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Monopolization and the regulation of genetically modified crops: an economic model

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ABSTRACT. Although genetically modified organisms (GMOs) have recently attracted a great deal of public attention, analysis of their economic impact has been far less common. This paper puts forward variants of a simple model of crop production, each one tailored to a particular aspect of transgenic food technology. The focus is on the possibility of monopolization and its consequential welfare costs. Risk factors identified include moderate cost savings from transgenic varieties, high seed storage costs, and high risks of crop loss. The paper also discusses some of the possible remedies including tighter regulation of anti-competitive practices and liberalization of the regulations governing the introduction of new GMOs.

1. Introduction

The introduction of genetically modified organisms (GMOs) into the market place has brought with it controversy, notably over the potential scientific risks of the new biotechnologies, but also over perceived threats, such as the monopolization of food supply, which have a strong economic dimension. Nevertheless, compared to discussion of the scientific issues, economic analysis of regulation has been far less common, despite the fact that some features of the new biotechnology industries, such as vertical restraint and monopolization, are familiar features of many other industries and thus have a long history, both of economic analysis and economic regulation by national governments.

Many of the fears about monopolization have been propelled by the rapid adoption of GM varieties in countries, such as the USA, where governments have placed relatively few regulatory hurdles in the path of the new biotechnologies. Beyond this lies a world-wide rise in concentration in the seed industry, coupled with greater integration between agrochemical, seed and life-science firms. Hayenga (1998), for instance reports C_4 (the percentage of the market supplied by the largest four producers)

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figures of 70 per cent for the US corn market, 47 per cent for the purchased soybean seed market, and in excess of 90 per cent for cotton seed.

The forces behind this rise in concentration are unclear. One possibility is that it arises from the inefficiencies of incomplete integration in the presence of asset specificity—along Williamsonian lines.[1] A second hypothesis is that the world-wide tightening of intellectual property rights legislation has raised the appropriability of biotechnology innovations. According to this argument, in the past weakness of property rights meant that any potential monopoly power gained through increases in concentration could not be exploited because of the ease of entry through imitation. A rise in the enforceability of property rights might then lead to the monopoly gains from concentration being reaped. A third possible source of concentration is regulation itself, since costs for regulatory approval tend to be fixed. This establishes an 'entry price' for competing in the regulated market; in turn limiting the feasible number of suppliers.

Whatever the sources of increased concentration, it is clear that, as with other forms of monopolization, there is at least the possibility of a reduction in consumer welfare. Consequently, this paper puts forward two variants of a simple model of crop production, each one tailored to understanding a particular aspect of transgenic food technology and its regulation. The first variant of the model considers the issue of the introduction of a new technology, owned by a monopolist, which lowers the costs of production. The argument here is quite standard: if the old technology remains available and there is free entry, then the introduction of the new technology cannot harm consumer welfare. However, in many agricultural industries effective competition between transgenic and non-transgenic technologies relies on the availability to farmers of traditional plant varieties in sufficient numbers. So in the second variant of the model the issue of predatory pricing by the monopolist is considered and it is shown that, if storage costs are sufficiently high, the introduction of the new technology can raise prices and make consumers worse off. Finally, I consider some of the public policy implications of these models for the prudential regulation of transgenic technologies.

2. Background

Transgenic foods are foods where genes from other species have been introduced into a plant or animal, usually to create or enhance specific properties that would not be feasible through traditional breeding methods. The most well-known examples include the Flavr-Savr™ tomato, designed to have a longer shelf-life compared to traditional varieties and the various Roundup Ready™ plants such as soybean, maize, and sugar beet, created by Monsanto. In the latter case, genes from bacteria which

[1] In Oliver Williamson's transaction cost approach, incompleteness of contracts covering the production and delivery of complex inputs means that there may be ample scope for moral hazard in the relationship between a firm and its suppliers. According to Williamson (1975), integration reduces the scope for moral hazard and raises the incentives for individuals and organizations to invest in the input.

Table 1. *Major transgenic crops in the USA, farmer-reported planting, 2001*

Crop	*Percentage of total acreage*			
	Herbicide resistant only	*Insect resistant (Bt) only*	*Stacked gene*	*Total*
Corn	16	7	1	24
Soybean	63	N/A	N/A	63
Upland cotton	28	13	23	64

Source: National Agricultural Statistics Service, 2001.

confer resistance to Roundup™ (Monsanto's glyphosate herbicide) were introduced into farmed plant species. As a result, the plants have a higher tolerance for glyphosate that can therefore be used at higher doses to combat weed growth. The herbicide can also be used at times in the growth cycle (such as after crop emergence) which would previously have been disastrous for yields. In addition, the transgenic varieties also change the feasible set of crop rotations: traditional maize varieties are sensitive to glyphosate, residues of which remain in the soil. Maize engineered to be glyphosate-tolerant can be planted in rotation with soybean crops for example, when previously this was not feasible.

By 1995, 60 plant species had been genetically modified and over 3,000 field tests of their use conducted world-wide in over 32 countries, including the USA, Japan, and most of the nations of the EU. The major crops modified in Europe include oilseed rape, maize, potatoes, tomatoes and sugar beet. Meanwhile in the USA and Canada, soya, maize, and cotton, are also among the crops most subject to modification, while in Japan, rice has been the subject of transgenic experiments.

Introduction of GMOs into the home has been gradual to date, with few crops grown commercially outside the USA and the rest of the Americas. The most widespread transgenic food is vegetarian cheese, production of which involves a genetically modified yeast. Meanwhile 2 per cent of US soybean production was transgenic in 1996, rising to 15 per cent in 1997 and as table 1 shows, by 2001, the majority of soybean and upland cotton plantings for the USA were transgenic. In Europe, Bt corn has been grown in France and Spain since 1998. Other GMOs used commercially include cotton, tomatoes, maize and bacteria modified to produce bovine somatotropin.

