Socially Efficient Allocation of GM and non-GM Crops under Contamination Risk

by

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Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Montreal, Canada, July 27-30, 2003

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Abstract

This paper develops a model of optimal allocation of GM and non-GM crops under contamination risk. The model is used to compare the producer optimal crop allocation at equilibrium to the social efficient crop allocation. From the socially optimum conditions, the paper identifies production environments under which GM crops are more likely to be overplanted.

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The USDA is considering a broader role in helping market genetically engineered crops and in segregating those crops from non-engineered ones. Segregation of crops is, however, becoming increasingly difficult since over 100 million acres of the world's most fertile land were planted with genetically modified crops in the year 2000, some 25 times more than just four years earlier. Actual acreages affected are even greater because of wind-blown pollen, commingled seeds and black market planting. Farmers and downstream users, therefore, face a production externality that stems from contamination between GM and non-GM crops across farms, which may grant some type of government intervention. Currently, some countries and food processors are demanding only nonmodified crops.

To evaluate the production externality, this paper compares the individual optimal crop acreage allocation of GM and non-GM crops at equilibrium to the socially efficient level of acreage allocation under contamination risk.[1] The economic model establishes that production of GM crops is greater than the socially efficient allocation levels principally in regions where the probability of contamination from GM to non-GM is small (i.e., areas where most crops are non-GM), and this disparity between the social efficient allocation and the market equilibrium is shown largest in areas where the probability of contamination is small.

The analysis considers two cases. The first case is a state invariant technology to contamination risk and the second case is a state dependent technology to contamination risk. For the first case, the social efficient allocation of crops that internalizes the production externality dedicates more acreages to non-GM crops than under the competitive equilibrium. For the second case, the economic model establishes that production of GM crops is not

[1] The focus of the paper is thus different from previous work that shows the incentives for genetic modification under uncertainty (Swanson, 2002); intervention in terms of impact on the environment (Ulph et al., 2002); and the implications of current regulation on biotechnology (Jackson et al., 2002).

necessarily greater than the socially efficient levels, but GM crops are more likely to be overplanted in regions when the probability of contamination from GM to non-GM is small (i.e., areas where most crops are non-GM). In both cases, if GM is overplanted relative to the social efficient allocation, then the shadow price of a social efficient solution is shown to decrease with the probability of contamination from GM to non-GM. That is, the shadow price of a socially efficient acreage allocation is larger in regions where most crops are non-GM. Therefore, geographical restrictions on GM crops intended for a socially efficient acreage allocation may be needed mostly in regions where most crops are non-GM.

The findings of the paper can be extended to the increasingly and related issue of contamination from gene altered corn for pharmaceutical usage. For example, environmental groups want pharmaceutical crops strictly confined to green houses or in remote area relative to food crops. These geographical restrictions may be consistent with the findings of the paper.

Assumptions and Optimal Crop Allocation

The likelihood of contamination from GM to non-GM crops is incorporated in a rational model of expected profit maximization. In the model, the crop outputs at state of nature s corresponding to GM and non-GM crops are $y_1^{(s)}$ and $y_2^{(s)}$ priced per unit at R_1 and R_2, respectively. The states of nature of non-contamination and contamination from GM to non-GM are denoted by the superscript $s = 1$ and $s = 2$, respectively, where the probability of contamination across farms (e.g., contamination through wind blow or at storage) from GM to non-GM crops is $\underline{p}$. The analysis explicitly models the production externality from contamination (i.e., the probability of contamination across farms or at storage in elevators) and, thus, abstracts from possible contamination within the farm.

In the event of contamination from GM to non-GM ($s = 2$), the producer price for conventional crops is discounted. For example, when contamination from GM to non-GM occurs, the price discount applied to non-GM crops is d_2. The GM and non-GM outputs under state of nature s are function of acreages allocated to GM, A_1, acreage allocation to non-GM crops, $A - A_1$, where total acreages, A, are assumed to be fixed, and the cost per acre of planting GM and non-GM crops are w_1 and w_2, respectively.

