Incentive Design for Introducing Genetically Modified Crops

by

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Abstract

The introduction of genetically modified (GM) crops raises several issues. This paper looks at incentives required to reduce problems of illegal and improper use of GM proprietary technology used in growing GM crops. A simple model of producer behaviour describes some key influences of a farmer's response to GM crops. The model is illustrated using the example of INGARD® cotton grown in Australia. The key findings are that legitimate adoption of a GM crop by a farmer depends on their attitude to risk, the relative profitability of growing the GM crop, the probability of detection of illegal or improper use of the GM crop and the severity of fines successfully imposed for fraud or contract breaches. In the case of INGARD® cotton the problem of illegal and improper use of the technology can be addressed with modest changes to some of these factors.

1. Introduction

Agricultural applications of the commercialisation of gene technology have increased rapidly in the 1990s (Riley and Hoffman, 1999). Adoption of genetically modified (GM) crops has been rapid in the United States and large areas are sown to GM crops in Brazil, China and Argentina. For example, in the United States by 1998 approximately 38 per cent of the soybean acreage and more than 40 per cent of the cotton area was planted to GM varieties (Carpenter and Gianessi, 1999; USDA/ERS, 1999). In Canada by 1998 GM varieties of canola accounted for 44 per cent of the area planted to canola (Fulton and Keyowski, 1999).

Most GM seed currently used by farmers offers benefits of pest and weed control. Examples include Roundup Ready® soybean and corn, Bt cotton and corn, Buctril herbicide resistant cotton and Liberty herbicide resistant corn. The on-farm benefits of these crops include decreased pest management costs, increased yields and greater crop production flexibility, although these benefits vary across regions (Klotz-Ingram et al, 1999).

To generate a commercial return on their R&D investment in developing and protecting gene technology most biotechnology companies are licensing or contracting the use of their GM products. For example, Monsanto imposes contractual obligations on growers opting to use their GM products. Growers are not allowed to retain seed. Growers must allow Monsanto or its nominee access to the farm's management records and access to the fields in which the GM crops are growing, in order to inspect and test those crops. This right of inspection lasts for up to three years after the last planting of the GM crop. Further, in the case of Roundup Ready® crops no other glyphosate chemical can be used other than Roundup®. Growers are required to pay technology fees to the seed company that in turn passes these to Monsanto in return for receipt of a handling fee. These technology fees or seed premiums are typically subject to discounting based on early purchase, volume discounts and package deals for other seed or chemical products sold by the same company (Hayenga, 1998).

However, this revenue received by gene technology developers is at risk of "piracy" by potential users. This piracy can stem from other gene technology developers illegally obtaining information and genetic products that are then incorporated in competitive R&D activity (Barton, 1998). The piracy can also come from growers using GM seed illegally. Lindner (1999), for example, indicates Monsanto, as at February 1999, had full-time Pinkerton investigators dealing with 525 cases of suspected infringement and their workload was increasing. His understanding is that the costs of enforcement will far outweigh payments for settlement of proven infringement. A related comment by Wright (1996) is that: "In a decentralised competitive farming sector, policing of replanting by farmers seems to be a challenge. Private wheat seed markets are reported to thrive only in parts of the United States where farmers have no on-farm storage." (p. 573).

Policing piracy is necessary for commercial as well as legal reasons. It needs to be cost-effective with the risk of detection and prosecution of piracy being sufficiently large to protect the profits of the companies rightfully selling the GM seed and associated crop inputs. Policing piracy may also be a necessary part of supply-chain management, to ensure identity preservation of GM and non-GM crops. Consumer and producer concerns surrounding the food and environmental safety of GM crops is requiring increased investment in the integrity of supply-chains to ensure identity preservation (Lalaitzandonakes and Maltsbarger, 1998). Also community concerns about GM crops and GM foods is causing many governments to review their GM policies and to increase the regulation of gene technology. For example, the draft Gene Technology Bill in Australia empowers a Gene Technology Regulator (ADHAC, 2000) to license, inspect premises, search and seize, monitor, enforce and prosecute breaches of the Act.