Table 2 lists some of the economic concerns associated with transgenic crops. The economic consequences of some of these risks have been considered extensively elsewhere. Barbara Sianesi and Alistair Ulph (1998) for instance, examine the impact of reductions in crop variety on habitat diversity and hence on the number of wild bird species. In a series of papers, Timo Goeschl and Tim Swanson (1996, 1997, 1998) examine carefully how best to value and maintain biodiversity, including the advantages of *in situ* rather than *ex situ* conservation of gene stocks. Meanwhile Munro (1997) considers the general impact of economic behaviour on evolutionary pressures, but does not consider the particulars of the new biotechnology. This paper is complementary to the previous work, more concerned with

Table 2. *The main economic risks from transgenic food technology*

Characteristic	*Associated risk, cost or externality*
Monopolization	1. Reduced choice and higher prices 2. Higher risks of crop failure 3. Reduction in biodiversity
'Genetic pollution'	4. Accelerated pest evolution 5. Transfer of antibiotic resistance to environment; 6. Transfer of herbicide resistance to weeds 7. Low-level Bt toxicity creating increased resistance

some of the conventional sources of market failure, which nevertheless still pose a risk with the new technologies.

3. Monopolization and vertical restraint

The models which follow are built around the example of engineered resistance to a herbicide, the form of transgenic crop which is most widespread. In a typical example of this, a gene (or genes) are introduced into a plant which confers resistance to a herbicide manufactured by the same agrochemical company. Typically the firm selling the transgenic seed does not have monopoly rights to the generic herbicide. However its ownership of the seed variety may give it the power to impose vertical restraints, forcing buyers of the seed to also use its own brand herbicide. In the case of Monsanto's 1996 Roundup Ready™ gene agreement, signed by farmers if they wished to buy Roundup Ready™ soybean seed, farmers agreed to use only Roundup™ glyphosate herbicide on the crop and not competing brands. To enforce this and other aspects of the agreement, they had to also to agree to the right of Monsanto to inspect and test the field crops for a period of up to three years and pledge not to save, re-use, re-plant or sell the seed (RAFI, 1997).

Although the biotechnology industry was increasingly concentrated prior to the introduction of transgenic foods, and although most of these large firms are producing genetically modified food, the model which follows assumes perfect competition in both seed and pesticide industries prior to an innovation. Thereafter, a single firm dominates the market. These assumptions place an upper bound on the potential costs from the risk of monopolization. Actual costs are likely to be lower.

A basic model of innovation.

I shall suppose that prior to the innovation, farms buy herbicide and seeds in a competitive market. The farms have a constant marginal and average cost of producing planned output, q, of c_n where the subscript 'n' refers to the non-GM status of the crop.

After all costs have been incurred there is a strictly positive probability γ of crop failure, possibly due to disease, in which case output to market is zero. I shall suppose that prior to the introduction of the GM variant there are a large number of seed variants supplied to farms with the following properties: none of the characteristics affects consumer demand or unit

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costs. However, each seed type is resistant to different potential diseases. For each seed type the probability of crop failure is assumed to be an independent variable[2] and the number of varieties of seed is sufficiently large such that if q is planted $(1 - \gamma)q$ reaches the market with certainty.

Suppose consumer demand is given by $a - p$ where p is price and $a > c_n > 0$ and suppose also that farmers sell into a competitive market. Let p^0, q^0 indicate the equilibrium price and planned production level respectively, then in the competitive equilibrium with risk neutral farms

$$p^0 = c_n/(1 - \gamma) \tag{1}$$

$$q^0 = (a(1 - \gamma) - c_n)/(1 - \gamma)^2 \tag{2}$$

Suppose now that one firm innovates, to produce a complementary seed-herbicide combination such that, for all input prices, $c_g < c_n$, where c_g is the representative farm's unit cost function with the new GM technology. Following Arrow (1962) there are two cases to consider. In the first case, the cost reductions from the innovation are sufficiently great that the monopoly price lies below the competitive price for the non-GM technology. Hence all competition in the seed and herbicide industries is destroyed. In the second case, the monopoly price is above the competitive price for the non-GM technology.

Case 1. Monopoly production of the seed and pesticide

A farm which uses the genetically modified product still faces a probability γ of crop failure. Let p_g be the equilibrium price with only the GM crop sown. In the competitive equilibrium

$$p_g = c_g/(1 - \gamma) \tag{3}$$

If the probability of crop failure is sufficiently large, then there is the possibility that some farms may find it profitable to be fringe producers—defined in this case as farms which use the non-GM technology. Free entry means that such suppliers make losses in years without GM crop failure, which are counterbalanced by the profits when the GM crop fails. For this not to be profitable, the following condition must be satisfied

$$\gamma(1 - \gamma)a + (1 - \gamma)^2 p_g - c_n < 0 \tag{4}$$

To understand this equation, consider a producer considering whether to produce an infinitesimal amount of the non-GM crop. It faces a marginal cost of c_n which must be incurred before it is known whether the GM crop or the non-GM crop fails. If neither fails (for which the probability is $(1 - \gamma)^2$) then the marginal revenue is p_g. If the GM crop fails, but the non-GM crop does not (which occurs with probability $\gamma(1 - \gamma)$) then marginal revenue is a—the price received when only an infinitesimal amount of any produce is available in the market. Using (3) to simplify (4) yields

$$(c_g + \gamma a)(1 - \gamma) < c_n \tag{5}$$

[2] Sources of risk that are highly correlated across all cultivars, such as drought, flood, or storm damage are therefore ignored. This maximizes the increase in risk, consequent upon the monopolization of production.

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This equation is satisfied when the risk of failure is sufficiently small and the cost advantage of the new technology is sufficiently large.

Case 2. If (5) is not satisfied, then fringe production is potentially profitable.

Let p^H be the price when the genetically modified crop fails. In the competitive equilibrium for fringe producers, expected profits are zero

$$p^H\gamma\,(1 - \gamma) + (1 - \gamma)^2 p_g - c_g = 0 \tag{6}$$

Meanwhile, for producers of the GM crop, expected profits are also zero, so that the value of p_g is given by equation (3).

Note that, in general the prices charged by the profit-maximizing supplier, GM seed and its complementary herbicide will differ between these two cases, hence unit costs and the price will also differ. However, the key issue is whether consumers lose or gain from the new technology and it is to this point that we turn.