Mathematically, optimal choices of GM and non-GM crops that maximize expected profits under possible contamination stem from the optimization,

$$\underset{A_1}{Max}\ E(\pi) = \sum_{i=1}^{2} [\{1 - \underline{p}\} \cdot R_i\, y_i^{(1)}(\vartheta) + \{\underline{p}\} \cdot R_i\, d_i\, y_i^{(2)}(\vartheta)] - w_1 A_1 - w_2 A_2 \qquad (1)$$

$$s.t.\ A_2 = A - A_1,$$

$$y_i^{(s)}(\vartheta) = y_i^{(s)}(A_1, A_2),\ for\ i = 1,2,$$

$$d_1 = 1$$

where the optimal solution from (1) can be derived from the first order condition:

$$\partial E(\pi)/\partial A_1 = \sum_{i=1}^{2} [\{1 - \underline{p}\} \cdot R_i\, (\partial y_i^{(1)}(\vartheta)/\partial A_1) + \{\underline{p}\} \cdot R_i\, d_i(\partial y_i^{(2)}(\vartheta)/\partial A_1)] \qquad (2)$$

$$- w_1 + w_2 = 0.$$

In particular, under the assumption that the production function under each state of nature is a strictly quasi-concave function with respect to acreage allocation, it follows that the first order condition in (2) corresponds to a maximum (MasCollel et al., 1995), and an explicit solution of (2) with respect to A_1 is:

$$A_1 = A_1(\underline{p}, R_1, R_2, w_1, w_2, A, d_2),$$

which implies that

$$A_2 = A - A_1(\underline{p}, R_1, R_2, w_1, w_2, A, d_2),$$

$y_i^{(1)} = f_{i1}(\underline{p}, R_1, R_2, w_1, w_2, A, d_2)$, and

$y_i^{(2)} = f_{i2}(\underline{p}, R_1, R_2, w_1, w_2, A, d_2)$

where $i = 1,2$.

The probability of contamination across farms $\underline{p}$ is exogenous at the farm level, but acreage allocation decisions by neighboring farms may change the probability of contamination. If this probability remains unchanged with the resultant choices in acreage allocation by all neighboring farmers, then the probability of contamination across farms from which producers based their optimal choices is in equilibrium. In particular, from the assumption of a representative farm, the probability of contamination at equilibrium, which represents an equilibrium solution consistent with the assumption of expected profit maximization, is

$\underline{p} = \underline{p}(R_1, R_2, A)$; .

and the producer optimal acreage allocation at the equilibrium is

$$A_1 = \underline{A}_1(R_1, R_2, w_1, w_2, A, d_2) \quad (3a)$$

and

$$A_2 = \underline{A}_2(R_1, R_2, w_1, w_2, A, d_2). \quad (3b)$$

Social Efficient Acreage Allocation under Contamination Risk

The acreage allocation of GM and non-GM crops at equilibrium in (3) is not generally consistent with the social optimum in the presence of externalities (Arrow 1969), e.g., existence of contamination from GM to non-GM. To derive the producer social efficient allocation of GM and non-GM crops, the paper maximizes expected social profits associated with (1). Specifically, under the representative producer assumption, the maximization of social profits is:

$$\underset{A_1}{\text{Max}} \sum_{i=1}^{2} R_i\,[\{1 - \underline{p}(A_1/A)\} \cdot y_i^{(1)}(\vartheta) + \{\underline{p}(A_1/A)\} \cdot d_i\, y_i^{(2)}(\vartheta)] - w_1A_1 - w_2A_2 \quad (4)$$

$s.t.\ A_2 = A - A_1,$

$y_i^{(s)}(\vartheta) = y_i^{(s)}(A_1, A_2), for\ i = 1,2,$

$d_1 = 1$

where the probability of contamination across farms is endogenous when maximizing social profits, i.e., $\underline{p} = \underline{p}(A_1/A)$ where $\partial \underline{p}/\partial(A_1/A) \geq 0$ and $\partial^2 \underline{p}/\partial(A_1/A)^2 \leq 0$. Intuitively, the probability of contamination from GM to non-GM across farms, $\underline{p}$, increases with the ratio of total acreages used for GM crops relative to total acreages planted, i.e., $\partial \underline{p}/\partial(A_1/A) \geq 0$, and an additional unit of (A_1/A) is less likely to contaminate non-GM when the level of (A_1/A) is high, i.e., $\partial^2 \underline{p}/\partial(A_1/A)^2 \leq 0$.

