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# Genetically modified crops as real options: Identifying regional and country-specific differences

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ABSTRACT

This paper employs real options methodology for evaluating profitability of genetically modified (GM) crops in volatile market and regulatory environments. Observed instances of market entry, or product introduction, are viewed as outcomes of profit maximizing decisions based on comparison of market entry costs, expected future returns, and the value of managerial flexibility. The process is estimated using simulated maximum likelihood. The estimates suggest that, in the developing countries, the downward volatility of the returns is higher resulting in lower adoption rates, whereas the environment in the top four industrialized GMO adopting countries appears to be costlier but much more optimistic. Commercial success of GM soybean and maize in Argentina, Brazil, and the U.S. is explained mostly by a combination of high upward return volatility and moderate entry costs. The findings may contribute to the general understanding, measurement, and possibilities of controlling the rate of technical advance in biotechnology.



## 1. Introduction

The introduction of crops genetically engineered to increase agricultural productivity has the potential of dramatically increasing returns in the agricultural sector and alleviating the problem of feeding the growing world population (Fedoroff et al., 2010). Further advancement and direction of biotechnology research and development (R&D), as well as marketing of biotechnological innovations, depend critically on current and potential foreign market opportunities.

The strengthening and harmonization of global intellectual property rights via the World Trade Organization (WTO) rules, especially via the Trade Related Aspects of Intellectual Property Rights (TRIPS) agreement, may increase market potential in many parts of the world where, heretofore, agricultural biotechnology has been only marginally profitable (Isaac and Kerr, 2003; Nelson et al., 2001; Gisselquist et al., 2002; Pew Initiative on Food and Biotechnology, 2004). Little is known, however, about the potential profitability and marketability of genetically modified (GM) crops in different parts of the world. In most cases, we are certain only about the fact that the returns are highly uncertain, in addition to being poorly recorded and reported, mainly due to unknown demands and the many controversies that surround GM products (Pinstrup-Andersen and Cohen, 2001). Consequently, methods should be sought that circumvent these data limitations.

In this article, we study marketing decisions of biotechnology firms that hold exclusive ownership rights to GM crops. These large companies are likely to have the capacity to realistically assess the profitability (and uncertainty thereof) of their products in different markets and regulatory environments. While not directly available, some of this valuable information might be reflected in the firms' actual marketing behavior. Consequently, the analysis is performed using a real options framework that utilizes firm behavioral data from different market and regulatory environments. In accordance with real options theory, observed instances of market entry, or product introduction, are viewed as outcomes of profit maximizing decisions based on comparison of unobserved entry costs, expected future returns, and the value of managerial flexibility, i.e., the right but not the obligation to enter a market with a GM product. As different combinations of these parameters result in different timing of product introductions (market entry), simulation of this decision process and subsequent estimation of the actual entry data may tell us something about GM crop profitability in different world regions and about the volatility of these returns, which can be of practical value. Our objective is thus to estimate a model that explains the observed market entry decisions of biotechnology firms with GM crops across different countries (grouped into regions)

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and to seek economic interpretation of the results. An important feature of our analysis is that it does not require detailed firm-level information, which is generally unavailable. In addition, the model does not treat mere patent counts as indicators of R&D profitability, a practice that has been referred to as the "Achilles' heel" of the empirical R&D literature (Lanjouw and Lerner, 2000).

The modeling framework is loosely based on a model of patent renewal in European countries originally specified in Pakes but has some important differences due to the fact that we model entry, rather than exit, options. In general, the real options methodology has been successfully applied in many other areas. Expansion, contraction, and abandonment options have been used to describe the behavior of natural resource industries, R&D companies, and in the analysis of newly introduced products in uncertain markets (Pindyck, 1988; Brennan and Schwartz, 1985). In agricultural economics, certain farming decisions have been modeled using the option to defer investment (Titman, 1985; Kulatiaka and Trigeorgis, 1994). In what follows, we develop and formally specify a stochastic discrete-choice model of optimal market entry by a generic firm owning a GM product. The model's parameters are then estimated using data on market entry frequency by GM crop ages defined as time between the date when a crop becomes available for market entry and the actual introduction. Parameter estimates are used as a means of explaining the marketing behavior of biotechnology companies and the profitability of GM crops across selected regions and crop types.