Consumer welfare

Let the consumer surplus be V. At a price, p, $V = ½[a - p]^2$, hence V is strictly convex in prices. As a result, a sufficient condition for expected consumer surplus not to fall in the wake of the introduction of the GMO is that the expected price does not rise. That is

$$\gamma p^H + (1 - \gamma)p_g \leq p^0 \tag{7}$$

In Case 1, since no produce is available when the GM crop fails, $p^H = a$ and $p_g = c_g/(1 - \gamma)$ which gives

$$\gamma a + (1 - \gamma)c_g = \frac{(1 - \gamma)\gamma a + (1 - \gamma)^2 c_g}{1 - \gamma} < \frac{c_n}{1 - \gamma} = p^0 \tag{8}$$

where the penultimate step in this argument follows from equation (5)—the condition which defines case 1. In case 2, by equation (6) the expected value of post-innovation prices is equal to the pre-innovation price. Hence is also satisfied, giving the following proposition:

Proposition *Expected consumer surplus does not fall in the wake of the GM innovation.*

This proposition is quite general, turning on the quasi-convexity of the indirect utility function and the constraint on the monopolist posed by the competitive fringe. Since producer surplus is zero before the innovation and positive afterwards, it is also true that the sum of expected surpluses also rises. The result is unsurprising (at least to economists) since the argument is closely based on Arrow's (1962) analysis of the benefits of cost-cutting technology. Since the price chargeable by the monopolist is bound above by the cost of the old technology, post-innovation prices cannot rise in this model and hence consumers cannot lose from the introduction of the new technology.

In order for consumers to lose, some other factor must therefore be important: either greater risk or the ability of the monopolist to eliminate competition from the existing technology or an externality. I consider each of these factors, in turn.

Risk

Crop yields are inevitably stochastic. Some risks are specific to a particular farm or region or not specific to particular varieties, but other risks, such as diseases, are often selective in the damage they do, harming yields from varieties that have a specific vulnerability in the germplasm, while being resisted by other varieties. If the introduction of new technologies means that a narrower range of crop varieties is grown, then, in theory, the variance of aggregate yields should rise as a result. The evidence to date on this is mixed. Wright (1997) concluded cautiously that:

> The hypothesis that greater world-wide uniformity of germplasm due to the increased dominance of high-yield varieties is not associated with greater relative yield fluctuations cannot be rejected at present.

For instance, Hazell (1989) reports an increase in the coefficient of variation from 2.8 per cent to 3.4 per cent for cereal yields (outside of mainland China) for a period running from the 1960s to 1983. Against this, Singh and Byerlee (1990) point to a declining variability in wheat yields for the 1951–1986 period.

In the specific case of Bt varieties, there is actually a reason for anticipating reductions in risk: damage to corn by the European corn borer is stochastic, varying from year to year, but positively correlated across farms within a region for a given year. As Gianessi and Carpenter (1999) point out, the fact that the Bt corn varieties reduce yield losses to the borer, has led to it being recommended for planting as a form of insurance.

However, let us suppose for the moment that the new technologies do lead to greater variance in aggregate crop production levels. As noted earlier, if the competitive fringe of producers using the old technology survives, then the welfare gains from the new lower-cost technology will still be positive. In addition, even if fringe producers do not survive, as long as the mean price is lower, then any higher variance of prices raises welfare still further, because indirect utility functions are quasi-convex. Any costs attached to higher variability in prices must therefore be costs to producers or due to the absence of the competitive fringe. On the first of these, note that in the models presented so far there is no producer surplus to consider. However, in general producer surplus is, like consumer surplus, convex in prices[3] and hence greater randomization (for a given mean) raises expected producers surplus. Now, this last result depends on the assumption that producers are neutral with regard to risk in income or have access to competitive insurance markets. However, when farmers are largely dependent on farm incomes and markets are

[3] Consider two scenarios: A, with a price p^1 for sure, and B, where the price could be either p^2 or p^3. Suppose p^1 is also the expected value of the price in B. If the firm produced the same output in B as in A then expected profit would be identical. So, it can do no worse in scenario B and may be able to do better. Hence profit and surplus are convex in prices.

incomplete as is often the case in developing countries, such assumptions are probably incorrect. It is then more reasonable to suppose aversion to farm income risk, especially for societies where significant drops in household income imply malnutrition or worse (see Newbery and Stiglitz, 1981). Where this is the case consumer welfare may rise with the new technology (since the average price falls), but producer welfare may rise or fall.

There is one other issue to consider. As Martin Weitzman (2000), points out, as concentration on one crop strain increases, there may be a tendency for pathogens to adapt specifically to this strain. In the context of the model, this amounts to a positive relationship between the switch to monoculture of the GM variety and the probability γ of crop failure. To the extent that such a rise in γ occurs with the use of GM crops, then this would limit the gains from their introduction.

To summarize, the risks from monopolization are likely to be largest in poor countries. In richer countries, where the consequences of crop failure are more easily moderated, there is less of a clear argument for control of the new biotechnology on monopoly grounds (though see next section). However, the fundamental issue of changes in the variability in food supply is currently unresolved and requires further research.

4. Predatory pricing

The results of the previous section rest on the existence of free entry using the old technology, which caps the price the monopolist can set. However, in the case of agriculture, an essential factor, namely seed, is subject to degradation if stored for sustained periods. Meanwhile planting and harvesting merely to maintain the health of the seed base may be financially unsustainable for small farmers. In this section I adapt the model to consider this possibility. In order to concentrate on the issue of predation, I ignore the possibility of crop failure.

