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Insuring Against Losses from Transgenic Contamination: The Case of Pharmaceutical Maize

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Abstract

Concerns about the risk of food supply contamination and the resulting financial losses have limited the development and commercialization of certain pharmaceutical plants. This article develops an insurance pricing model that helps translate these concerns into a cost-benefit analysis. The model first estimates the physical dispersal of maize pollen subject to a number of weather parameters. This distribution is then validated with the limited amount of currently available field trial data. The physical distribution is then used to calculate the premium for a fair-valued insurance policy that would fund the destruction of possibly contaminated fields. The flexible framework can be readily adapted to other crops, management practices, and regions.

Keywords: contemporaneous fertility, costs and benefits, insurance, pharmaceutical maize, pollen dispersal, risks and benefits, stochastic model.

Insuring Against Losses from Transgenic Contamination:

The Case of Pharmaceutical Maize

Pharmaceutical crops are those that have been genetically adapted to produce recombinant proteins such as antibodies, enzymes, and vaccines for use in human and animal medicine. To date, these crops have typically been grown on small experimental plots and are viewed as a less expensive and more scalable alternative to the current practice of growing bacteria, yeast, or hamster cells in closed vessel fermentation facilities. Other possible benefits are the absence of animal or cell culture contaminants, and convenience of oral delivery of the product (Graff and Moschini).

To date, about 60% of the approximately 500 approved field trials have been conducted with maize (Stewart and Mclean). Maize is easy to grow and produces relatively high yields. A particular advantage of maize is that kernels that contain the pharmaceutical compound can easily be stored in preparation for the kind of dramatic increase in demand that can occur with vaccines. Because of the ease with which maize can be stored, the costs associated with purification are not borne unless the compound is needed.

Following 2002 and 2003, field trials of pharmaceutical maize fell off in response to concerns by the industry group BIO, the National Food Processors Association, and the Grocery Manufacturers of America about possible cross-contamination of the commodity corn crop. Trial numbers began to increase in 2004 (Graff and Moschini).

The exact locations of these pharmaceutical maize plots are typically not announced because of concerns about possible protest, but it is known that some are located in the Corn Belt (Brasher).

Pharmaceutical maize is grown under stringent guidelines developed by USDA APHIS that are designed to avoid cross-contamination or cross-pollination with commodity maize (USDA-APHIS 2003). These guidelines are based on the best available experimental evidence on pollen movement. These plot-based experiments to evaluate pollen movement were designed to achieve tolerance levels that are much higher than the *zero tolerance* that is currently used by APHIS with respect to pharmaceutical maize.

Weather events that might occur in one in one million years are of little relevance when the acceptable tolerance level is at 1%, but these events may become important at extremely low or zero tolerance levels. The available experimental evidence on pollen movement does not contain information on pollen flows under extreme weather events. It is clearly impractical to use a plot-based experimental design to gather this data because the required weather events are so rare that it might take thousands of years of experimental data to ensure that all possible weather events have been measured. The alternative that is followed here is to use the information that has been collected as well as related information on the physics of particle movement and weather patterns to simulate the probability of long-distance pollen movement.

Many of the antibodies that have been grown or are in the research pipeline are likely safe if ingested through consumption of contaminated commodity maize (Wolt et al.). However, the existing zero tolerance APHIS guidelines may have created the

impression among some that there is zero probability of cross-contamination, and any detection of these products in commodity maize may attract attention and generate a negative consumer reaction. Thus, it seems far more likely that any cross-contamination that does occur will cause economic losses driven by human health concerns rather than any negative impact on human health itself. Under this scenario, the relevant tolerance level is that which can be detected, rather than that which might cause human harm.

Economic harm associated with pollen movement might occur in two ways. In a worst-case scenario, contaminated commodity maize might be detected in the transportation system in commingled product that has lost its identity. Here, losses associated with contamination would be borne by all maize producers and would take the form of a price discount on U.S. maize. A second and less harmful scenario is that the owner of the pharmaceutical maize might realize that unusual weather conditions may have led to contamination of surrounding maize crops. In this case, the economic harm is that which is associated with the destruction of these crops.

This article calculates the fair value of an insurance product that pays for the destruction of any nearby commodity maize that might possibly have been contaminated above a specified tolerance level. These calculations serve three purposes. First, the size of the fair insurance premiums provides a very intuitive measure of the magnitude of the risks that are involved. This risk can then be compared against any economic benefits associated with the production of pharmaceutical maize. The use of a fairly valued insurance product allows us to compare risks against benefits by putting a dollar value to the risk. In so doing, the work presented here attempts to bridge a divide between

biologists who are concerned with risks and benefits and economists who are more used to costs and benefits. A second purpose is that this insurance policy, if available, might provide an incentive structure that would encourage companies to report possible contaminations and provide a way of transferring the costs associated with this risk to the owners of the pharmaceutical maize rather than to the producers of commodity maize who now bear this risk. The availability of such an insurance product would solve the moral hazard problem associated with self-reporting.

The use of an insurance pricing model also solves a technical problem. This problem arises because winds that might move one pollen particle a long way will also move thousands of others. This creates a non-linearity in the relationship between wind speed and the probability of contamination, with zero contamination at low wind speeds and a large amount of contamination once a critical wind speed has been encountered. This problem is solved by insuring against contamination levels *in excess* of a certain tolerance level.

