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20. Temporal Uncertainty and Irreversibility - A Theoretical Framework for the Decision to Approve the Release of Transgenic Crops

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Chapter 20

Temporal Uncertainty and Irreversibility - A Theoretical Framework for the Decision to Approve the Release of Transgenic Crops

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Introduction

The scientific revolution in the biological sciences with its rapid advances in molecular biology offers great potentials for productivity gains in agriculture. Food crops that have higher yields and better nutrition content, plants that are resistant to drought and pests, livestock that are immune to disease, and fisheries that are sustainable, are possible developments which can result from the application of biotechnology (Krimsky and Wrubel 1996).

However, opposing the expected gains, there are risks related to the widespread use of transgenic crops. Gene flow in plants can enable domesticated plants to become pernicious weeds, or enhance the fitness of wild plants which might be serious weeds, thus shifting the ecological balance in a natural plant community. New viruses could develop from virus-containing transgenic crops. Plant-produced insecticides might have harmful effects on unintended targets. While some of these scenarios are highly unlikely, little is known about the overall impact that transgenic crops can have on biodiversity, ecosystem balance and the environment (Kendall et al. 1997).

Proponents of genetic engineering press for the rapid release of transgenic crops while opponents either reject the use of transgenic crops in general or want to postpone their release until further information on the related risks is available. An immediate release of a transgenic crop will provide immediate and future benefits through the positive effects on yields, product quality, production costs, and/or other characteristics of the crop.[2] On the other hand, an immediate release will expose society to potential environmental risk. Therefore, a decision to delay or reject a release delays or avoids those risks, but also the benefits of an immediate release. Any such decision includes, implicitly or explicitly, a comparison of costs and benefits. Even a decision which is based on the assumption that the risk cannot be estimated and therefore transgenic crops should not be released implicitly assumes that the expected risks are higher than the expected benefits. As decisions have to be made, most developed countries have established regulating agencies which approve the release of transgenic crops. The problem the government officials face is that if they decide to release the new crop and discover later that the transgenic crop has a negative impact on health and/or the environment, they may be able to prevent consumption and thus to reduce the impact on health, but they cannot retrieve the genes released into the environment. They may regret that they have allowed the release of the transgenic crop and did not wait until further information on the impact of this transgenic crop on health and the environment was available. On the other hand, every delay in release is a loss in the expected benefits. Therefore, the agency has not only to weigh the benefits of an immediate release against the expected risk but also against the option to delay the decision into the future.

This decision making problem can be described as one under temporal uncertainty and irreversibility (Sianesi and Ulph 1998, Wesseler and Weichert 1998). Temporal uncertainty exists because future prices, yields and other benefits as well as environmental risks of transgenic crops are uncertain; irreversibility exists as once transgenic crops are released, their genetic information cannot be gathered again.

Two similar approaches have been developed in parallel to model decision under uncertainty and irreversibility. In the literature on natural resources, Arrow and Fisher (1974) and Henry (1974) address the problem of irreversible environmental damages. They show that decisions based on traditional cost-benefit-analysis could result in socially non-optimal allocation of resources, if the value of delaying a decision and waiting for additional information is neglected. Arrow and Fisher call this the quasi-option value. At the same point in time, models to value financial options were developed (Black and Scholes 1973, Merton 1973) and later applied to several problems outside the financial economics literature.[3] This has been called the real options approach (Trigeorgis, 1996). Pindyck and Dixit (1994, 1995) suggest several application of the real option approach including policy decisions.

Sianesi and Ulph (1998) used a dynamic model to derive the optimal time path of growing transgenic crops including the socially optimal level of research and loss in bio-diversity under certainty. It can be expected that their results will change significantly, if uncertainty is included. Pindyck (1998) developed a model to analyze the optimal timing of environmental policies under uncertainty and irreversibility in the context of global warming.

The aim of this paper is to analyze the decision of the release of transgenic crops into the environment under uncertainty and irreversibility using the real option approach. Specifically, the following questions will be addressed:

- What are the impacts of temporal uncertainty and irreversibility on the decision to release transgenic crops?
- People have different views regarding the benefits from transgenic crops. Do these different perceptions influence the results in a significant way?
- What are the effects of certain parameter changes (policies) on the results? Do they increase or decrease the tendency to release transgenic crops?