The assumptions of the model

Sequence of events. There are three time periods, 0, 1, and 2. Figure 1 summarizes the time-line for decisions. The GMO technology is introduced without announcement at time 0, after the previous year's crop production

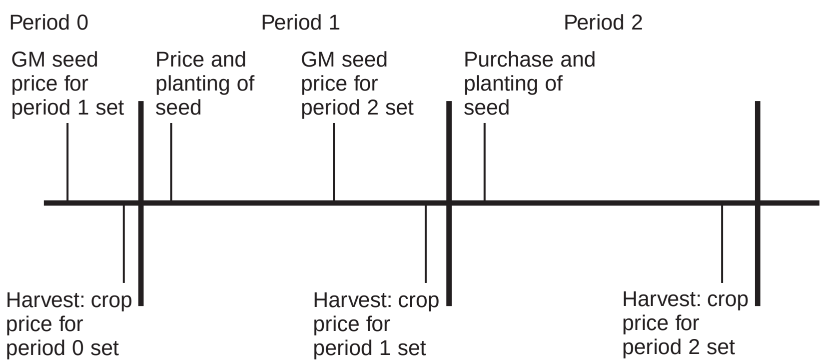

Figure 1. *The timing of decisions*

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has been set, but not yet sold.[4] Farms can either sell the non-GMO crop for seed, keep it for seed,[5] or sell it to consumers. In period 1 farms must choose whether to stay in the industry or exit (or enter), then which technology to use. Crop production is then set, the product harvested, and farmers make the same decisions about what to do with the harvest as at the end of period 0. Period 2 is a re-run of period 1, except all product is consumed at the end. While this adds an artificial end to the model, it provides a convenient means of analysing the problem faced by agents involved.

Consumer behaviour. In each period demand is given by $a - p_t$ where p_t is the price of seed in period $t = 0, 1, 2$. Storage by consumers is not possible. I shall make the simplifying assumption that consumers have no preference between GM and non-GM varieties. Assuming that they had a preference for the non-GM variety would, in the present context, weaken the market power of the GM producer.

Farm cost functions. Prior to the introduction of the GMO, a proportion of the crop is held back each year in order to provide seed for the following season. Suppose that to produce 1 tonne of the crop, α tonnes of the previous year's crop are required.[6] In addition to the opportunity cost represented by this input, there is an additional cost of c_n per tonne of product. The total unit cost for year t is therefore $c_n + \alpha p_{t-1}$. With the GM technology, unit costs are $c_g + \alpha_g r_t$, where c_g is the cost of production, r_t is the price of the GM seed in year t, and α_g is the amount of seed required to produce one tonne of the GM crop. For both type of crops, costs must be incurred one growing season before the revenue accrues; therefore there is also an opportunity cost of funds to consider. Let $\rho \geq 0$ be the per period cost of capital for farmers. Hence total units costs are $(1 + \rho)(c_n + \alpha p_{t-1})$ using the traditional technology and $(1 + \rho)(c_g + \alpha_g r_t)$ employing GM seed.

GM Supplier behaviour. The firm's profits are $\pi = \pi_1 + \pi_2/(1 + \rho)$ where π_t, $t = 1, 2$ is the profit in period t. The firm chooses r_1 and r_2 to maximize profits. If the marginal cost of producing the seed is k,[7] then

[4] Alternatively, the announced price for the following season's seed could be after the harvest. The only significant difference produced by making this alternative assumption would be to the price in period 0, when the sudden introduction of the new technology would lead (possibly) to a second market opening for the produce from period 0. The qualitative results of the story would not be changed.

[5] Obviously only the latter is feasible for some crops, such as hybrid maize, in which case the power of the would-be monopolist is strengthened.

[6] For many crops, the multiplication factor ($= 1/\alpha$) is high, making seed costs a small fraction of overall costs. Elizabeth Cromwell *et al*. (1992) for instance, lists multiplication factors of 25 for wheat and 50 for rice.

[7] It seems reasonable to suppose that, post-development costs, the GM seed is produced using a technology similar to the main crop. If this is the case then $k \approx (1 + \rho)c_g/(1 - \alpha g - \alpha g \rho)$. For simplicity, I shall take this relationship to be exact in the simulations of the next section.

$$\pi = \pi_1 + \pi_2 = \alpha_g(r_1 - k)(a - q_{n1} - p_1 + \alpha q_{n2}) + \alpha_g(r_2 - k)(a - q_{n2} - p_2)/(1 + \rho) \tag{9}$$

where q_{ni}, $i = 0, 1, 2$ is the total output of the non-GM crop in periods 0, 1 and respectively and q_{gi}, $i = 1, 2$ is the output of the GM crop in periods 1 and 2. I assume that the GM technology does have a cost advantage over the non-GM method, that is $k\alpha_g + c_g < c_n/(1 - \alpha)$. Given this, at least some production of the crop will be via the GM technology.

A key issue in models of predation is the ability of firms to commit to particular time paths for output or prices. I shall assume that the firm supplying the GM is unable to commit to a second period price in period 0, when it chooses its price for period 1. It chooses a price for period 1 knowing this. This inability to commit reduces its power to price in a predatory manner.

Farm behaviour. As in the previous section, farms take prices as given and there is free entry and exit in each period with rational expectations about prices. Farmers who produce in both periods 1 and 2 have a choice of four generic strategies: (1) plant the GM crop in both time periods; (2) plant the non-GM crop in period 1, sell it, then plant the GM crop in the second period; (3) plant the non-GM crop in both time periods; and, finally, (4) plant the GM crop in the first period and the non-GM crop in the second.