This paper develops a simple model of producer behaviour regarding the availability of a GM crop and examines the role of incentive design in influencing farmer adoption of the GM crop. The model is used to illustrate the importance of illegal and improper use of GM technology that represents a leakage of technology fees to gene technology developers. The approach in this paper is drawn from studies of compliance to environment schemes. In particular this study initially follows the approach of Latacz-Lohmann and Webster (1999) who examined non-compliance in agri-environmental schemes in Europe. Their approach is extended to consider yield risk and risk aversion and is applied to GM crops.

2. A Model of Producer Response to GM Crops

To grow a GM crop typically requires a farmer to agree to license or contract obligations that oblige the farmer to undertake a series of actions and purchases as part of their production of the GM crop. Often farmers are required to participate in a closed marketing loop whereby they sell all grain harvested from the GM crop to a single firm. Often they are required to use particular chemicals at particular times and to adopt particular management practices such as planting buffer or refuge crops. This set of contractual activities can be represented as n activities forming the set A where $A= \{a_1, a_2, \ldots, a_n\}$. The annual cost of this set of activities, in some cases offset through receipt of cost-savings (eg less herbicide or pesticide used), can be stated as C_a, and the income associated with sale of the GM crop is Y_a.

Occasionally the management records and practices of a farmer may be investigated to ensure the farmer complies with required practices. Violation of the contractual agreement can be represented as a set of activities C where $C = \{c_1, c_2, \ldots, c_m\}$. This differs from set A. The probability of violation detection can be represented by $p(V)$ and the penalty for violation, as specified in the licence agreement, is V. If use of GM seed is governed by contract law then legal judgements regarding contract violations and liabilities will specify V. In practice, V could be a fixed fine or some function of the revenue or profit from growing the GM crop (e.g. $V=f(Y_a\text{-}C_a)$).

Employing the terminology of Latacz-Lohmann and Webster, farmer behaviour can be modelled as *amoral calculation*. Assuming a farmer is a risk-neutral *amoral calculator* indicates that the farmer's chief interest is profit. The farmer will abide by or break agreements whenever it is profitable. This assumption allows this behavioural extreme to be a benchmark case.

Thus, the farmer's decision problem can be stated as maximising profit by selecting among the following choices:

> Option 1: Legitimately adopting the GM crop and generating profit, π_A. This requires utilising activity set A with $\pi_A = Y_a\text{-}C_a$.
>
> Option 2: Not adopting the GM crop and generating profit, π_B. To generate this profit involves utilising the activity set B where $\pi_B = Y_b\text{-}C_b$ and $B = \{b_1, b_2, \ldots, b_m\}$. In this case set B includes activities required to grow a traditional non-GM crop.

Option 3: Using the GM crop illegally. There are two main cases in option 3. Firstly, a farmer may sign the contract to grow the GM crop yet may knowingly or unwittingly not abide by all its terms and conditions. This farmer's actions are represented by the activity set C where $C = \{c_1, c_2, \ldots, c_m\}$ and the farm generates profit π_C where $\pi_C = Y_c\text{-}C_c$. The expected profit can be expressed as:

$$E(\pi_C) = \overline{\pi}_C - p(V_C)V_C \qquad (1)$$

where π_C is the optimal profit generated by utilising activity set C, the penalty for scheme violation is V_C and the probability of detection is $p(V_C)$.

Secondly, a farmer may opt to not become a licensee yet the GM seed is obtained and used illegally. In this case no contract would be signed and the farmer's actions are activity set D, the penalty for scheme violation is V_D and the probability of detection is $p(V_D)$. Expected profit can be expressed as:

$$E(\pi_D) = \overline{\pi}_D - p(V_D)V_D \qquad (2)$$

Typically $p(V_C) > p(V_D)$ because a licensee, through contractual obligations involving external monitoring and scrutiny, would be more likely to have their contract breaches noticed than a farmer about whom a licensor would have no initial suspicion of illegal use of GM technology. Practical evidence of $p(V_C) > p(V_D)$ is the fact that measures such as toll-free tip lines accompany large scale introduction of some GM crops; in effect encouraging illegal users of GM crops to be identified by members of their communities.