By addressing this questions it is hoped to provide a theoretical framework for the decision to approve the release of transgenic crops. A simple continuous time stochastic model will be presented that addresses the questions. The different views about benefits from transgenic crops will be modeled using different stochastic processes and numerical changes of parameters and their impact on the results to address the third question.

The Model

The model will be developed by assuming a hypothetical agency that has to decide on the release of transgenic crops. The agencies' decision are based only on the benefits and costs related to the release of a transgenic crop as explained below. The political economy of the decision - making process is not considered in the model.

The agency considers as social benefits V only the additional benefits that result from the use of transgenic crops compared to non-transgenic crops (in the following called conventional crops) and as social costs I only the additional costs related to the release of transgenic crops. Strategic costs and benefits of the company requesting the release of the transgenic crop are ignored.[4] Further, the agency considers only domestic costs and benefits. Across border effects are ignored. The last two conditions were included to keep the model simple. Had they been omitted, the analysis would have been complicated by the need to allocate cost and benefits correctly, as the benefits and costs of a multinational company are not necessarily equivalent to those at the domestic market.

The additional social benefits of transgenic crops as compared to conventional crops are assumed to originate from changes in yields, prices and/or variable production costs under the assumption of perfect elasticity of demand and perfect non-elastic supply. Overhead costs are assumed to be the same for transgenic and conventional crops. Therefore, the additional benefits can be described by the difference in gross margin between transgenic and conventional crops. Positive environmental effects of transgenic crops and possible health effects due to the consumption of transgenic crops are assumed to be reflected in yields, prices and variable production costs. If, for example, soil erosion is reduced due to the practice of zero tillage in combination with a herbicide like *Round-up*[â] and a *Round-up*[â] resistant crop, positive on-site effects would result in a higher yield of the crop and/or less use of fertilizer. Also, possible health effects of transgenic plants are assumed to result in price adjustments, assuming that consumers are informed about the health effects through, e.g., labeling of the products.

Additional welfare benefits arising from the application of the new technology through "peace of mind" (Monsanto, 1998, p. 4) are assumed to be balanced by concerns about the new technology.[5]

The irreversible costs of the release of transgenic crops are assumed to be the loss in biodiversity (Mooney and Bernardi 1990, ACRE 1997, Tiedje et al. 1980). For tractability of the model, it is assumed that the irreversible costs *I* are known with certainty at the time when the decision is made. Further, it is assumed that the conditions for contingent claim analysis are fulfilled.[6]

Uncertainty about the irreversible costs could also be included in the model but would result in two major problems. One is to identify a suitable stochastic process for the costs of biodiversity. The second is to justify the use of contingent claim analysis for loss in biodiversity, as the necessary spanning asset will be difficult to find. The alternative use of dynamic programming leads to the problem of identifying the correct discount rate (Wesseler and Weichert 1998).

Bearing in mind the assumptions described above, the objective of the regulatory agency can simply be described as maximizing the value *F(V)* of the decision to release transgenic crops:

(1) $$F(V) = \max E\left[\left(V_T - I\right)e^{-mT}\right],$$

with *E* the expectation operator, V_T the present value of the incremental benefits at the time of release *T*, *I* the irreversible costs and *m* the discount rate. V_T is the present value of the benefits from the release of transgenic crops.

In the following it will be assumed that the uncertain benefits *V* follow a stochastic process. As there are different views about the benefits of transgenic crops, two main views will be modeled using two different continuous time stochastic processes.

Views on Costs and Benefits

The Optimist

One view can be described as assuming that transgenic crops will generate continuously increasing but stochastic benefits. A person who takes this view will here be defined as the optimist who trusts in scientific progress.

According to the optimist, the benefits *V* follow a stochastic process with a positive trend. As commonly done, the stochastic process will be assumed to be a geometric brownian motion. More specifically:

(2) $$dV = aVdt + s\,Vdz$$

where a is the trend variable, s is the standard deviation and *dz* is a brown-wiener process.