Solution to the model

In this section I solve for the conditions governing the GM supplier's optimal strategy. Interpretation of the results occurs in the following subsection. Define p_p as the anticipated value of p_0 prior to the introduction of the GMO. The zero profit condition is, $p_p = (1 + \rho)(c_n + \alpha p_p)$, or $p_p = (1 + \rho)c_n/(1 - \alpha - \alpha\rho)$. Consumer demand is then $(a - p_p)$, so that, $q_{n0} = (a - p_p)/(1 - \alpha)$. Given q_{n0}, there are nine unknowns to solve for in this system: q_{n1}, q_{n2}, q_{g1}, q_{g2}, p_0, p_1, p_2, r_1, and r_2. The three market equilibrium conditions are

$$a - p_0 = q_{n0} - \alpha q_{n1} \tag{10}$$

$$a - p_1 = q_{n1} - q_{g1} - \alpha q_{n2} \tag{11}$$

$$a - p_2 = q_{n2} - q_{g2} \tag{12}$$

The zero profit conditions for farms are

$$p_1 = (1 + \rho)(r_1\alpha_g + c_g) \tag{13}$$

$$p_2 = (1 + \rho)(r_2\alpha_g + c_g) \tag{14}$$

Now the non-GM technology will only be employed if its costs do not exceed those for the GM technology. Hence

$$q_{n1} = 0 \text{ or } r_1\alpha_g + c_g = \alpha p_0 + c_n \tag{15}$$

$$q_{n2} = 0 \text{ or } r_2\alpha_g + c_g = \alpha p_{01} + c_n \text{ or } r_2\alpha_g + c_g = (1 + \rho)\alpha\,(\alpha p_0 + c_n) + c_n \tag{16}$$

The last term in condition (16) requires some clarification. Farmers who use the non-GM technology to supply the market in period 2 can achieve that goal in one of two ways. The first method is to buy seed in period 1;

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the second method is to plant seed for period 1 and then use that crop for seed for period 2. If the second method is used then the last condition must obtain. The remaining two equations for the system are the profit maximizing conditions for r_1 and r_2. I now turn to their derivation.

There are three cases to consider: blockaded entry, predation and 'live and let live'—in which the GM and non-GM technologies are both employed to produce the crop in periods 1 and 2. I shall focus on the conditions under which predation occurs.

Blockaded entry. Let r_t^m, $t = 1, 2$ be the pair of prices which maximize profits for the GM firm in the absence of any competition from the non-GM technology. If these prices are sufficiently low then using the non-GM technology will not be profitable. Under such conditions, entry is said to be blockaded, in the language of industrial organization. The GM supplier does not have to deliberately seek to eliminate the competition—its monopoly prices are sufficient to achieve this aim. Using (15) and (16) it can be seen that the monopoly prices are sufficiently low if

$$r_1^m < \frac{\alpha p_0 + (c_n - c_g)}{\alpha_g} \equiv r_1^* \tag{17}$$

$$r_2^m < \frac{(1 + \rho)\alpha(\alpha\, p_0 + c_n) + (c_n - c_g)}{\alpha_g} \equiv r_2^* \tag{18}$$

where, in these equations, p_0 is at its value when none of the original crop in period 0 is kept back for seed. In other words $p_0 = a - q_{n0}$.

Figure 2 depicts these equations.[8] The axes show the prices of the GM

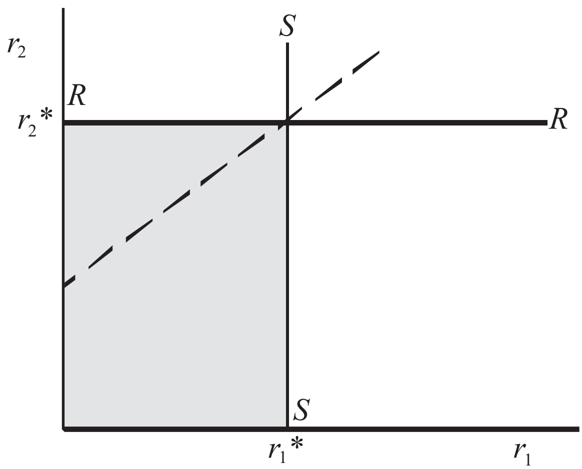

Figure 2. *Conditions for blockading the non-GM technology*

[8] Note that r_1^* is less than r_2^* because at these prices all the non-GM crop is sold to the consumer in period 0. Consequently p_0 lies below p_p and so p_0 also lies below $(1 + \rho)(\alpha p_0 + c_n)$.

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seed in the first and second periods. The line *SS* shows the boundary for equation (17) and *RR* shows the boundary for (18). The shaded area therefore shows all the prices at which the non-GM technology is excluded from the market. Meanwhile, along the broken line farmers are indifferent between selling any old-technology crop produced in the first period and using it to produce a second period crop.

If blockading is successful, then the price of GM seed is equal to its monopoly price in both periods. That is

$$r_1^m = r_2^m = \frac{\left(a - (1+\rho)c_g\right) + (1+\rho)\alpha_g k}{2(1+\rho)\alpha_g} \tag{19}$$

This corresponds to a price for the crop of

$$p_1 = p_2 = \frac{1}{2}\left[a + (1+\rho)c_g + (1+\rho)\alpha_g k\right] \tag{20}$$

Thus the monopoly price is, as might be expected, increasing in a (demand), increasing in the non-seed costs of producing the crop, and increasing in the marginal costs of seed production and the discount rate.

Predation. When blockading is not optimal, predation will occur if it is profitable to set r_1 to eradicate the use of the non-GM technology. Because the GM firm cannot pre-commit to its price in the second period, predation can not be successfully accomplished if r_2^m lies above r_2^*. If $r_2^m > r_2^*$ then it would be optimal for some farms to use the non-GM crop in period 0 for seed, subsequently planting the seed from the crop in period 1 to produce a crop for sale in period 2. Hence a necessary condition for predation is that (18) is satisfied. The other condition which must hold is that it must be profitable to set r_1 below r_1^*. More precisely, profits must decrease as r_1 is increased at r_1^*. In the appendix I derive the conditions under which this is the case.

Interpretation

It can be seen from equations (17) and (19) that blockading is most likely to be the outcome when the GM technology has a large cost advantage over its non-GM competitor. This can arise either because the non-seed costs are lower for the GM technology ($c_g < c_n$) or because the seed multiplication factor is higher for the GM technology or because its costs of production are lower.

The condition (A5), governing the optimality of predation, is not so transparent. However it can be rewritten as

$$2(1+\rho)\alpha_g(r_1^m - r_1^*) - (r_1^* - k)\frac{\alpha_g^2}{\alpha^2} < 0 \tag{21}$$

In the first part of the left-hand side, $(r_1^m - r_1^*)$ is the difference between the monopoly price and the price which excludes all competition. The first part of the left-hand side of (21) therefore represents the benefits of raising prices above the price which excludes competition. If the difference is negative, because the monopoly price lies below the price that excludes competition, then (21) is automatically satisfied and we are back to the blockaded case. On the other hand, when the cost advantage of the GM technology is relatively small the term $(r_1^m - r_1^*)$ will tend to be positive. The second term on the left-hand side is the marginal loss to profits of allowing the non-GM technology to maintain a presence in the market. Its size is increasing in the GM supplier's margin and in the multiplier factor for the GM crop relative to the non-GM variant. If the second term is large then predation is more desirable for the monopolist.