This analysis combines several heretofore-separate research areas. Wind parameters are drawn from a Weibull distribution following the work of meteorologists Seguro and Lambert. The physical movement of pollen through space is then modeled using the Langevin equation from fluid dynamics and climatology as provided by Wilson. In a Monte Carlo exercise, the existing theoretical results are then combined in which one can track millions of pollen grains under all possible wind conditions to calculate the fair value of an insurance policy. This insurance policy is valued using

Monte Carlo procedures that have been used to value revenue insurance (Hennessy, Babcock, and Hayes; Stokes, Hayda, and English; Mahul and Wright).

This article introduces two conceptual advances. First, it solves the agronomic problem associated with a lack of experimental data on distance traveled by pollen under extreme weather conditions, and it does so in a simulation exercise that is accepted in the finance literature (Corwin et al. 1996, Boyle 1975 and 1977). The accuracy of this simulation is shown by replicating the limited data that does exist on pollen dispersion. A second conceptual advance is the use of the Monte Carlo insurance model to allow a translation of *risk* versus benefits that is familiar to biologists into an analysis of *cost* versus benefits that is familiar to economists.

APHIS allows for two different ways to control pollen flow from pharmaceutical plants. The key differences relate to the mandated separation from commodity corn and the control of pollen. Under controlled pollination, producers must detassel the corn or use a male sterile variety. If they are prepared to control pollen in this manner, the mandated separation distance is one-half mile. If pollen is not controlled in this manner, the separation distance increases to one mile.

Given that the possibility of contamination and the fair value of the insurance product are greater than zero, our results raise some questions about who should pay for damage and/or for the insurance product. These same property right issues have come up with respect to contamination from genetically modified crops and, surprisingly, they have not yet been resolved. The paper therefore includes a section on property rights and

shows how the model could be used to help resolve this issue both for pharmaceutical and for genetically modified crops.

Predicting Pollen Dispersal

Previous studies of pollen and gene dispersal in maize have relied upon sample data to estimate the true underlying spatial distribution. This research has depended upon either the physical collection of pollen or the pollination of maize and later identification of distinctive transmitted traits. Only those in the second category capture the relevant dispersal of genes instead of pollen (Feil and Schmidt). As a whole, these analyses are deficient for determining global isolation distances because of the small amount of data collected and the unique set of weather conditions that affected pollen flow for that particular experiment.

Theoretical models, in contrast, allow one to use known physical parameters and relationships to approximate the actual distribution. Having thorough knowledge of fundamental determinants of particle dispersal, one can more accurately estimate the distribution of possible outcomes, especially those events that are rare in occurrence. These models also have the advantage of allowing for unique scenarios to be addressed by simply altering model parameters rather than conducting new field experiments.

Modeling Maize Pollen Dispersal

The Weibull distribution is used to represent the wind speed distribution (Seguro and Lambert). The equation

$$(1) \quad f(x; k, \lambda) = \frac{k}{\lambda} \left(\frac{x}{\lambda} \right)^{k-1} e^{-(x/\lambda)^k}$$

shows the probability distribution function with k , the Weibull shape parameter; λ , the Weibull scale parameter; and x , wind speed. It is important to note that only nonzero wind speeds are used in the calculation.

Pollen Dispersal under Various Wind Conditions

The physical dispersal of pollen is estimated by conducting a Monte Carlo simulation using a Langevin model. Here, the path of many individual particles rather than the concentration of a mass of particles is modeled. We begin with instantaneous wind speeds taken every 15 minutes, and we use these to seed the model. We then implicitly assume that these wind speeds are sustained, but we also recognize that the pollen will be pulled down by gravity and that it will dry out. If the wind conditions are characterized by instantaneous gusts that are not sustained then our model will overstate the distance travelled. For this reason, we have calibrated the model to the actual data that has become available.

The horizontal movement of particles dX is determined by equations (2) and (3). Equations (4) and (5), similar to those presented by Wilson, model vertical movement dZ and satisfy the well-mixed condition outlined by Thomson. They differ in that the maize pollen's settling velocity, v_s , has been added to the vertical field of flow in equation (5) following Aylor and Flesch.

$$(2) \quad U(z) = \frac{u_*}{k} \ln \left(\frac{z-d}{z_0} \right)$$

$$(3) \quad dX = U(Z(t))dt$$

$$(4) \quad dW = \left[-\frac{C_0 \varepsilon(Z)}{2\sigma_w^2(Z)} W + \frac{1}{2} \frac{\partial \sigma_w^2}{\partial z} \left(\frac{W^2}{\sigma_w^2} + 1 \right) \right] + \sqrt{C_0 \varepsilon} d\xi$$

$$(5) \quad dZ = (W - v_s)dt.$$

Equation (2) calculates wind speed, U , as a function of height, z , and other parameters. It requires knowledge of the frictionless wind speed, u^* (whose value may be calculated by rearranging 4 and inputting a sample wind speed), von Karmen's constant, k (a universal value approximately equal to 0.3), the zero displacement level, d , and the roughness length, z_0 . The zero displacement level and roughness length vary according to the ground cover, i.e., maize or soybeans. The zero displacement level for maize has been estimated at 1.7 and the roughness length at 0.3 meters (Hosker and Lindberg). In the case of soybeans, z_0 and d take values of 0.13 and 0.47 meters (Perrier et al.). Equation (3) uses this information to model the horizontal movement of pollen across space. The time step, dt , and its calculation are discussed later in the article.