A licensor and, if applicable, a national GM regulator may also seek greater legal and social redress from farmers who are not licensees and who illegally grow the GM crops. For example, for GM canola in Canada, Monsanto pays for radio advertisements that name farmers who have been caught saving seed (Lindner, 1999). Also the draft Gene Technology Bill in Australia includes a feature of publishing the names of offenders (eg those illegally growing GM crops).

In the United States some illegal users are prosecuted vigorously in order that publicity about their cases acts as a deterrent to others. So in practice, it is likely that $V_D > V_C$. However, for the purpose of illustration, the decision problem in Figure 1 portrays V as a linear function of $Y_a\text{-}C_a$ and does not discriminate between licensees who act improperly and those illegally acquiring GM seed and growing the GM crop.

{Figure 1 about here}

As shown in Figure 1 if the net returns from legitimate adoption are greater than $Y''_a\text{-}C''_a$ then legal fully compliant adoption is the preferred option for the risk neutral farmer. However, for returns in the range $Y'_a\text{-}C'_a$ to $Y''_a\text{-}C''_a$ the farmer would prefer to either improperly or illegally use the GM technology. In practice this might mean illegally obtaining or retaining and using GM seed, falsifying records or failing to adhere to various practices. Because $p(V_C) > p(V_D)$ and given V is an assumed linear function of $Y_a\text{-}C_a$, then in the range $Y'_a\text{-}C'_a$ to Y^*_a-

C^*_a the legal yet improper use of the GM technology is preferred. From Y^*_a-C^*_a to Y''_a-C''_a the illegal use of the technology is preferred.

For the farmer to accept the gamble that their violations will be detected, as shown in Figure 1, then *p(V)* and *V* must be sufficiently small to provide the required incentive. If returns are less than Y'_a-C'_a then the farmer would rather not adopt the GM crop.

The above decision problem highlights a few areas in which adoption of GM crops by risk neutral farmers can be influenced and the illegal and improper use of proprietary technology can be reduced. The options are to increase *p(V)* or *V* or both. As shown in Figure 1 if *V* is a function of Y_a-C_a then increasing the difference between $Y_a$and C_a will increase *V*. Increasing Y_a-C_a can be achieved in various ways. For example, a rigorous scrutiny of the activity elements of set *A* may reveal better, fewer or cheaper ways to grow successfully the GM crop and therefore reduce C_a. The size and nature of the technology fees charged by the owners or licensors of the GM technology is obviously an important component of C_a.

The proprietary technology may enable farmers to increase Y_a, by higher yields through better pest and weed control, better supply-chain management and improved marketing. Assuming the increase in Y_a is also associated with increases in Y_a-C_a and that *V* is positively related to Y_a-C_a as in figure 1, then the greater size of *V* is a further disincentive for illegal and improper use of the proprietary technology. Also, in the future if price premia for GM crops arise, due to their quality improvements, then Y_a may increase.

Increases in *p(V)* are possible through a range of measures such as the licensor allocating more resources toward surveillance, rewarding those who inform against illegal use of GM products and widely broadcasting news about prosecutions. The purpose of such litigation would be twofold; firstly to ensure the cost to a farmer of being detected (*V*) was very high and secondly to publicise this cost and to create the impression that the owners of the GM technology property rights were keen to detect breaches of their proper use (i.e. *p(V)* was not negligible). Further, increases in *p(V)* may be possible due not to the actions of the owners of the GM technology but rather due to the actions of either regulators or purchasers of non-GM crops and crop products. To maintain consumer confidence in the integrity of the non-GM status of their products some purchasers may insist on testing the grain or product delivered to them, thereby increasing the likelihood of detecting growers who use non-GM marketing channels to sell their illegally grown GM crops. Failure of growers to supply non-GM grain or product could result in fines or dockages. Some government regulators may also engage in monitoring, inspection, policing and prosecution to safeguard community concerns about the food and environmental safety of GM crops. Hence, with such activities *p(V)* and *V* could be sufficiently high to deter the illegal growing of GM crops.

