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Contributed Paper presented to the 47th Annual Conference

Of the Australian Agricultural and Resource Economics Society

At

Fremantle,

February 12-14, 2003

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ABSTRACT. This study examined the potential economic impacts in the United States of the commercial adoption of a corn rootworm (CRW) resistant transgenic corn. Using a counterfactual approach, we estimated that if the technology had been made available in the year 2000 at a price that would equate per acre costs to those for insecticide-based corn rootworm control, and adopted on all of the acres treated for corn rootworm in that year, the total benefits would have been $460 million. This benefit includes $171 million to the technology developer and seed companies, $231 million to farmers from yield gains, and a further $58 million to farmers from reduced risk, time savings, and other non-pecuniary benefits associated with reduced use of insecticides. This is a one-year benefit with 100 percent adoption. Our nation-wide survey of corn producers suggests that initial adoption might be as low as 30 percent, which means that the first-year benefits might be only one-third of the value implied by 100 percent adoption. Different pricing assumptions would mostly change the distribution of the benefits between farmers and others, so long as the pricing did not influence the adoption rate as well. Benefits over time would reflect changing adoption patterns and evolving insect resistance. Further analysis could include the effects of any refuge requirements implemented to slow the development of resistance, when such requirements are known.

1. Introduction

Transgenic technologies are changing the face of agricultural production. The innovation process that began to take commercial effect less than ten years ago has already had major impacts, and the significance and value of those past impacts has been evaluated in a rapidly growing number of economic evaluation studies (e.g., see Marra, Pardey, and Alston for a review of the work on farm-level impacts). The past evaluation studies have included both *ex ante* and *ex post* evaluations of both farm-level and aggregative impacts. In all such work, issues arise about the methods and data used, and their implications for the analysis. In this paper we report the results of an *ex ante* analysis of an important new transgenic corn technology. It is described in our survey work as a generic transgenic corn developed to be resistant to the corn rootworm, planted with a seed treatment to control additional corn insect pests, or "CRW resistant transgenic corn."[1]

The purpose of this study was to estimate the likely economic impacts in the United States of the commercial adoption of this technology. The study involved evaluating the farm-level economic impacts of the adoption of CRW-resistant corn varieties and translating those farm-level impacts into an estimate of the economy-wide impacts. In conducting this analysis we used information from an extensive data base on the actual incidence of the problems across agroecological environments, combined with experimental data on the consequences of the alternative treatments for corn rootworm (various pesticides and CRW-resistant transgenic corn technology) under different levels of corn rootworm infestation, in addition to a computer-assisted telephone survey of 601 corn farmers.

[1] The first introduction of CRW resistant transgenic corn, which is designated as Yieldgard® Rootworm, was developed by Monsanto and is currently in the approval process.

The scope of a study of this type could be very broad. Adoption responses are central to the analysis of new technologies. These responses are driven primarily by relative profitability, which, in the case of seed technologies such as CRW-resistant transgenic corn, depends on the price of the new seed, its performance, and on the availability, nature, and relative price of close substitutes, including other CRW-resistant corn technologies, or conventional CRW control technologies. As well as determining adoption, the availability and relative price of the various alternatives are critical determinants of the benefits from any particular technological package at the level of both the individual farm and the nation. To make the problem manageable, we adopted a counterfactual approach, in which we compared hypothetical (counterfactual) alternatives against the actual past outcomes, under a set of assumptions that would imply a specific pattern of adoption. Specifically, we set out to estimate what would have been the impacts in a specific recent past year—i.e., 2000—if CRW-resistant transgenic corn technology had been available, was priced such that the variable cost per acre would be the same as for a representative conventional (non-transgenic) CRW control technology, and was the only transgenic CRW control technology available.