Equation (4) describes how changes in vertical velocity, W , are generated. Changes are a function of current velocity, W , its variance, σ_w^2 , the TKE dissipation rate, ε , and C_0 , a dimensionless universal coefficient. The second part of the equation includes the stochastic term $d\xi$, which has mean zero and variance dt . Equation (5)

describes the vertical movement of pollen across space, which accounts for the settling velocity, v_s , of pollen.

Equations (3) and (5) are very similar to those used in continuous-time finance to model the movement of prices. In this context, equation (3) shows the evolution of prices across time and equation (5) shows the level of drift in prices. In this model the drift term is typically downwards because of the influence of gravity on the pollen spore, whereas the drift term in finance is typically upwards to allow for the cost of carry.

For the Monte Carlo simulation, the wind speed profile represented by the Weibull distribution (1) provides the basis for the derivation of other necessary atmospheric values. In the case of calibration, either a distribution or a representative wind speed may be used.

Using the value of frictionless wind velocity, one is able to determine the values of σ_w and T_l , the standard deviation of vertical wind velocity, and the Langevin timescale, using equations (6) and (7).

$$(6) \quad \sigma_w = 1.3u^*$$

$$(7) \quad T_l = \frac{ku^*z}{\sigma_w^2}.$$

The model is modified to address the relatively large size of the maize pollen. Walklate recommended the adjustment of the variance of the fluid downward to reflect the drag associated with larger particle sizes. Wilson, however, found the difference between those with altered and unaltered variance negligible and thus the adjustment is

ignored by the model. The model includes a scaled time step using the equation derived by Sawford and Guest and used by Aylor and Flesch in their study of spore dispersal.

Equations (8) and (9) present the relationships between the Langevin time scale, T_l and τ , and the velocity time scale. In (9), β is a constant relating the Eulerian timescale to the Langevin timescale and is placed equal to 1.5 in this study as by Sawford and Guest, and Aylor and Flesch.

$$(8) \quad \tau = fT_l$$

$$(9) \quad f = \frac{1}{\sqrt{1 + (\beta v_s / \sigma_w)^2}}$$

Next, the deposition from the air onto either open ground or other crops is addressed. The deposition of pollen onto open ground and non-fertile maize occurs when the pollen crosses a certain height, z_s . This height is set equal the zero plane displacement level, d .

For deposition onto fertile maize, the biological processes involved are discounted. The probability of pollination of a plant by source pollen is defined as a ratio

$$(10) \quad P = Q_T / Q_V$$

where Q_T is the amount of transgenic pollen and Q_V is the total amount of viable pollen in the vicinity of the plant (Emberlin, Adams-Groom, and Tidmarsh).

Growers of the pharmaceutical maize may choose to make use of a biological mechanism, such as those described by Daniell, to reduce the likelihood of gene dispersal. The mechanism used is assumed to be imperfect, failing a certain percentage of the time. This failure results in the release of pollen containing restricted transgenes that

can be transferred to other maize. Because the model is linear, this probability can be adjusted for different failure rates in these biological mechanisms. For example, if the biological process has a failure rate of 10% instead of the 1% assumed here, then the resulting probabilities would be 10 times the size of those presented. Similarly, the model can also be adapted to incorporate bagging or detasseling by dividing through by the rate of human error. Equation (10) can be modified to address the likelihood of genetic seepage, P_s , as shown in (11).

$$(11) \quad P = \frac{P_s Q_r}{Q_v}$$

The federal regulations that require a temporal separation of planting times of maize likely have further-reaching effects. This results from the assumption that producers of pharmaceutical maize do not dictate the time of maize planting outside their field but rather delay their planting relative to surrounding maize production by the time denoted by federal regulations. While federal timing conditions must be met within designated distances, it is possible that maize produced beyond this distance, because it is planted relatively late or develops more slowly, could share a period of fertility with the pharmaceutical-producing crop.

To accommodate for the contemporaneous fertility of the pharmaceutical and neighboring maize crops, a distribution of periods of fertility is constructed. This distribution is derived using USDA Crop Progress Reports data on silk emergence, a proxy for fertility, in the state of Iowa. The time of silk emergence is assumed to follow a normal distribution, with both parameters estimated from the silking data. The results

indicate that a test plot planted 28 days after those within one-half and one mile will share a period of fertility with fields outside the regulated distance with a probability of approximately 1%.

Validation of the Model

The model is validated using data from field trials presented by Goggi et al. In this study, 1 hectare of yellow transgenic maize was planted within a 36-hectare field of white non-transgenic maize at the Iowa State University Experiment Farm in Ankeny, Iowa,¹ during 2003 and 2004. Both fields were managed with normal production practices and monitored to determine silk exposure and pollen shed, during which time a portable weather station was placed in the field. Wind speed and direction were measured at 3.17 meters with 15-minute average values recorded during periods of pollination shed.