Increases in *p(V)* or *V* cause the lines π_C and π_D in Figure 1 to pivot downwards from the points where they intersect the vertical axis (farm profit). Eventually the farmer is restricted to choosing across a range of Y_a-C_a values to either legitimately adopt or not adopt the GM crop. Thus it is possible to remove the problem of illegal and improper use of GM technology by setting *p(V)* and/or *V* high enough. The effect of raising *p(V)* and/or *V* would cause lines π_C and π_D in Figure 1 to eventually pass through point P. Only at this point would the farmer be indifferent between not adopting or legitimately adopting the GM crop.

In the preceding model the only risky decision involved the probabilistic gambles of option 3. A risk-neutral farmer would avoid illegal and improper use of GM technology if $\pi_A > \pi_C$ and

$\pi_A > \pi_D$. However, for a risk-averse farmer contemplating adoption of GM crops, a range of uncertainties exist. The impact of such uncertainties will influence their adoption decisions. For such a farmer to avoid illegal and improper use of GM technology:

$$E(U(\pi_A)) > E(U(\pi_C)) \text{ and } E(U(\pi_A)) > E(U(\pi_D)) \qquad (3)$$

As shown in the appendix equation (3) may hold for a risk-averse farmer but not $\pi_A > \pi_C$ and $\pi_A > \pi_D$ due to the possibility of there being a greater variance of income associated with illegal use of GM crops. That is, although expected profit from the legal use of a GM crop may be less than expected profit from illegal use of the crop, a risk-averse farmer may still prefer the legal use of the crop due to the dominating effect of profit variance.

Hence, to reduce illegal and improper use of GM technology, there is a range of factors to consider. Included are the relative profitability of growing the GM crop, the probability of detection of improper or illegal use of the GM crop, the probability of successful prosecution surrounding such uses of GM seed, the severity of fines for fraud or contract breaches and the risk attitude of the farmer. In the next section the relative importance of these factors is illustrated using the Australian example of INGARD® cotton.

3. A Numerical Illustration: INGARD® cotton

The problem of illegal and improper use of GM technology and the responses to it can be illustrated using the case of INGARD® cotton grown in Australia. The parameter values used in the numerical analysis are outlined in Table 1.

{Table 1 about here}

Complementing these parameter values in Table 1 is the risk attitude of the farmer. A farmer's attitude to risk can be represented by the mean-variance formulation of expected utility[1]:

$$E(U(\pi)) = U(E(\pi)) + \frac{1}{2}U''(E(\pi)).Var(\pi) \qquad (4)$$

where,

$U(\pi)$ is the utility function of profit and $U'(\pi)>0$ and $U''(\pi)<0$.

Following Fraser (1991) the farmer's utility function of profit can be represented by the constant relative risk aversion form:

$$U(\pi) = \pi^{1-r} /(1-R) \qquad (5)$$

where:

$R = -U''(\pi)\pi / U'(\pi)$ and

R is the farmer's coefficient of relative risk aversion.

[1] See Hanson and Ladd (1991) for arguments supporting this approach.

Table 2 shows the expected profit, variance of profit, expected utility and farm management decisions for a range of risk attitudes, given the parameter values in Table 1. The results in Table 2 are the base case findings. The results show the importance of risk attitude in influencing farmer behaviour. Risk neutral or slightly risk averse farmers, as *amoral calculators,* would use illegally the GM crops. Moderate and highly risk averse farmers would accept and abide by INGARD® technology agreements. In adopting this technology this latter group of farmers would experience lower expected profits but less profit variance. The switch in farmer behaviour from preferring illegal use to lawful adoption of the INGARD® technology, as risk aversion increases, illustrates the potential dominating effect of profit variance as outlined in the Appendix.