## 2. Model description

The pivotal assumption of our model is that biotechnology companies that hold patents on GM crops can choose where and when to market them.[3] Different GM crops have different potential profitability in different markets at different points in time. Entering a particular market provides a flow of uncertain future profits, but imposes sunk entry costs associated with building production, storage, and retail capacities, securing regulatory approvals and local intellectual property rights (IPR) protection, obtaining customer and producer loyalty through PR, etc. Before entering a particular market, the owner of a GM crop must weigh the costs and benefits of this decision. The entry decision involves not only comparing the entry cost with the expected value of future operational profits, which cannot be observed, but also accounting for the option value of postponing entry which can be significant considering uncertainty about the profitability and safety of bio-engineered products.[4] Postponing the market entry decision allows a firm to wait until new relevant information arrives; i.e., over time, new benefits or hazards of a GM crop may be discovered, consumer attitudes may change, or more viable GM crops substituting the old ones may appear. A firm that postpones entry can thus revise expected costs and returns and make a more informed decision, albeit at the expense of forgone current operational profits. A well-known result from options theory is that option values increase with both the volatility of returns and the option's time to expiration, i.e., the option, or product, life (Dixit and Pindyck, 1994; Trigeorgis, 1999). When a product's profitability is highly uncertain and a firm believes that new, clarifying, information may arrive in the near future, the value of postponing entry into a particular market may well exceed expected current returns from entering immediately.

The main differences between our model and that of Pakes (1986) is that we model entry, rather than exit, option, and that neither returns nor entry costs are observable which allows estimation of only their relative values. The model is also more parsimonious in terms of the number of parameters in order to accommodate the relative paucity of the data. Consider a biotechnology firm that at time $t=0$ acquires an option to market a GM crop that is protected by a patent of duration $T$.[5] The patent provides the firm with an exclusive right to market the crop, and therefore earn monopoly profits, during the patent's lifetime. We assume that, after the patent expires, the operating profits are competed away. At the beginning of each period $t=0,1,2,3,\ldots, T$, the firm must decide whether to introduce the crop (enter a market), provided it has not already done so, or to postpone the decision for at least another period. Upon introducing the crop at time $t$, the firm incurs a one-time sunk entry cost $C_t$, and acquires a stream of current and uncertain future operating profits realized each period over the lifetime of the patent, $\{R_t, R_{t+1}, R_{t+2},\ldots,R_T\}$. The distribution of $R_{t+1}$ conditional on all information known at time $t$ is a function of the current profit $R_t$ and time $t$.

Operating profits may be affected by two distinct classes of significant market events, one unfavorable and one favorable. First, with positive probability, operating profits may drop to zero and remain there for the rest of the product life.[6] This may occur, for example, if the GM crop has been proven to have harmful health or environmental effects, low yields, etc., or a new, superior substitute GM crop is introduced by a competitor or by the firm itself, or the market fails to honor property rights and producers take full possession of the GM seeds (replant instead of purchasing). Second, with complementary positive probability, operating profit remains positive for at least one more period. In this case, the profit either remains the same or rises to a new, higher level due to a favorable change, such as unanticipated liberalization of regulations governing the marketing of the GM crop or a surge in demand due to various causes. Let

$$\pi(R) = 1-\exp(-\theta R)$$

denote the probability that revenue remains positive next period, given that current revenue is $R$, and let

$$g(R,Z) = \max(R,Z),$$

with density $f(z)=\exp(-z/\mu)$, denote next period revenue, given that the current revenue is $R$, that the revenue remains positive, and that a revenue shock $Z>0$ is experienced, so that

$$R_{t+1} = \begin{cases} 0 & \textit{with probability } 1-\pi(R_t) \\ g(R_t, Z_{t+1}) & \textit{with probability } \pi(R_t) \end{cases}$$

The returns from marketing and the entry costs are only expressed as relative to each other because the data on the actual values of both are not available. The mean value of the initial returns is therefore normalized to one, and their distribution is assumed to be log-normal, with a scale parameter $\sigma$ and location parameter $-\sigma^2/2$ that ensures normalization.

Instead of introducing a depreciation parameter for the revenues, we make the model more flexible by introducing a depreciation/appreciation parameter for the entry costs because, in the case of GM crops, entry costs are likely to decline as more market entries of the same crop occur setting precedence and the associated property rights develop. Possible appreciation of the returns is complementary to entry cost depreciation in this setup and is likely due to increasing

[3] The distinction between patents on crops and broader patents on traits, events, genes, or gene inserting techniques is irrelevant to our analysis, as the model is about owning crops earning positive profits for a period of time as a result of patent protection, regardless of its breadth, i.e., whether it is the crops themselves or the traits from which the crops are derived. For a good review of IPRs in the industry, see Marco and Rausser (2008).

[4] Examples include inconclusive empirical research on profitability of Roundup-Ready soybeans and Bt corn prior to their introduction to the US market.

[5] Possible patent renewals are ignored in this analysis because, as described in the data section, hardly any of the patents on crops in our database have expired.

[6] The Guardian, 2004a,b.