The remainder of this paper is structured as follows. In section 2 we begin with a brief discussion of the nature of the economic problem caused by corn rootworm, including relevant information about the biology of the pest, its prevalence, the extent of the economic damage it causes (including both control costs and crop losses), and its implications for production practices (including rotations and the use of insecticides, and some of the burdens these impose on farmers and their neighbors). Key simplifying assumptions used in the analysis are set forth in section 3. Section 4 lays out an approach to understanding and quantifying the economic determinants of the likely future patterns of adoption of the new transgenic CRW technology, and for translating those patterns into estimates of farm-level and national benefits. Section 5 presents the actual methodology used in this study and the quantitative results on farm-level benefits. Along with best-bet estimates, we provide some simple sensitivity analysis to show how the benefits from adoption depend on key variables in the analysis. The measures of benefits in section 5 include only the pecuniary benefits associated with improvements in farm productivity. They do not include some non-pecuniary benefits perceived by farmers, associated with the use of non-chemical technologies. Measures of these non-pecuniary benefits, based on a survey of corn growers, are presented in section 6. Section 7 summarizes results and concludes the paper.

2. Nature and Economic Importance of Corn Rootworm

Corn rootworm (*Diabrotica* spp.) causes extensive economic damage to corn in the United States. Populations of the western corn rootworm (*D. virgifera virgifera* Le Conte) and the northern corn rootworm (*D. barberi* Smith and Lawrence) together are estimated to result in annual yield losses and control costs that exceed $1 billion (Metcalf). The larvae hatch in the spring and feed on corn roots for several weeks. The damage to the roots can result in stunted growth of the corn plant, lodging, and eventual yield losses. Adults emerge from the soil in the summer and female adult corn rootworms lay their eggs to overwinter in the soil. Dense populations of feeding adults can cause some yield loss but most of the damage is caused by the root feeding of the larval stages (Wright, Meinke and Jarvi).

In general, corn rootworms cannot complete their life cycle without the food supplied by corn plants. Therefore, until recently they caused damage almost exclusively in fields where corn is grown at least two years in a row. A crop rotation with one year of corn has been an effective control strategy. Lately, however, two variants of corn rootworm have developed. The soybean variant (SBV) of the western corn rootworm has adapted its egg-laying behavior to lay eggs in crops other than corn (Levine and Oloumi-Sadeghi). So, in areas where corn/soybean rotations are common, eggs laid in soybean fields will hatch in corn fields in the following spring. It evolved in eastern Illinois and has since spread into Indiana, Michigan and Ohio (Onstad et al.). The extended diapause variant (EDV) of the northern corn rootworm has adapted to two-year corn rotations as well (Krysan, Jackson, and Lew). While most corn rootworm eggs hatch in the following spring, for the EDV, some of the eggs hatch after two winters and, thus, the larval stages are able to feed on corn roots even in rotated corn. The EDV is most prevalent in eastern South Dakota, northeastern Nebraska, northwestern Iowa, and southeastern Minnesota.

We identified a total of 11 distinct corn production regions (or sub-regions) in the United States, which we treat as separate agroecologies for the purposes of this analysis. The regions are roughly equivalent to the nine Farm Resource Regions as recently defined by the Economic Research Service of USDA (Heartland, Northern Crescent, Northern Great Plains, Prairie Gateway, Eastern Uplands, Southern Seaboard, Fruitful Rim, Basin and Range, and Mississippi Portal) plus two additional sub-regions within the Heartland where the two corn rootworm variants, the extended diapause variant (the EDV region) and the soybean variant (the SBV region), are currently found. Table 1 presents an overview of corn production in the 11 regions as defined in this study. Within all of the regions corn is grown either continuously or as an element of a crop rotation plan. In many regions corn rootworm is a significant problem only in continuous corn. In the Heartland region, in particular, however, corn rootworm damage can be a significant problem both in first-year corn (corn grown where a different crop was grown in the previous year) and in continuous corn (corn grown where corn was grown in the previous year). These observations are reflected in the figures for the percentages of continuous and first-year corn acreage treated for corn rootworm (table 1), and the treated acres of continuous and first-year corn (table 2).[2]

[Table 1: *Corn Acreages and Shares Treated for CRW, by Region in 2000*]

[Table 2: *Treated Acres,…Insecticides, and Average Cost per Acre, by Region*]