Twenty-five ears of maize were harvested at distances of 1, 10, and 35 meters from the transgenic plot, while 100 ears were collected at distances of 100, 150, 200, and 250 meters, the minimum sample sizes needed to ensure detection of a minimum level of outcrossing. Ears were then shelled and sorted by machine and were then inspected by hand to ensure all yellow seed had been identified. Next, the number of seeds in 454 grams was counted by machine, and the total number of yellow or white was estimated by multiplying the number of seeds counted by color times the sample weight. If the total yellow kernel sample weight was less than 454 grams, seeds were counted by hand.

Synchrony between pollen release from the yellow transgenic plot and silk exposure by the white non-transgenic maize occurred over July 30-31 in the 2003

experiment and over July 19-21 in 2004. The highest percentage of outcross for both years was to the south downwind from the prevalent wind during the days of flowering synchrony. Table 1 presents the maximum and average of wind speeds in m s^{-1} .

Table 2 presents the actual relative outcrossing of yellow transgenic maize along each of the three downwind transects. Relative outcrossing is calculated by normalizing the outcrossing percentage by the percentage of outcrossed kernels from the 1-meter sample. For example, the amount of outcrossed kernels along the SW transect in 2003 at 35 meters was 1.33% of that at 1 meter. This method is used because the actual amount of pollen released by each maize field is unknown but assumed to be equal.

Table 3 presents the percentage of relative outcrossing generated using the Langevin model at wind speeds of 1, 2, and 3 meters per second. For the two highest wind speeds, the percentage of relative outcrossing predicted by the model serves as the upper bounds of actual outcrossing, as presented in table 2. At a wind speed of 1 meter per second, the amount of outcrossing predicted by the model is less than that measured by Goggi et al. Given the actual wind speeds measured by Goggi et al. presented in table 1 and the impossibility of measuring which gust of wind carried each grain of pollen, the model does a very credible job of predicting the actual outcomes.

A reviewer pointed out that one should be very careful about extrapolating pollen dispersal data based on only two years of observations. As was mentioned in the introduction, the results of relevance to this study are all in the extreme tails of the wind distribution, and these data are not likely to have occurred in the limited wind data that we have. This means that the calibration results should be treated with caution. However

it is also true that it might take decades of field experiments to obtain actual pollen dispersal data that results from extreme wind events even if one could afford to run the Goggi et al. trials in a way that allowed one to measure out-crossing at such extreme distances. This reviewer also pointed out that these pollen dispersal results are specific to the location of these trials. In corn growing areas where the topography is different from Central Iowa, the actual pollen dispersal results might be very different.

Application of the Model

Wind data collected at Boone Airport in Central Iowa from 1986 to 2007 between 9 a.m. and noon during the third week of July was used to estimate four Weibull distributions in each of the cardinal directions. This is the approximate time of maize pollination during recent years in Iowa (Miller). Daily wind direction is modeled using a Markov chain.

The probability of contamination of fields neighboring the source field is determined by simulating 10,000,000 crop years using knowledge of the distributions of wind speed, wind direction, and the pollen dispersal model described previously. For each year, first-day wind direction is generated using the initial distribution. Wind speed, generated conditionally on wind direction, provides the necessary information to model pollen dispersal. The next day's wind speed is determined using the transition matrix, with the process repeating until data for seven days of pollen dispersal are simulated.

It is assumed that source and receptor fields, each 40 acres in size, release the same amount of pollen equally over the seven-day period, with receptor fields being at one-half, three-quarters, or one mile depending on the scenario (figure 1). When the

relative level of source pollen to receptor pollen exceeds the tolerance in the downwind direction, the receptor field is considered contaminated, and the direction and distance from the source field are recorded. Contamination of fields by distance and direction is tallied across the 10,000,000 crop years. The probability of contamination is calculated by dividing the number of years that contamination occurs by 10,000,000.

Contamination Levels under APHIS Production Guidelines

The probability of contamination by distance and direction for uncontrolled pollination is presented in table 4. With a tolerance level of .001, the probability of contamination of a 40-acre field one-half mile downwind from the source field is .0024. For a 40-acre field located three-quarters of a mile or further downwind, the probability of exceeding a tolerance level of .001 is 0, meaning that none of our simulations produced such an event. The probability that contamination occurs in more than one direction at a distance of one-half mile or more when the tolerance level is .001 is also 0. With a tolerance of .00065, the probability of contamination of a 40-acre field one-half mile downwind increases to .135. At three-quarters of a mile downwind the probability of contamination is .000025. The probability of contamination a mile or more downwind or in more than one direction one-half mile from the source is 0.

With a tolerance of .0005, the probability of contamination of a 40-acre field one-half mile downwind in at least one direction is .4; in two directions, it is .00005. The probability of contamination of a 40-acre field three-quarters of a mile downwind is .015. For a distance of one mile the probability of contamination is .003.