{Table 2 about here}

In the model of producer response outlined in the previous section, there are various factors that influence farmer behaviour regarding the adoption of GM crops. Sensitivity analysis reveals how these factors affect the illegal and improper use of the GM technology by farmers. For example, for the base case parameters, the results in Table 2 show the problems of illegal and improper use decrease with increasing risk aversion. Results in Table 3 also show the role of the probabilities of detection, the severity of fines, the cost of the INGARD® technology agreements and the cotton price in influencing producer reactions to the INGARD® technology.

{Table 3 about here}

For producers with R=0.1, only relatively small changes in the probabilities of detection, the severity of fines, the cotton price and the cost of the INGARD® technology agreements are needed to overcome the problem of illegal use. However, it also is worth noting that for producers with R=0.5 or R=0.9, similarly small changes in the probabilities of detection, the severity of fines, the cotton price and the cost of the INGARD® technology agreements can stimulate illegal use of the technology.

The results in Table 3 point to only modest changes in one or a combination of the following being necessary to form an incentive-compatible policy to address the problems of illegal and improper use: the probability of detection, the fine severity and the cost of the INGARD® technology. Although the cotton price will also influence producer behaviour, in practice it is unlikely to be accessible to control.

To-date Monsanto has shown its preparedness to adjust its INGARD® technology fee. Initially in Australia the fee was set at $245 per hectare. Subsequently the fee was lowered by $35 per hectare and in 1998 the fee was further adjusted to be effectively $155 per hectare. These changes in the technology fee were not a response to any perceived problems of improper or illegal use of the INGARD® technology. Rather the fee reductions were in response to growers' mixed experience concerning the profitability of the technology (Clark and Long, 1998; Pyke, 1998). However, it could be inferred that such reductions in the technology fee would have lessened the likelihood of the problems of illegal and improper use alluded to in this paper.

Most studies of the risk attitude of Australian farmers (Bardsley and Harris, 1987&1991; Abadi, 1999) reveal a range of risk attitudes, with the majority being identified as slight to moderately risk averse. If a similar range applies to cotton farmers then the problems of illegal and improper use could be addressed by relatively small changes in factors such as the technology fee and the severity of fines.

4. Conclusions and Limitations

The increased commercialisation of gene technology is giving rise to a greater array of GM crops. As pointed out in this paper, there is a potential problem of illegal and improper use associated with the release and adoption of GM crops in farming communities. To generate a commercial return on their R&D investment most biotechnology companies are licensing or contracting the use of their GM technology. The revenue received by these companies however, is at risk of "piracy" by potential users.

In this paper two forms of grower piracy are considered; growers who use GM seed illegally and growers who fail to comply with technology agreements and thereby lessen the revenue flow to the licensor. A model of producer response to GM crops is developed that outlines these problems and the factors influencing them.

This model is illustrated using the example of INGARD® cotton grown in Australia. Ingredients of the mechanism design to reduce the problems of illegal and improper use of GM technology are illustrated. Results show that these problems are likely to increase with decreasing risk aversion. As risk aversion decreases there is a switch in farmer behaviour away from the lawful adoption of the INGARD® technology, due to the declining influence of profit variance. Results point to only modest changes in the probability of detection of illegality, the fine severity and/or the cost of the INGARD® technology being necessary to form an incentive-compatible policy to address the problem of illegal and improper use. Although such changes can address this problem, this paper has not extended the analysis to consider the costs to the biotechnology companies of implementing these changes, in spite of the changes potentially being small. The producer model that underpins the analysis also has not been extended to consider other sources of uncertainty and differences between farms (apart from risk attitude). Further the model does not account for the ease with which the GM technology can be obtained illegally or used improperly. In the case of cotton farming, farmer-saved seed is not the norm so policing cotton seed sales is fairly simple. However in canola production, use of farmer-saved seed is common so the opportunity to illegally obtain or retain GM canola seed might be greater and therefore the costs of policing could be higher.

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Appendix: Income variance associated with the illegal use of a GM crop

Consider the impact of yield risk upon the issue of moral hazard for a risk-averse farmer. Such a farmer's profit per hectare from illegal use of a GM crop is:

$\pi_{ND} = py - c$ where *p* is the fixed price of grain, *y* is the uncertain crop yield and *c* is the fixed per hectare cost of production and no detection of illegal use occurs and,

$\pi_D = py - c - f$ where detection occurs and a fine, *f*, is imposed.