This optimistic view about the benefits from transgenic crops will not necessarily result in a decision to immediately release them. It has been shown elsewhere (McDonald and Siegel 1986), that by assuming $F(V) = AV^{b_1}$ the optimal value of V for a decision under temporal uncertainty and irreversibility, where benefits follow a geometric brownian motion, will be of the form:

$$(3) \qquad V^* = \frac{b}{b-1} \cdot I, \qquad \text{with}$$

$$b = \frac{1}{2} - \frac{r-d}{s^2} + \sqrt{\left[\frac{r-d}{s^2} - \frac{1}{2}\right]^2 + 2r/s^2} > 1,\ b > 1,$$

where r is the risk-free interest rate, and d the difference between the discount rate m, which is the risk adjusted market rate of return and the trend α.

If the irreversible costs I are set $I=1$, equation (3) shows that the benefits from the release of transgenic crops have to be higher by the factor $b/(b-1) > 1$ to justify an immediate release from the economic point of view, whereas the traditional cost-benefit-analysis would suggest an immediate release if $V^* \geq I$ (Abel et al., 1996). Thus, neglecting the value of the option to delay the release of transgenic crops can result in the wrong decision to release them immediately.

The Pessimist

The optimist's model assumed a continuous increase in benefits through transgenic crops. Critics argue that benefits, if at all, will be only available for a short period of time. Weeds and pests become resistant to the herbicides and crop produced pesticides and this much faster than previously expected (e.g. Bergelson et al. 1998, Haung et al. 1999). This pessimistic view about transgenic crops can be modeled by assuming a mean-reverting process with respect to benefits, where initial additional benefits V from transgenic crops decrease over time until they become zero:

$$(4) \qquad dV = h(\overline{V} - V)Vdt + sVdz$$

where h is the speed of mean reversion, $\overline{V}$ the value to which V tends to return, in the following set to zero assuming no additional benefits after some years, and V is the value of the initial additional benefits through the introduction of transgenic crops.

An approach to find the optimal hurdle is provided by Dixit and Pindyck (1994: 161-167). Defining the option function $F(V)$ as:

(5) $$F(V) = AV^{q}H\left(\frac{2h}{s^{2}}V;q,b\right)\text{; with}$$

$$q = \frac{1}{2} + \left(m - r - h\overline{V}\right)/s^{2} + \sqrt{\left[\left(r - m + h\overline{V}\right)/s^{2} - \frac{1}{2}\right]^{2} + 2r/s^{2}}$$

where *A* is a constant and *H(...)* a hypergeometric function. Analytical solutions for *V** do not exist but can be found numerically.

The Optimist Versus the Pessimist

To get some insights into the optimist's and the pessimist's view on the immediate release of transgenic crops, *guesstimates* for the different parameters are used. Following common practice, the discount rate *m* is assumed to be 8%, the risk-free rate of return *r* to be about 4% and the standard deviation *s* to be 20% (Dixit and Pindyck 1994). The average growth rate *a* (optimist model) is expected to be 4%, a rather low value, whereas the immediate benefits from transgenic crops (pessimist model) are assumed to be in the order of 20%. Further, it is assumed that the speed of mean-reversion will be approximately 7 years.

Using these *guesstimates* provides interesting results (see Table 1). The critical value *V**, the factor by which the benefits have to exceed the irreversible costs, is in the order of two for the optimist. The benefits have to be two times the irreversible costs to justify an immediate release of transgenic crops. Surprisingly, the hurdle rate of the pessimist model is much lower. The benefits only have to exceed the irreversible costs by a factor of 1.07. Therefore, the pessimist would tend to justify a release earlier than the optimist. This result holds for other reasonable parameter values as well (see Table A1 and Table A2 in the appendix).