APHIS controlled production guidelines allow for pharmaceutical corn to be produced as close as one-half mile from non-pharmaceutical corn when using bagging or detasseling and when at least 28 days separation between planting occurs. The results in table 5 assume failure rates of .01 for bagging and detasseling, and a calculated .01 probability that the source and neighboring crops are simultaneously fertile to show the probability of contamination under these controlled conditions. These results show that the probability of exceeding a tolerance level of 0.0005 is zero. The probability of exceeding a tolerance level of 0.0001 under APHIS controlled management practices is 0.000024, or about once every 40,000 years. The probability of exceeding a tolerance level of 0.000005 is 0.004, or about once every 250 years.

Note that the tolerance levels used in tables 4 and 5 are chosen to emphasize the conditions under which the probabilities are non-zero. As a result, the tolerances in table 5 are much lower than in table 4. These tables do contain one common tolerance level of .0001 for purposes of comparison.

Comparison of the results in Tables 4 and 5 show a very large difference between the two approved APHIS production methods. Even though the uncontrolled production method has a separation of one mile, the probability of contamination is far greater than with controlled contamination and a distance of only one-half mile. The intuition here is that high wind speeds can easily move the pollen cloud a distance of more than the required separation distance of one mile. High wind speeds are not uncommon when compared to the very small tolerances that are used. Once this pollen is airborne, it must still find and fertilize a receptive female that has typically been planted at least 28 days

previously. These receptive females will be relatively rare because of the temporal separation, but the sheer size of the pollen cloud and the large number of females within the relevant radius makes it likely that some females will be fertilized. This result is consistent with the theoretical result contained in Aylor, Schultes, and Shields, which reports that “although pollen concentrations decrease rapidly with the distance from the source, they are directly proportional to the size of the source” and that “experiments using small plots can lead to the erroneous conclusion that pollen concentration will decrease exponentially with distance from a large source.”

Insuring Against Catastrophic Risk

Although probability theory rules out the possibility of completely eliminating genetic contamination in a theoretical sense, in cases in which low levels of contamination are acceptable, risk management tools can be used to offset financial losses resulting from contamination. While the contaminated maize could be blended to meet minimum acceptability levels, possibly resulting in costs less than those of destroying the crop, this practice will be ignored here. Instead, it is assumed that a wind speed monitor is installed in the pharmaceutical field and that whenever the wind speed is such that the probability of contamination exceeds the specified level, the crop is purchased and destroyed.

Theories, methods, and measures from the field of catastrophic risk management are employed because of the correlation of claims. As “correlation between sites drops off quickly with distance” (Namovisz 2003), claims are asserted to be independent of one another. This differs from traditional areas in which catastrophic risk management

methods have been employed (e.g., earthquakes, hurricanes) whereby claims are often correlated and solvency issues are significant.

An exceedance probability curve provides the necessary information to calculate the expected loss, average annual loss, and probable maximum loss. They are calculated using the framework presented by Grossi, Kunreuther, and Windeler (2005).

In the context of genetic contamination resulting from pollen dispersal by wind, define E_i as a wind event that occurs with annual probability p_i , resulting in a loss of L_i . With events assumed to be independent Bernoulli random variables, each has a probability mass function defined as $P(E_i \text{ occurs}) = p_i$, $P(E_i \text{ does not occur}) = (1 - p_i)$.

The expected loss from a particular event in a given year is

$$(12) \quad E[L_i] = p_i L_i.$$

The average annual loss is the expected loss from all events in a given year:

$$(13) \quad AAL = \sum_i p_i L_i.$$

If during a given year only one disaster occurs, the exceedance probability for a given level of loss, $EP(L_i)$, is given by

$$(14) \quad EP(L_i) = (P(L > L_i) = 1 - P(L \leq L_i))$$

$$(15) \quad EP(L_i) = 1 - \prod_{j=1}^i (1 - p_j).$$

The probable maximum loss (PML) is the loss associated with a given probability of exceedance.

It is assumed that crop yield is 150 bushels per acre and that the market price is three dollars per bushel. Thus, the cost of destroying a 40-acre field is \$18,000. As stated previously, all fields in the downwind direction are destroyed. So at one-half mile, seven fields would be destroyed if the level of contamination exceeds the acceptable level, while at three-quarters of a mile, nine fields would be destroyed. It is assumed that producers follow APHIS controlled production guidelines, detasseling corn and staggering planting.

With a tolerance of .00001 and controlled pollination, destruction of fields one-half mile downwind would be necessary only about once every 40,000 years. The expected loss would be \$4.20.

Catastrophic risk measures for tolerances of .000005 and controlled pollination are presented in table 6. Five events are considered, with the probability of no loss being the highest. The average annual loss is \$561. Contamination of fields in two directions one-half mile from the source field is rare, with an annual probability of occurrence of .0000005, but with a relatively high loss of \$234,000. The annual expected loss from such an event is \$0.12. The most costly occurrence would be contamination of fields just over one mile from the source, at \$486,000. The annual expected loss from this event is \$14.58. The contamination event with the highest annual probability occurrence is for contamination of fields one-half mile from the source in a single direction. While the resulting loss is the lowest, at \$126,000, the high probability of contamination results in the event having the highest annual expected loss of \$504.

