the number of approvals decline.

- The other is by dividing the world into two regions represented by industrialized and developing countries.[14] Assuming (rightfully) that the influences within the two regions are similar yet there are significant differences between the two, and that the entry costs are proportionate to the size of the market, such division should highlight the differences in uncertainty of the returns and thus in the value of the patents between the two regions. Arbitrarily assigning Argentina, Brazil, China (?), Mexico, Philippines, Russia, South Africa, and Uruguay to the second region and the rest to the first, we get the following trends, presented in the Figure 3.[15]

Figure 2



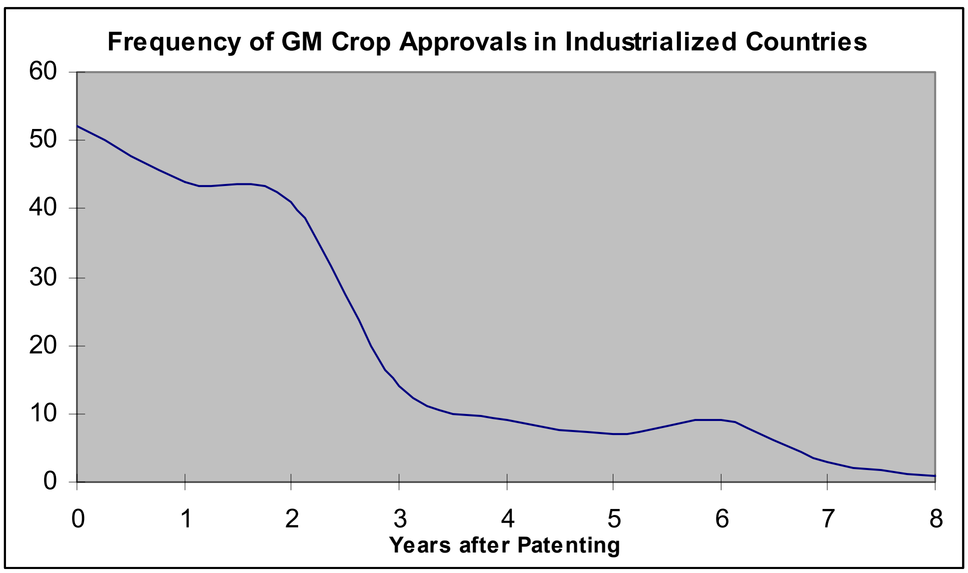
It is obvious from the figure 3 that, while in the industrialized countries most of the events get approved soon after patenting, the overwhelming majority of approvals occurs just above age 2. On the one hand, this might be indicative of the fact that it takes relatively longer to get a crop approved in the developing countries, which is not a good guess because approval is probably more difficult and lengthy in countries like EU and Japan. On the other, the difference in patterns in figures 3.A and 3.B might signify that

[14] The word industrialized applies to agriculture as well.
[15] Other refinements of the current data are possible, like adjusting the size of agricultural markets or omitting the less popular crops.

1) the volatility of the returns (parameters σ and σ_R in the model) is higher in the developing world;
2) the probability of discovering that an event cannot be marketed at all (negatively related to parameter θ in the model) is also higher in the developing world, which results in high value of the option to defer entry, hence the pattern.
3) the depreciation/obsolescence rate of introduced genetic events (parameters δ and ϕ in the model) in the industrialized world is higher due to substitution.

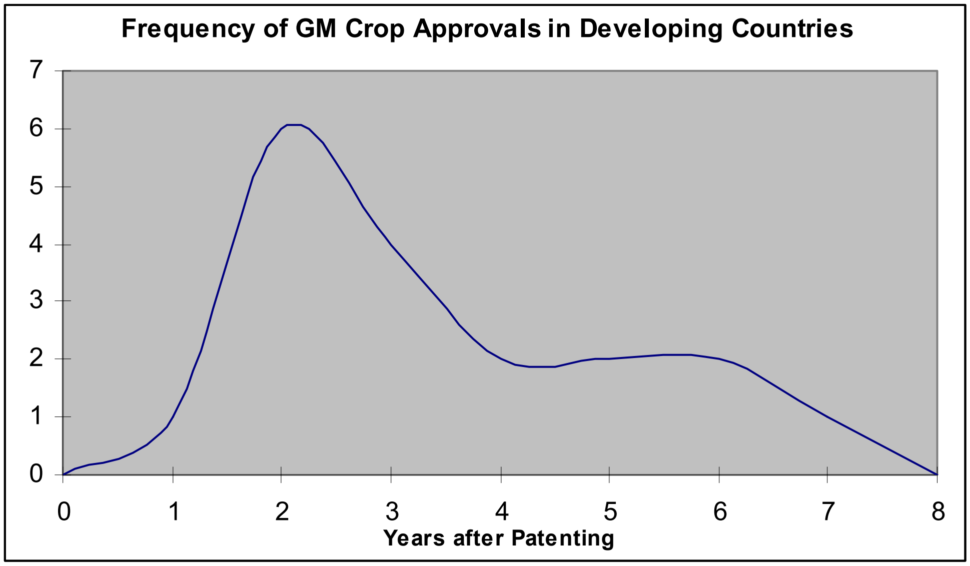
And, again, the difference between the decline in the approval frequency immediately after the peak and closer to patent expiration is more pronounced in the developing world. As we argued above, this reflects a higher option value due to greater uncertainty.

Figure 3. A.