TABLE 1 Hurdle Rate V* for Given Parameter Values

parameter	**optimist**	**pessimist**
discount rate, *m*	0.08	0.08
risk-free RoR, *r*	0.04	0.04
standard dev. *s*	0.20	0.20
trend α	0.04	
mean-reverting, *h*		0.76
Hurdle rate *V**	**2.00**	**1.07**

This observation can be explained by the fact that under increasing stochastic benefits a later release reduces the risk of negative net benefits because of the positive trend, whereas the mean reverting process has no positive trend effect to counterbalance downside risk.

Therefore, three areas are of importance. The first area is the one where both models suggest an immediate release of transgenic crops. That is where even under an optimistic view the benefits are above V^*. The second area is where a pessimistic view suggests an immediate release whereas an optimistic view suggests a delay. The third area is where even a pessimistic view suggests a delay of the release.

Effects of Parameter Changes and Regulatory Policies

In the following, policies to regulate the release of transgenic crops are discussed with respect to their impact on the parameter values of the two models. The effects of such policies are summarized in Table 2.

TABLE 2 Effects of Parameter Changes on the Hurdle Rate

parameter	optimist	Pessimist
- decrease discount rate	increase	Increase
- increase in risk	increase	Increase
- decrease in benefits	decrease	Ambiguous
- decrease in h		Ambiguous

One common policy option is to tax the cultivation of transgenic crops and to use the tax returns for compensation of potential environmental damages. This policy will reduce the net-benefits from transgenic crops. An ex-ante tax can be modeled as a decrease in dV and hence a decrease in the trend and the risk parameter in the optimistic model. Both parameter changes result in a decrease of the hurdle rate and therefore increase the tendency to release transgenic crops earlier. The impact of a tax assuming a mean-reverting process is ambiguous. A decrease in benefits decreases, c.p., the value of h. As the Table A2 shows, lowering the value of h first decreases V^* and, as h becomes sufficiently small, increases V^*. It will depend on the initial parameter values and the taxation whether the hurdle rate will decrease or increase.

The same results hold for a set-aside policy where for every acre of transgenic crops farmers are requested to cultivate x acres of conventional crops to provide refuge areas, as this policy reduces the benefits from transgenic crops as well.

The assumed discount rate of 8% is fairly high. Many economists and non-economists have argued to use a low discount rate for investments which affect public interests. If the discount rate is reduced, the hurdle rate in both models increases. Further, an increase in the risks of the benefits, e.g. by further trade liberalization in agriculture, will increase the hurdle rate as well.

Conclusions

Temporary uncertainty and irreversibility are two important characteristics of the benefits and costs related to the release of transgenic crops into the environment. The economic literature on real option pricing theory has shown that under temporary uncertainty and irreversibility an additional value, the value of the option to delay the decision, has to be included as an additional cost into the traditional cost-benefit framework. Therefore, decisions on the release of transgenic crops that are based on the traditional cost-benefit framework may be wrong.

The two stochastic processes used to model the benefits of transgenic crops reveal important results. Under an optimistic view about transgenic crops, which was modeled by assuming a geometric brownian process, the benefits have to be much higher to justify an immediate release than under a pessimistic view, which was modeled by assuming that benefits follow a mean-reverting process. The difference in the results shows that it is not only important to include the option of delaying the release of transgenic crops into the cost benefit analysis, but also that the result will depend to a large extent on the assumptions about the benefits from transgenic crops in the longer run.

The results also provide a puzzle for proponents and opponents of transgenic crops. Those who are pessimistic about the benefits would require a lower hurdle rate than those who are optimistic about transgenic crops. Pessimists would, c.p., tend to release a transgenic crop earlier than optimists.

Effects of parameter changes under an optimistic view show that policies like taxation of transgenic crops or mandatory refuge areas decrease the benefits and the hurdle rate and therefore support an earlier release. The effects of parameter changes are ambiguous modeling a pessimistic view.

So far, parameter values of the model are based on *guesstimates*. Further research should be conducted to estimate the parameters empirically. Fortunately, the necessary data are available. Time series data on the returns from crops where genetically modified seeds have been introduced would allow to estimate the trend variable a as well as the standard deviation s. The discount rate m and the risk less rate r can be estimated from time series of the futures market. There are also several on-going and completed studies on the economic measurement of biodiversity that can provide information on irreversible costs.