This tolerance level of .000005 is extremely low and yet these expected losses are small relative to the value of pharmaceutical crops. This suggests that when pollen is controlled, the APHIS guidelines do come close to meeting the zero tolerance guideline that has been proposed, and it also suggests that some of the controversy surrounding this issue has been overblown. However the results shown in table 4 show that when pollen is uncontrolled these conclusions can be reversed.

Pollen versus Property Rights

The previous analysis raises the question as to who should pay for such an insurance product and equivalently who should pay for uninsured crops that are damaged by pollen flow. One would expect that the legal rules surrounding this issue would have long ago been established because of existing pollen flow issues between GM and non-GM crops, especially for crops sold as certified organic production. As it turns out, much has been written about this issue, but the legal questions have not been resolved, in part because there has not yet been a legal case in the United States.

Much can be learned about the property rights issue based on what has been written about GM pollen flow, and in addition, it turns out that our model can help shed some light on the tolerance levels that might be used if, as now seems likely, the GM pollen flow issue does motivate a damage case.

In a classic study entitled “Of Coase and Cattle,” Ellickson (1986) described how rural landowners in Shasta County, California, responded to a series of legal changes that allocated property rights associated with damage caused by cattle trespass, first to the

owner of the livestock, and then back to the owner of the land damaged by livestock. The choice of Shasta County was ideal because the county board had implemented and then removed several closed-range ordinances over the period examined in the study. The study shows that the landowners responded exactly as Coase had predicted in that the initial allocation of property rights did not have an impact on the size of the cattle herds or the quality of the fences.

However, the field evidence that was gathered “suggests that a change in animal trespass law indeed fails to affect resource allocation not because transactions costs are low, but because transactions costs are high.” Rather than use the legal system to enforce the ever-changing property rights, the participants ignored the formal law in order to reduce legal expenses and to maintain the health of “complex continuing relationships that enable them to enforce informal norms.”

The U.S. legal system has not finalized rules associated with damage caused by pollen drift. However, as argued by Kershen (2004) with respect to inadvertent pollen from genetically modified and patented plants into the surrounding field, “the law of stray animals is the best candidate for a satisfactory resolution, in most fact patterns of the issue of inadvertent presence in patent infringement cases” (Kershen 2004, page 592). Under this interpretation, the owners of patented plants “become subject to liability for any damage caused by trespass” (Kershen 2004, page 602).

In circumstances in which the roving animal or pollen mates with a receptive female, the amount of damage is related to the “reduction in value of the female ... in accordance with the greater number of authorities” and in addition may be also entitled to

“show the difference in value of the offspring born from the trespassory breeding [in a] minority of jurisdictions” (Kershen 2004, page 597). In the case of organic crops, so long as the organic grower has taken reasonable steps to avoid contact with genetically modified seeds, the patent holder of the genetically modified seeds “would then have the duty to promptly respond to remove transgenic plants and seeds from the organic farmer’s fields” (Kershen 2004, page 609).

A very similar situation to that described by Ellickson appears to have occurred with respect to property rights associated with damages caused by pollen drift from genetically modified varieties to conventional or organic fields. The recipients of unwanted pollen appear to have the right (under the law of stray animals) to collect damages associated with drift, but they have not yet pursued this right via the legal system. To date, no reported case has assessed liability for the farm-to-farm admixture of genetically modified DNA via pollen drift (Endres 2005, section A. 1.). The reasons for this lack of action also appear to be very similar to those described by Ellickson and relate to “complex continuing relations” that enforce informal norms in U.S. agriculture.

As discussed in Endres (2005), seed companies recognize that they are often subject to damage when their seed fields are contaminated by pollen flow, but they also own patents on genetic modifications and may even have sold the seed that produced the offending pollen. Farmers, regulators, grain handlers, and processors typically recognize the value of the genetically modified varieties to agriculture and are sometimes involved in both GM and non-GM production.

Producers who specialize in organic production have apparently decided that the transaction costs associated with the legal enforcement of their property rights as well as those associated with the loss of goodwill among neighbors exceed the damages that are caused by the pollen flow. As a result, “specialty crop producers (including organic producers) have historically borne all of the costs necessary to achieve desired purity standards” (Endres 2005 Section A.1). They are supported in this approach by USDA organic standards that specifically allow for the “presence of a detectable residue of a product of excluded methods” so long as the organic producer has “not used the excluded methods and has taken reasonable steps to avoid contact with the products of excluded methods” (National Organic Program 2000).

This “don’t ask, don’t tell” policy has not suited all groups. In recent years, consumers, particularly those in the EU, have begun to participate in the process. Under 2003 guidelines issued by the European Commission, “farmers introducing a new production type (presumably GM crop production) must bear the responsibility for implementing the farm management practices necessary to limit admixture” (Endres, Section B.1). Food or feed that has a proportion of GMOs in excess of 0.9 of approved GM varieties may not be marketed in the EU. The tolerance for non-EU-approved GMOs is zero. Private organic certification organizations “in response to consumer demand” have imposed their own tolerance standards, and as a result, some grain elevators and processors have recently begun to refuse to accept otherwise organically certified shipments, or shipments destined for the EU that contain adventitious amounts of

modified DNA (Endres, Section A 3). Some counties in California have established GM-free zones to avoid drifting GM pollen.