What is not apparent from (21), but which can be shown by differentiation of A5, is that a higher discount rate means that the condition for predation is more easily satisfied. A higher value of ρ raises production costs and hence raises the maximum value of r_1 below which the non-GM crop is not grown. Simultaneously, the higher costs of production created by a higher value of ρ reduces the monopoly value of r_1. Consequently, $r_1^m - r_1^*$ is squeezed by higher values of ρ and this, as we have seen, means that the opportunity cost of pursuing predation is also reduced.

Storage

The possibility of storage places two kinds of constraints on the GM producer. If the crop is storable then the GM crop in the final period may face competition from the crop harvested in period 1 and then stored. This is the durable good problem (see Coase, 1972; Gul, Sonnenschein, and Wilson, 1986). Suppose that storage costs are b, so that 1 tonne of the seed stored becomes $1 - b$ at the end of the storage period. Define $\varphi = (1 - b)/(1 + \rho)$, the opportunity cost of keeping the crop from market for one period. For arbitrage through crop storage not to be profitable, then $p_0 > \varphi p_1$ and $p_1 > \varphi p_2$. The first of these cannot be profitable in the context of blockading or predatory behaviour, because in these two cases $p_0 > p_1$. However the second inequality may be binding if b and ρ are low enough. As an alternative to storing the crop for sale, seed may be stored for planting at a later date. It may be possible for the GM firm to monitor when its seed is planted, thus preventing its storage for later planting, but the firm can have no such control over the non-GM seed. In particular non-GM seed from period 0 may be stored through period 1 and planted for harvesting in period 2. This is not profitable provided $-\alpha p_0 + (1 - b)([p_2/(1 + \rho)^2] - [c_n/(1 + \rho)])$ is negative. In other words, provided $-\alpha p_0 + \varphi[r_2\alpha_g + c_g - c_n]$ is negative or

$$r_2 < \varphi r_1 + \frac{(c_n - c_g)}{\alpha_g}[1 - \varphi] \qquad (22)$$

Thus storage effectively puts a cap (which may not be binding) on the GM producer's second period price. If storage is costless, so that $b = 0$, and $\rho = 0$, then reduces to $r_2 = r_1$, in which case predation can never be optimal. As with increases in the discount rate, rises in the costs of storage mean that predation or blockade become more attractive relative to the alternative of live and let live.

Simulation

Most of the relevant parameters in the critical equations (such as) are not known with any certainty. Nevertheless a small amount of simulation provides some flesh on the bare bones of the analytical results. I begin by normalizing the demand system by setting $a = 1$. A reasonable figure for a monopoly price is 10–50 per cent above its competitive value, which would imply a range for $c_n/(1 - \alpha)$ from 0.833 to 0.5. As noted earlier, for many crops values of α are typically small, usually under 0.1, so I take c_n to lie in the range 0.5 to 0.9, while α lies between 0.02 and 0.1.

Some preliminary estimates of the cost advantages from GM crops are available from US field trials and from farm data. Fernandez-Cornejo and McBride (2000) provide an accessible survey. Most of the evidence suggests that yields from herbicide-resistant varieties of soybean, cotton, and corn are currently at or below traditional varieties. The gains to farmers come from simpler and cheaper methods of weed control, combined with the ability to plant more closely. Hence for herbicide resistance, $\alpha \approx \alpha_g$, but $c_g < c_n$. For Bt varieties of cotton and corn, the gains come from lower pest damage, leading to both lower pesticide costs and higher yields, in other words $\alpha < \alpha_g$, and $c_g \leq c_n$. Typically, cost savings are of the order of 5–15 per cent though as Fernandez-Cornejo and McBride (2000) point out, in some regions of the USA in particular years, the returns to GM technology appear negative, though not significantly so. According to field trials, (see, e.g., Gianessi and Carpenter, 1999) the returns are higher for Bt traits than for herbicide resistance. This may be of significance in the tropics where pest damage can reach very high levels. In the simulations I take reductions in α and in costs to be between 1 per cent and 15 per cent.

Figure 3 depicts critical values of φ above which predatory pricing is not constrained by the possibility of storage of non-GM crops during period 1 for planting in period 2. The top two lines are for values of $c_n = 0.7$; the bottom two curves are for $c_n = 0.9$. For each pair of curves, the top one represents $\alpha = 0.2$, with $\alpha = 0.4$ in the bottom curve. The bottom axis shows the reduction in non-seed costs associated with the GM variety. So, for instance, with a cost advantage for the GM crop of 0.04, $c_n = 0.9$ (implying a cost saving of 4.4 per cent) and $\alpha = 0.4$, storage opportunity costs of greater than 25 per cent per time period imply no constraint on the ability

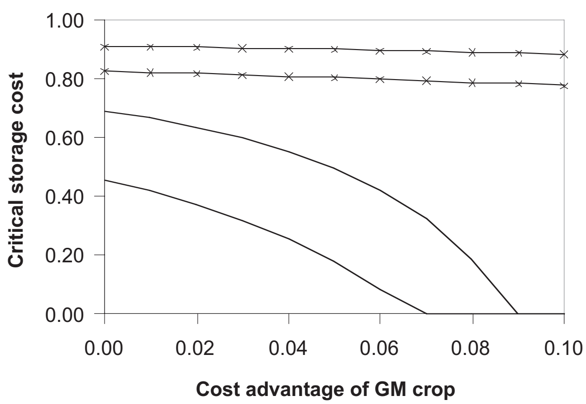

Figure 3. *Predation and storage costs*

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of the GM producer to price in a predatory fashion. Note that, for these particular parameter values, predation is indeed the optimal strategy for the GM producer. For higher values of cost savings, where the curves in figure 3 join the *x*-axis, production of the non-GM varieties is blockaded.