Given the probability of detection is *r* then the farmer's expected profit from illegal use is:

$$E(\pi) = p\bar{y} - c - rf \qquad (1\text{-}1)$$

and the variance of profit is:

$$Var(\pi) = \int^{y} (1-r)((py-c) - E[\pi])^2 f(y)dy + \int^{y} r((py-c-f) - E[\pi])^2 f(y)dy \qquad (1\text{-}2)$$

After substituting for $E[\pi]$ using equation (1-1), equation (1-2) can be re-expressed and simplified to:

$$Var(\pi) = p^2 Var(y) + rf^2(1-r) \qquad (1\text{-}3)$$

For a farmer not engaged in any illegal use of a GM crop their expected profit is:

$$E(\pi_L) = p\bar{y} - d$$

where *p* is the fixed price of grain, *y* is the uncertain crop yield and *d* is the fixed per hectare cost of production.

Their profit variance is:

$$Var(\pi_L) = p^2 Var(y) \qquad (1\text{-}4)$$

Note that comparing equations (1-3) and (1-4) reveals that:

$p^2 Var(y) + rf^2(1-r) > p^2 Var(y)$ due to $0 < r < 1$ and $f > 0$.

Hence the profit variance associated with the illegal use of the GM crop exceeds that for the legal use. Thus even if the expected profit from the legal use of the GM crop does not exceed that from its illegal use, a risk-averse farmer may still prefer the legal use of the crop because of the dominance of income variance in the farmer's selection decision.

Table 1: Parameter values for the numerical analysis

		Conventional	INGARD®	Improper use	Illegal use
Cost of production	$/ha	541	384	354[a]	354[a]
Technology fee	$/ha	-	155	155	-
Yield	t/ha	1.516	1.526	1.526	1.526
	variance	0.0231	0.0246	0.0246	0.0246
Cotton price	Aus c/kg	230	230	230	230
Probability of detection				0.3	0.06
Severity of fine	$/ha			1000	2500

Note: [a] Excludes any fine associated with detection of improper or illegal use. This estimate assumes some cost-savings by farmers through to use of cheaper inputs and avoidance of some management costs (eg provision of refuges).

Sources: Yield data came from Table 58, NSW lint yield 1984 to 1997, *Australian Commodity Statistics 1998* (ABARE 1998). Price data came from Table 62, Australian raw cotton prices 1984 to 1997, *Australian Commodity Statistics 1998* (ABARE 1998). Production costs are based on published farm surveys of Australian cotton growers (Pyke, 1998; Clark and Long, 1998).

Table 2: Base case findings

	Management Choices				
	Conventional	INGARD	Improper use	Illegal use	*Optimal decision*
E(π)	2946	2989	2701	3006	
Var (π)	122199	130134	340134	482634	
E(U(π)) (R=0.1)	1472	1491	1359	1496	Illegal use
(R=0.5)	108.6	109.1	103.3	108.9	INGARD® use is slightly preferred
(R=0.9)	22.23	22.25	21.99	22.22	INGARD® use is slightly preferred

Table 3: Sensitivity analysis of problem of illegal production of GM crops

Switching values of[a]	Unit	Risk attitude			Difference from base case		
		(R=0.1)	(R=0.5)	(R=0.5)	(R=0.1)	(R=0.5)	(R=0.9)
Fine for illegal use	\$/ha	2671	2354	2149	171	-146	-351
Probability of detection of illegal use	no.	0.064	0.056	0.050	0.004	-0.004	-0.010
Technology fee	\$/ha	144	167	190	-11	12	35
Cotton price	c/kg	231	229	228	1	-1	-2

[a] These are the parameter values that cause $E(U(\pi_A)) = E(U(\pi_D))$ in equation (3). In words, the farmer is indifferent between accepting and abiding by the terms of the INGARD® technology agreement or using the technology illegally.

Figure 1: An illustration of the farmer's decision problem