Endres argues that the current situation will cause the domestic agricultural community to face continued uncertainty and a patchwork of questionably effective regulations. With the widespread adoption of GM corn in the U.S., it appears impractical to attempt to limit the flow of pollen from these fields. Instead, he proposes a “complete study of the extent of adventitious presence” and a revision of domestic laws to provide accurate information. In other words, one needs to acknowledge that all U.S. corn now carries a certain amount of GM contamination and that this base level can be measured and used as a base for a new tolerance level. Once this has been decided, then the GM and non-GM sectors will be in a position to co-exist. Consumers who purchase U.S. corn would do so knowing that a minor amount of contamination existed, and they would not be in a position to reject or discount shipments so long as this tolerance level was not exceeded. Endres does not propose a tolerance level, in part because the current level of contamination was not known prior to the results presented here.

As is true for contamination of commodity pollen from pharmaceutical pollen, the actual level of contamination will vary from location to location and year to year because of differences in wind speed and topography. Sampling across locations and years will eventually provide a measure of the contamination level, but this kind of sampling is expensive and must necessarily include several years of data. The proposed model has the potential to bootstrap this process by allowing simulations across topographies and climatic conditions.

The model presented earlier was used to assess the likelihood that a 1% tolerance level was exceeded in 40-acre cornfields that were 10 yards away from the source field. It was assumed that there was no temporal separation. The results suggested that the probability of exceeding this tolerance level in at least one of the surrounding fields was 27%. This suggests that by now most seed lines and most commodity corn production in the U.S. has a high chance of failing a 1% standard.

The model was also used to simulate the level of contamination in a field that is one-half mile from the GM source field, again assuming no temporal separation. The expected contamination for these two 40-acre fields was .0002625. This very low level suggests that it is relatively easy to meet a 1% tolerance level if some attempt is made to isolate the non-GM field. If U.S. regulatory bodies, or the U.S. private sector, ever implement a tolerance level for GM crops, this model, appropriately adjusted for local wind and topographical conditions, should be of use for determining appropriate spatial isolations.

Summary and Conclusions

This research provides estimates of the fair-value price of insurance to protect against transgenic contamination of maize grown under two alternative current federal guidelines regarding pharmaceutical maize production. The method bootstraps existing plot-based data on pollen dispersal by means of a Monte Carlo model that simulates wind speeds and the physical movement of pollen under these wind speeds. By framing the question in terms of an insurance product, one can compare the risks and benefits that are familiar to biologists with the costs and benefits that are familiar to economists.

Because of the extremely low tolerance levels that are used, the results are open to interpretation. At a tolerance level of 0.0005, APHIS guidelines that involve the control of pollination at the pharmaceutical plot and a one-half mile separation achieve the zero tolerance target in all of our 10 million scenarios. However APHIS guidelines for fields where pollen is not controlled and where a one-mile separation is used, all fail the zero tolerance guideline at the same 0.0005 tolerance level.

These results do have policy implications. If future tolerances used in the marketplace are in the range of the tolerance levels provided here, then the production and regulation of pharmaceutical maize in the Corn Belt with uncontrolled pollen might eventually lead to a discovery of contamination in commodity corn. However, the results also suggest that so long as pollen is controlled in pharmaceutical maize, the risk of accidental release is very close to the target level of zero.

Our paper raises some interesting questions about who should pay for damage and/or for the insurance product. These same property right issues have rights because damage will typically occur on fields that are owned by individuals who are not involved in the pharmaceutical production process. This same issue has come up with respect to pollen flow from genetically modified crops and, surprisingly, the issue has not yet been resolved. It appears that the owners of surrounding fields have the right to damages under the same rules that protect against damage done by straying animals. But these rights have not been enforced because it has not been possible to predict the probability of adventitious presence. This paper also shows how the model can be used to address this issue.

Endnotes

¹ This farm is approximately 30 miles southeast of the Boone airport site used to collect the wind data.

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Table 1. Wind Speed Summary Statistics (in m/sec)

Year	Date	Max	Average
2003	July 30	2.3	1.6
	July 31	2.9	2.0
2004	July 19	2.2	1.8
	July 20	1.3	0.7
	July 21	2.1	1.5

Table 2. Relative Outcrossing from Goggi et al.

		Transect		
Year		SE	S	SW
Relative Outcrossing (%)				
2003	1	100.00	100.00	100.00
	10	8.28	7.13	6.43
	35	1.91	0.92	1.33
	100	0.11	0.14	0.09
	150	0.06	0.09	0.01
	200	0.02	0.02	0.02
	250	0.01		0.00
2004	1	100.00	100.00	100.00
	10	20.75	6.86	7.79
	35	3.30	1.31	2.60
	100	0.42	0.10	0.32
	150	0.05	0.07	0.13
	200	0.05	0.03	0.06
	250	—	0.07	0.26

Table 3. Relative Outcrossing Predicted by the Model

Distance (m)	Windspeed		
	3 m/sec	2 m/sec	1 m/sec
	Relative Outcrossing (%)		
1	100.00	100.00	100.00
10	18.53	18.73	0.42
35	7.26	6.93	0.04
100	2.53	2.35	0.01
150	1.49	1.38	0.01
200	1.07	0.96	0.00
250	0.83	0.74	0.00