The curves depicted in figure 3 are fairly typical. Higher values of α reduce the critical values of φ (because each seed is less productive) and greater cost savings lower the critical value. It is also the case (not shown) that reductions in the value of α_g, relative to α reduces the critical value of φ, although the effect is small. To put these figures in context, note that Cromwell, Friis-Hansen, and Turner (1992) report typical storage costs (i.e. b) of 40 per cent per annum in some African countries. Such figures would make predation feasible for multiplication rates of 25 at cost advantages for GM crops of only 4–5 per cent and a value of $\rho = 0$. However, for temperate zone crops such as wheat grown in richer countries, the much lower storage costs would place a limit on monopoly power.[9]

Consumer welfare

Table 3 sets out the equilibrium prices with and without the introduction of the GM crop on the assumption that predation or a blockade is optimal and for the case where the storage constraints are non-binding.

Prices in the periods 0 and 1 are below prices in the non-GM scenario. If entry is blockaded then the monopoly price in period 2 is also below the non-GM price and so consumers gain from the innovation as they did in the third section. If entry is prevented only by predatory pricing in period 1, then the price in period 2 is above that in the non-GM scenario. Consumer welfare is decreasing in the price level, so obviously if the weight attached to period 2 in consumer welfare is sufficiently large then consumer welfare will have fallen overall.[10] However, if the reduction in

Table 3. *Prices in the post-GM market*

Price	*Non-GM*	*With GM crop*
Period 0	$(1+\rho)c_n/(1-\alpha-\alpha\rho)$	$a - q_{n0} = (-a\alpha(1-\alpha) + (1+\rho)c_n)/(1-\alpha)^2.$
Period 1	$(1+\rho)c_n/(1-\alpha-\alpha\rho)$	$(1+\rho)\mathrm{Min}(\alpha_g r_1^m + c_g, \alpha(a - q_{n0}) + c_n)$
Period 2	$(1+\rho)c_n/(1-\alpha-\alpha\rho)$	$(1+\rho)[\alpha_g r_1^m + c_g]$

[9] The details of these results are likely to be sensitive to the formulation of the demand curve. I have repeated the derivation of A5 and some of the simulations with a constant elasticity of substitution (CES) utility function for consumers. With the CES function, predation is still possible, but the possibility of storage severely circumscribes its relevance. However, in some ways the CES function is less satisfactory compared to the linear demand case, because CES functions typically generate an enormous gap between the competitive and monopoly price for which there is no empirical support.

[10] Period 2 could be viewed as the 'long-run' with periods 0 and 1 representing the initial phases of adjustment to the new technology. If this is the case, placing a higher weight on period 2 welfare, compared to welfare in periods 0 and 1, might well be justified.

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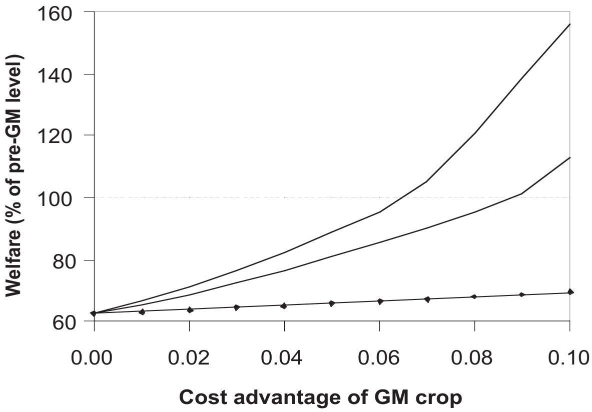

Figure 4. *Welfare effects of the new technology*

prices achieved in periods 0 and 1 is sufficiently large, then overall consumer welfare improves, even with the charging of the monopoly rate in the final period. Again this is a familiar lesson: consumers gain from predatory price wars, while the wars are in progress. It is only when competition has been eliminated that consumers suffer.

Figure 4 provides some evidence from simulation in which welfare for each period is equally weighted. The figures shown are net welfare gains for the cases of $c_n = 0.9$ and 0.7. In descending order, the top two curves represent $c_n = 0.9$, $\alpha = 0.4$, and $c_n = 0.9$, $\alpha = 0.2$. The bottom curve shows the case of $c_n = 0.7$ and $\alpha = 0.2$. Note that the $\alpha = 0.4$ is not depicted in this case because it is only marginally different from the $\alpha = 0.2$ case. As might be expected, when $c_n = 0.9$, a higher cost saving is associated with a larger welfare gain, which becomes positive for the largest values of cost saving where the monopoly price is below the pre-GM competitive value. However, for smaller cost savings, the net welfare effect is negative. When $c_n = 0.7$, the monopoly price is much larger than the competitive price and, in this case, welfare gains are never positive. Comparing figures 3 and 4 it can be seen that it is perfectly possible for storage costs to be such that predation is feasible and welfare gains are negative.[11]

5. Discussion

An early draft of this paper was entitled 'Should we ban the terminator gene?' The answer from this paper is 'not necessarily' but there are clear indications that under some circumstances GM crops may lower welfare. Monopolization in itself though is not a cause of welfare loss, since the usual route to monopoly control for a new technology is via greater efficiency. If there is no advantage to the GM crop then it will not be

[11] Note that placing a greater weight on period 1 rather than period 2 raises welfare, but may still not yield a net welfare gain.

planted. If its cost or yield advantage is sufficiently large then it will eliminate the old varieties at a price to farmers which is always below the unit cost of the technologies it replaces. However at intermediate cost savings there is the possibility of effective predation by the GM producer. Predation is most likely to be a threat to welfare when: (1) there is only one GM producer; (2) the cost advantage of its product over traditional varieties is not large; (3) there is pre-existing uniformity in the varieties being grown; (4) the monopoly price of the crop is high relative to the competitive value; (5) there is an absence of publicly supported *in situ* and *ex situ* conservation; and (6) total storage costs are high.