The quantification of benefits and costs of releasing transgenic crops, even if not all of them can be monetized, provides a useful step to improve the decision making of regulatory agencies. Even though the impact of the decision on the life-science industry is not included in the model, it provides a first step towards establishing the necessary theoretical framework for analyzing policy decisions related to the release of transgenic crops.

Appendixes

TABLE A1 Hurdle Rates V* for Different Parameter Settings Assuming a Geometric Brownian Process

trend	discount rate m[a]				standard deviation s[b]				
a	0.10	0.08	0.06	0.04	0.10	0.2	0.4	0.8	1.2
0.01	1.3333	1.4678	1.7403	2.4574	1.1429	1.4678	2.4843	6.0484	11.8088
0.02	1.3904	1.5774	2.0000	3.4142	1.1896	1.5774	2.7583	6.9034	13.6177
0.04	1.5774	2.0000	3.4142	****	1.4215	2.0000	3.7321	9.8990	19.9499
0.06	2.0000	3.4142	****	****	2.4254	3.4142	6.7016	18.8941	38.9487
0.08	3.4142	****	****	****					

[a]The standard deviation *s* is set to 0.2 and the risk-free rate of return *r* to 0.04.
[b]The expected rate of return *m* is set to 0.08 and the risk-free rate of return *r* to 0.04.
Source: own calculations.

TABLE A2 Hurdle Rates V* for Different Parameter Settings Assuming a Mean-Reverting Process

mean-reverting	discount rate m[a]				standard deviation s[b]				
speed h	0.10	0.08	0.06	0.04	0.10	0.2	0.4	0.8	1.2
0.05	1.1710	1.2037	1.2500	1.3173	1.1710	1.2037	1.2500	1.3173	4.6004
0.10	1.1211	1.1371	1.1579	1.1856	1.1211	1.1371	1.1579	1.1856	3.6131
0.20	1.0760	1.0822	1.0894	1.0980	1.0760	1.0822	1.0894	1.0980	2.8085
0.30	1.0552	1.0586	1.0620	1.0661	1.0552	1.0586	1.0620	1.0661	2.4233
0.40	1.0433	1.0453	1.0474	1.0498	1.0433	1.0453	1.0474	1.0498	2.1871
0.50	1.0363	1.0376	1.0390	1.0405	1.0363	1.0376	1.0390	1.0405	2.0235
0.60	1.0349	1.0360	1.0370	1.0380	1.0349	1.0360	1.0370	1.0380	1.9032
0.70	1.0452	1.0463	1.0474	1.9557	1.0452	1.0463	1.0474	1.9557	1.8082
0.80	1.1010	1.1184	1.5122	1.9944	1.1010	1.1184	1.5122	1.9944	1.7319
0.90	1.2540	1.3650	1.5691	1.9990	1.2540	1.3650	1.5691	1.9990	1.6690
1.00	1.2824	1.3852	1.5753	1.9997	1.2824	1.3852	1.5753	1.9997	1.6162

[a]The standard deviation *s* is set to 0.2 and the risk-free rate of return *r* to 0.04.
[b]The expected rate of return *m* is set to 0.08 and the risk-free rate of return *r* to 0.04.
Source: own calculations.

Endnotes

[1]J. Wesseler is a consultant working in the field of agricultural and environmental resource economics. The author wishes to thank the Institute of Horticulture Economics at Hanover University, Germany for supporting this research project.

[2]If there were no direct benefits, there would be no incentive for farmers to buy the seeds of transgenic crops.

[3]Merton (1998) provides review on application of option pricing models outside the financial economics literature.

[4]I also question if the impact on the company asking for approval should be included into the analysis at all, as in the long run the company can put the government under pressure.

[5]Monsanto (1999) cites as one positive benefit from transgenic crops the positive mental effect on users, because of the positive impact of transgenic crops on the environment. They call this kind of benefits *"peace of mind."*

[6]For the assumptions on contingent claim analysis see e.g. Duffie (1992).

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