The socially efficient acreage allocation associated with (4) is:

$$A_1^* = A_1^*(R_1, R_2, w_1, w_2, A, d_2) \tag{5a}$$

and

$$A_2^* = A_2^*(R_1, R_2, w_1, w_2, A, d_2) \tag{5b}$$

where (3) and (5) are generally different and will be equal only by chance. The next section compares the individual optimal solution at equilibrium to the socially efficient acreage allocation between GM and non-GM.

Comparing the Social Optimum to the Equilibrium solution

A comparison of the first order conditions associated with the optimizations in (1) and (4) can be used to evaluate whether GM are overplanted or underplanted. In particular, the first order condition for a maximum in (4) under the social optimum equals the first order condition in (2) plus the additional term:

$$\{- [R_1 y_1^{(1)}(\vartheta) + R_2 y_2^{(1)}(\vartheta)] + [R_1 y_1^{(2)}(\vartheta) + R_2\, d_2\, y_2^{(2)}(\vartheta)]\}\partial \underline{p}/\partial(A_1/A). \tag{6a}$$

The term in (6a) captures endogeneity of the probability of contamination across farms when evaluating the socially efficient acreage allocation, while the absolute value of (6a) represents the shadow value of an efficient social acreage allocation in the presence of contamination risk. The sign of (6a) also determines whether GM are overplanted or underplanted. For example, if (6a) is negative, then individual optimizing behavior produces a larger proportion of GM crops than under the social optimum.[2]

Moreover, since $\partial \underline{p}/\partial(A_1/A) \geq 0$, the term in (6a) is negative only if the revenues under the state of nature of non-contamination from GM to non-GM are larger than the revenues under the opposite state of nature. In this case, GM crops are overplanted. Note that revenues under the state of nature of non-contamination from GM to non-GM are larger than the revenues under the opposite state of nature only if the loss in revenues from the discount faced by farmers from contamination of GM to non-GM crops dominates any gain in total yield from contamination from GM to non-GM.

The Case of State Invariant Technologies to Contamination Risk

For types of genetically modified crops not expected to increase yield, the technology is state invariant to contamination risk and, thus, (6a) reduces to:

$$\{- R_2 y_2^{(1)}(\vartheta) + R_2 d_2 \; y_2^{(2)}(\vartheta)\}\partial \underline{p}/\partial(A_1/A) \qquad (6b)$$

where (6b) is negative since $d_2 \leq 1$. GM crops are, therefore, overplanted relative to the social efficient acreage allocation if the technology is not state dependent to contamination risk.

Next, the paper examines the relation between the shadow value of a socially efficient crop allocation (the absolute value of (6)) and the probability of contamination and, thus,

[2] This necessarily occurs given the embedded curvature assumption needed for obtaining a maximum, i.e., the objective function is a concave function.

determines conditions under which geographical restrictions on GM crops may be more pressing in terms of a socially efficient acreage allocation. To develop comparative static analysis on the shadow value of an efficient social acreage allocation with respect to the probability of contamination, we need to establish the relation between the probability of contamination from GM to non-GM and the ratio of total revenues under each state of nature in (6). To show this relation, we next define the indirect profit function associated with (1), and use duality results.