It is therefore worth re-emphasizing that as long as competing seed remains readily available, for the owner of GMO patent rights, the power to set prices is heavily circumscribed. In addition, with only a limited number of crops and few in direct competition with one another,[12] the current situation is unlikely to last. More competition between transgenic varieties is likely to be a feature of the future, especially given the fact that the new technologies lower the costs of developing new varieties, compared to traditional breeding techniques. World wide, there is also an established series of *ex-situ* seed-banks and storage facilities and this again limits monopoly power, particularly in countries with well-organized systems and where storage costs are low. In other countries, where storage costs are high[13] the power of the GMO producer may be stronger.

Goeschl and Swanson (1998) demonstrate the limited value of *ex-situ* storage when there is rapid evolutionary change in weeds and pests and hence rapid change in the optimal genotype of a crop. It is not clear how this affects the monopoly power of the GMO producer since, presumably rapid and localized change in the optimal genotype would also limit the extent of the market penetration of a standardized variety in the first place.[14] If, however, pricing was sufficiently low to capture the market, the opportunity costs would be that much higher.

Finally it is worth noting the implicit assumption of full appropriability of the returns from the GM technology. If this is not possible, either because Genetic Use Restriction Technologies (GURTs), such as the so-called Terminator Gene, are prohibited, e.g. by law or social norm, or economic and legal means of appropriation, such as the contractual devices mentioned in the second section, are not completely effective, then this may limit the ability of the GM producer to eliminate competitors.

The public policy implications of the threat of predatory pricing are unclear. In the EU countries, one option is regulatory control through

[12] For instance, the National Corn Growers Association (USA) website lists only four GM varieties (from three companies) of corn with approval for import into the European Union as of mid 1999.

[13] Cromwell, Friis-Hansen, and Turner (1992) note that 'the cost of installing and operating controlled environment stores in tropical countries is very high and this is seldom an economic approach if real costs are to be passed on to farmers' (p. 41).

[14] In fact the localized nature of the optimal variety is a general factor limiting monopoly power.

national competition policy or, if the relevant conditions were satisfied, through Article 86 (Abuse of Dominant Power) of the Treaty of Rome. The fine of Euro 8.8m levied on Irish Sugar Plc in 1997, shows that the European Commission has been willing to act against agricultural firms engaging in predatory pricing (McDonald and Dearden, 1999). A less reactive and more structural approach to promoting competition would be to relax the regulations governing development and deployment of new transgenic varieties.[15] Such an approach would likely prove contentious and serves to illustrate the difficulties of marrying competition and environmental policy. A third option, less likely to run into the same controversy is greater support from the public finances for *ex-situ* and *in-situ* conservation.

A final option is reducing the cost of storage. As already noted, this can involve investment in storage facilities, in transport infrastructure, or in direct subsidies. However, if the constraint placed by storage on the GM producer's pricing policy is not actually binding, then small changes in the costs of storage may have no effect on the prices of GM crops.

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[15] In addition to the four varieties of transgenic maize approved for import into the European Union, the NCGA website lists another seven varieties awaiting approval.

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Appendix

In this appendix I derive the conditions governing the optimality of predation. The derivative of profits with respect to r_1 is

$$\frac{d\pi}{dr_1} = \frac{\partial \pi_1}{\partial r_1} + \frac{\partial \pi_1}{\partial q_{n1}}\frac{dq_{n1}}{dr_1} + \frac{\partial \pi_1}{dq_{n2}}\frac{dq_{n2}}{dr_1} + \frac{1}{1+\rho}\left(\left[\frac{\partial \pi_2}{\partial r_2} + \frac{\partial \pi_2}{\partial q_{n2}}\frac{\partial q_{n2}}{\partial r_2}\right]\frac{dr_2}{dr_1} + \frac{\partial \pi_2}{\partial q_{n2}}\frac{dq_{n2}}{dr_1}\right) \tag{A1}$$

By the envelope theorem, the terms in the square brackets sum to zero. Since (18) must also be satisfied if predation is to be profitable, then q_{n2} is zero and we need only worry about the direct effect of r_1 on profits and the indirect effects via q_{n1}. Thus (A1) simplifies to:

$$\frac{d\pi}{dr_1} = \frac{\partial \pi_1}{\partial r_1} + \frac{\partial \pi_1}{\partial q_{n1}} \frac{dq_{n1}}{dr_1} = \alpha_g\left[a - (1+\rho)(2r_1\alpha_g + c_g - k\alpha_g)\right] - \alpha_g\left[r_1 - k\right]\frac{dq_{n1}}{dr_1} < 0 \qquad \text{(A2)}$$

Recall that the derivative is evaluated on the border SS depicted in figure two. At this point

$$r_1 = \left(\alpha(a - q_{n0}) + c_n - c_g\right)/\alpha_g \qquad \text{(A3)}$$

The derivative in the last term of (A2) is found by using the market clearing condition for the initial period: $a - p_0 = q_{n0} - \alpha q_{n1}$ which gives, $q_{n1} = (q_{n0} - a + p_0)/\alpha$. Meanwhile the value for p_0 is derived from the fact that if some non-GM does not yield losses then $\alpha p_0 + c_n = \alpha_g r_1 + c_g$. Substituting this into the expression for q_{n1} yields

$$q_{n1} = \frac{q_{n0} - \alpha}{\alpha} + \frac{r_1\alpha_g + c_g - c_n}{\alpha^2} \qquad \text{(A4)}$$

Differentiating this with respect to r_1, produces α_g/α^2. Then, using the value of r_1 in (A3) and inserting the results into (A2) yields

$$\alpha(a - q_{n0}) + (c_n - c_g) > \frac{a - (1+\rho)c_g + k\alpha_g\,[(1+\rho) + 1/\alpha^2]}{2(1+\rho) + 1/\alpha^2} \qquad \text{(A5)}$$

If this is satisfied and (18) is also satisfied, but blockading is not optimal, then predation is profit maximizing. If (A5) is not satisfied, then it is profit maximizing for the GM supplier to tolerate a fringe of producers using the non-GM technology.