Table 4. Probability of Contamination for Uncontrolled Scenario

Distance (miles)	Directions	Tolerance			
		0.001	0.00065	0.0005	0.00001
0.5	1	0.0024	0.135	0.4	1
0.5	2	0	0	0.00005	0.0996
0.75	1	0	0.000025	0.015	1
1.0	1	0	0	0.003	1

Table 5. Probability of Contamination for Controlled Scenario

Distance (miles)	Directions	Tolerance			
		0.0005	0.00001	0.0000065	0.000005
0.5	1	0	0.000024	0.00135	0.004
0.5	2	0	0	0	0.0000005
0.75	1	0	0	0.00000025	0.00015
1.0	1	0	0	0	0.00003

Table 6. Catastrophic Risk Measures Tolerance of 0.000005

Distance (miles)	Number of directions	Annual probability of occurrence	Loss	Exceedance probability	Expected loss
0.5	2	0.0000005	\$234,000	0.0000005	\$0.12
1.0	1	0.00003	\$486,000	0.0000305	\$14.58
0.75	1	0.00015	\$288,000	0.00030495	\$43.50
0.5	1	0.004	\$126,000	0.004179773	\$504.00
—	—	0.99582	0	0.995837	0
Average annual loss					\$561.90

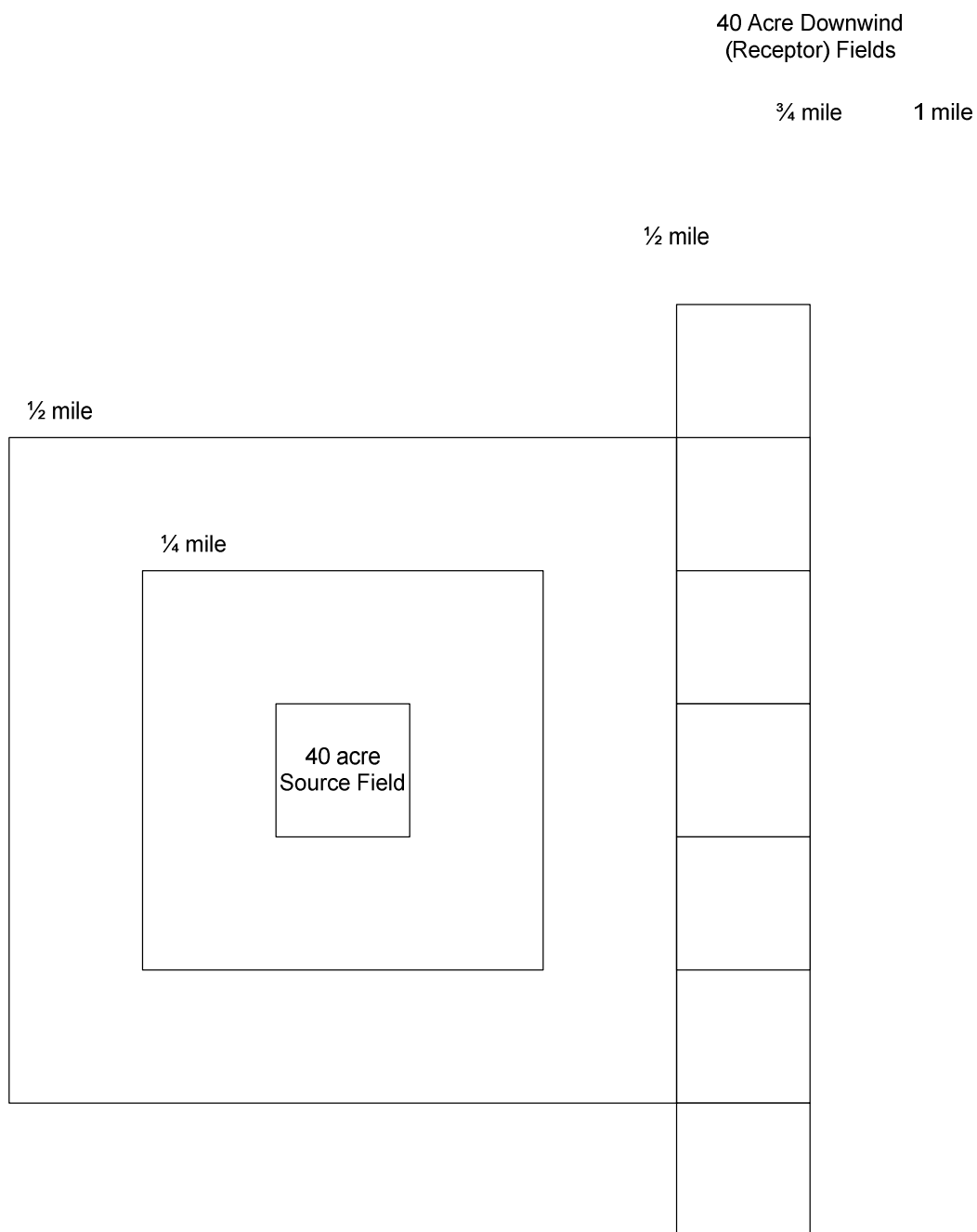


Figure 1. Management scenarios