In particular, the indirect value function of (1) is:

$$\pi^* = \pi^*(\underline{p}, R_1, R_2, A)$$

where from the envelope theorem:

$$\partial\pi^*/\partial\underline{p} = -\ [R_1 y_1^{(1)}(\vartheta) + R_2 y_2^{(1)}(\vartheta)] + [R_1 y_1^{(2)}(\vartheta) + R_2\, d_2\, y_2^{(2)}(\vartheta)].$$

Convexity of π^* with respect to $\underline{p}$ (see the Appendix for proof) then implies that

$$\partial\{-\ [R_1 y_1^{(1)}(\vartheta) + R_2 y_2^{(1)}(\vartheta)] + [R_1 y_1^{(2)}(\vartheta) + R_2\, d_2\, y_2^{(2)}(\vartheta)]\}/\partial\underline{p} \geq 0. \tag{7}$$

Hence, as the probability of contamination from GM to non-GM increases, total revenues at the state of nature of contamination increases relative to the revenues at the state of nature of non-contamination where the result in (7) for (6a) directly follows for (6b). Next, the result in (7) is used to determine the sign of the partial derivative of (6) with respect to an exogenous component of the probability of contamination.

In particular, redefine $\underline{p}$ as:

$$\underline{p} = \underline{p}[(A_1/A)*q) = \underline{p}(C) \tag{8}$$

where $q \geq 0$ and q is the exogenous component of (8), and differentiate (6a) with respect to q:

$$Z(\vartheta) = [\partial\{-\ [R_1 y_1^{(1)}(\vartheta) + R_2 y_2^{(1)}(\vartheta)] + [R_1 y_1^{(2)}(\vartheta) + R_2\, d_2\, y_2^{(2)}(\vartheta)]\}/\partial\underline{p}][\partial\underline{p}/\partial(C)][A_1/A]$$

$$+ \{-\ [R_1 y_1^{(1)}(\vartheta) + R_2 y_2^{(1)}(\vartheta)] + [R_1 y_1^{(2)}(\vartheta) + R_2\, d_2\, y_2^{(2)}(\vartheta)]\}\{[\partial\underline{p}^2/\partial C^2]\}[A_1/A].$$

The sign of $Z(\vartheta)$ thus depends on the curvature properties of (8) in (4), and on the results in (6b) and (7). In particular, from (4), (7), and (6b) it follows, respectively, that:

$\partial \underline{p}/\partial C \geq 0$, and $\partial \underline{p}^2/\partial C^2 \leq 0$;

$\partial\{- [R_1 y_1^{(1)} (\vartheta) + R_2 y_2^{(1)} (\vartheta)] + [R_1 y_1^{(2)} (\vartheta) + R_2\, d_2\; y_2^{(2)} (\vartheta)]\} / \partial \underline{p} \geq 0$;

and

$$- \; [R_1 y_1^{(1)}(\vartheta) + R_2 y_2^{(1)} (\vartheta)] \; + \; [R_1 y_1^{(2)}(\vartheta) + R_2\, d_2\, y_2^{(2)} (\vartheta)] \leq 0.$$

Therefore,

$$Z(\vartheta) \geq 0. \qquad (9)$$

But, since (6) is negative, then absolute value of (6) decreases with a higher probability of contamination. Hence, from (9), the shadow value of a social efficient allocation decreases with the probability of contamination from GM to non-GM when (6) is negative. However, the term in (6) is always negative under a state invariant technology to contamination and, therefore, the shadow value from a social optimal allocation of acreages is larger when the probability of contamination is low, which occurs in geographical areas where most crops are non-GM.

The Case of State Dependent Technologies to Contamination Risk

For the case of a state dependent technology to contamination risk, the result in (7) shows that as the probability of contamination from GM to non-GM increases, total revenues at the state of nature of contamination increases relative to the revenues at the state of nature of non-contamination. Moreover, since $\partial \underline{p}/\partial(A_1/A) \geq 0$ in (6a), the likelihood that (6a) is negative (i.e., GM crops are overplanted relative to the social optimum) decreases with the probability of contamination from GM to non-GM. Therefore, in regions where most crops are conventional (where the probability of contamination from GM to non-GM is low), the social efficient acreage allocation for the case of state dependent technologies to contamination is more likely to require less usage of GM than the individual acreage allocation equilibrium.