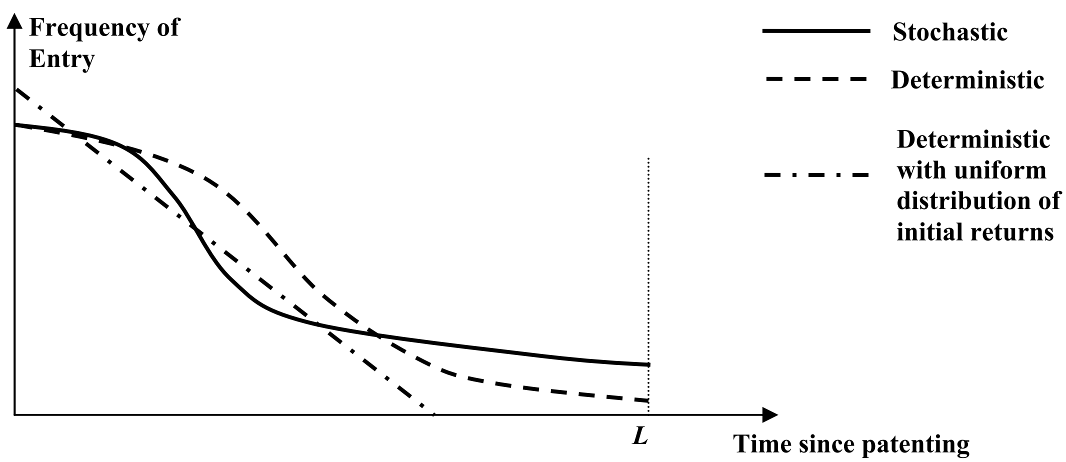


The simulation results from the model described in the paper confirm the above observations. As the results are preliminary, for the time being, we do not provide any plots or tables and use loose language in the discussion below.

Figure 3. B.



Comparison of the simulation results of the stochastic model to those of its deterministic counterpart show that entry occurs earlier if the returns are perfectly predictable – there is no option value to entry deferral to forego. This result is obvious but illustrative.



The mean of the entry probability distribution (equivalent to entry frequency in case of multiple firms and markets) shifts to the right with an increase in the volatility of both the initial or subsequent distribution of the returns from marketing, which implies that the option value becomes more significant and entry in the early ages is less likely. In particular, the right tail of the distribution becomes thicker in response to an increase in the parameter σ, which defines volatility of the truly random component of the returns, z. Similar transformation is observed in response to a decrease in θ, *i.e.*, to lower probability of suddenly finding out that the event has no market value.

Sensitivity of the preliminary simulation results to the changes in the "trend" parameters is quite predictable. An increase in the depreciation rate δ, as well as a decrease in ϕ (increase in the "depreciation" and the volatility of the random variable z that can sometimes lead to appreciation of the returns), lead to earlier entry, and thin the right tail of the distribution. Finally, a faster decline in the entry costs shifts the distribution to the left in an almost linear fashion, which warrants a possible modification to the model: specifying a stochastic process for the entry costs, which might better reflect the reality.

CONCLUSION

Even with the currently available data, it is possible to make some interesting conclusions by comparing our observations to the preliminary simulation results obtained from the model.

The distribution of incidences of market entry is indicative of the heterogeneity of the values of GM crops (patented genetic events). Roughly speaking, the flatter this distribution, the more heterogeneous the patent values are. A part of this heterogeneity is attributed to heterogeneous profitability of the crops/events themselves and the other part accounts for the differences in the profitability of the markets where the entries occur. The insufficient volume of the currently available data prevents us from separating these two effects perfectly. However, the differences between the frequencies/proportions of entry in the industrialized and developed countries show that an average value of a GM event is lower and heterogeneity of the values is higher in the latter. This confirms the well-known facts about poor intellectual property rights enforcement in the developing world, as well as high entry costs there, which prevent biotech companies from entering those markets. There has been a lot of controversy about whether GM crops actually benefit the developing countries or harm them in the way the "green revolution" arguably did, but it appears that many of the genetic events can potentially be more beneficial to the developing countries than to the industrialized ones, at least in the short run (in particular the crops with enhanced nutrient content). So far, the data analyzed in the light of out model suggest that biotech companies recoup most of their R&D expenses (and earn most of the profits) from marketing their agricultural products in the industrialized part of the world, despite the sometimes strong consumer and government opposition. However, at the current stage of the research, it is hard to determine what proportion of patents (read inventions) accounts for the bulk of the profits from the R&D activities. More extensive simulation exercises and data estimation will shed light on this matter.[16]

Overall, the sensitivity analysis of our preliminary simulation results suggests that the option value of deferring entry (the option value of patents on crop genetic events) is higher in the developing countries. High volatility of the returns from marketing GM crops makes biotechnology firms delay entry into foreign markets in order to obtain more information on the prospects there. (Of course, the higher option value does not compensate for the difference from the value in the industrialized world; it only partially offsets the unfavorable influences present in the developing world.) In particular, the results suggest that the probability that marketing a GM crop will bring zero profits, and the volatility of the returns evolution, are both higher in the developing countries. However, the returns from marketing GM crops in the third world do not decay at as high a rate as in the industrialized countries, possibly due to higher arrival rate of substitutes in the latter – something that also partially offsets the disadvantages of marketing there.

At present, we continue working on both the model and data collection. In particular, we are looking for distributional assumptions that would describe the real-life situation better and forward to estimating the data with the maximum likelihood method.

[16] Though the industry facts and adoption volumes suggest that most profits have been earned from selling glyphosate resistant soybeans and Bt corn to the farmers.

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