As in the previous section, the result in (9) shows that the shadow value of a social efficient acreage allocation decreases with the probability of contamination GM to non-GM, if the GM crops are overplanted in a state dependent technology. Therefore, geographical restrictions on GM crops may be needed mostly in regions where most crops are non-GM, and controls on adoption of GM crops should be targeted differently in regions accordingly to whether adoption is expected to be generalized or sporadic.

Summary

The paper has shown that GM crops are overplanted for state invariant technologies in the presence of contamination risk, and the shadow value of a social efficient allocation is larger when the probability of contamination is small. Therefore, major social effects from contamination may occur in regions where GM is starting to grow. For state dependent technologies, the paper shows that the status of GM as being underplanted or overplanted relative to the social optimum is ambiguous. However, the paper establishes that in regions where the probability of contamination is small, it is more likely that the social efficient acreage allocation requires less usage of GM crops. For space dependent technologies in which GM is overplanted, the shadow value of a socially efficient acreage allocation decreases with the probability of contamination.

Appendix

To show convexity with respect to $\underline{p}$, it suffices to show that

$$\pi(\lambda \underline{p}_1 + (1-\lambda)\underline{p}_2, \Gamma) \leq \lambda\pi(\underline{p}_1, \Gamma) + (1-\lambda)\pi(\underline{p}_2, \Gamma)$$

where $0 \leq \lambda \leq 1$, *and* $\Gamma = (R_1, R_2, A)$. The proof is as follows:

At $(\underline{p}_1, \Gamma)$, the optimal acreage allocation is $A_1(\underline{p}_1, \Gamma)$ and $A - A1(\underline{p}_1, \Gamma)$ with a corresponding profit function $\pi(A_1(\underline{p}_1, \Gamma), \underline{p}_1, \Gamma)$, which represents maximum profits when the production environment is characterized by $(\underline{p}_1, \Gamma)$. Therefore,

$$\pi(A_1(\underline{p}_1, \Gamma), \underline{p}_1, \Gamma) \geq \pi(A_1(\underline{p}_3, \Gamma), \underline{p}_1, \Gamma)$$

where $A_1(\underline{p}_3, \Gamma)$ is optimal acreage allocation to GM when the probability of contagion is $\underline{p}_3 = \lambda\underline{p}_1 + (1 - \lambda)\underline{p}_2$. Similarly,

$$\pi(A_1(\underline{p}_2, \Gamma), \underline{p}_2, \Gamma) \geq \pi(A_1(\underline{p}_3, \Gamma), \underline{p}_2, \Gamma)$$

Hence,

$$\lambda\pi(\underline{p}_1, \Gamma) + (1 - \lambda)\pi(\underline{p}_2, \Gamma) \geq \lambda\pi(A_1(\underline{p}_3, \Gamma), \underline{p}_1, \Gamma) + (1 - \lambda)\pi(A_1(\underline{p}_3, \Gamma), \underline{p}_2, \Gamma).$$

However, since $\pi(\underline{p}_1, \Gamma)$ in (1) is linear with respect to $\underline{p}$, then

$$\pi(A_1(\underline{p}_3, \Gamma), \underline{p}_1, \Gamma) + \pi(A_1(\underline{p}_3, \Gamma), \underline{p}_2, \Gamma) = \pi(A_1(\underline{p}_3, \Gamma), \lambda\underline{p}_1 + (1 - \lambda)\underline{p}_2, \Gamma) = \pi(\underline{p}_3, \Gamma) .$$

Consequently,

$$\lambda\pi(\underline{p}_1, \Gamma) + (1 - \lambda)\pi(\underline{p}_2, \Gamma) \geq \pi(\lambda\underline{p}_1 + (1 - \lambda)\underline{p}_2, \Gamma).$$

This shows convexity.

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