Control methods available currently to deal with the corn rootworm problem include (a) crop rotation (in all but the EDV and SBV regions), (b) soil-applied insecticides to control corn rootworm larvae, and (c) insecticide sprays to control corn rootworm adult beetles. The opportunity cost of rotation is assumed to be positive in many areas, given the large acreage of continuous corn each year. Table 2 presents an overview of conventional corn rootworm insecticide use by region in crop year 2000. The cost of soil-applied insecticides averaged about $12.43 per acre in material and application costs across the United States, but varied slightly among regions.[3] Spraying for adult beetles is not as prevalent as soil-applied larval control (USDA-NASS). Total expenditure for corn rootworm-targeted insecticides topped $171 million in the 2000 crop year (Doane's Market Research).

3. Key Assumptions

As noted above, we assume that the seed price premium is set so that the variable cost per acre for the new technology equals that of the next-best alternative technology. We also

[2] Multiplying the total acreage by the percentage treated for corn rootworm in table 1 yields the number of acres treated. In the figures for "treated acres" in table 2 some acres are counted more than once, reflecting the fact that some acres were treated more than once.

[3] The figures for CRW insecticide cost per acre in table 2 were from Doane's Market Research (2000). They refer specifically to the cost of materials, but they are regarded as providing a reasonable measure of total insecticide costs including costs of both materials and application, since the insecticides were applied at planting.

assume there is no price premium or discount for the transgenic over conventional corn and that the transgenic corn yields at least as well as the conventional alternative. These two assumptions combined mean that CRW-resistant transgenic corn would have been at least as profitable, per acre, as the conventional alternative. Some other factors, both pecuniary and non-pecuniary in nature, also affect the grower's decision to adopt the technology.

The CRW-resistant transgenic corn technology is expected to provide a yield gain relative to conventional control, since its effectiveness does not depend on timing, weather, calibration of application equipment, or soil condition. This yield gain is estimated to range between 0 and 7 percent, depending on the insect pressure (Mitchell). In addition, the CRW-resistant transgenic corn technology will be safer and more convenient for operators and farm workers to handle relative to conventional chemical treatments, and it also may yield some savings in planting time.[4]

Along with the other features of the technology, our pricing assumptions imply that profit-maximizing producers would have adopted CRW-resistant transgenic corn on all of the acres that were treated for corn rootworm in that year. They also imply that the benefits from any resulting yield gains (and other on-farm benefits) would have been captured entirely by farmers.[5] The actual distribution of the benefits from this new technology among farmers, consumers of corn, and suppliers of CRW control technologies (including seed, agricultural

[4] Without the insecticide application equipment attached to the planter, larger seed hoppers can be installed, saving refilling time, and farmers may also save time spent on calibration and safety precautions. Some debate about this point exists, but farmers in our survey indicated they would be willing to pay a small amount for such savings in time and related variable costs.

[5] The technology supplier might be able to charge a slightly higher premium, but this would be constrained by competition from suppliers of conventional and transgenic alternatives. Moreover, the firms supplying the next-best alternative technology might be expected to drop their price in response to such competition, such that farmer benefits were even greater. Hence, this particular pricing assumption is less extreme than it might appear at first blush.

chemical, and biotechnology companies) will depend on the nature of competition and the underlying market supply and demand conditions, which will govern the pricing and adoption of the technological alternatives. The main implication of the pricing of the technology is for the distribution of the benefits rather than for the total benefits, and the pricing assumption we have adopted is both plausible and useful for obtaining a measure of farmer benefits that is a reasonable proxy for "total" benefits.[6] Making assumptions about the pricing structure is unavoidable. Our particular assumptions allowed us to take greatest advantage of our detailed data on the spatial incidence of corn rootworm problems, and on the adoption of alternative pesticide treatments, across different agroecological environments.

Another complicating factor is insect resistance management (IRM). Because any requirements for an IRM program, such as refuge requirements, had not been defined at the time when this analysis was done, we did not allow for the implementation of an IRM program. An IRM program would involve both direct costs and indirect costs and thus would reduce the net benefits in any year. On the other hand, the purpose of any IRM program is to preserve the benefits from the new technology over a longer time period. An effective IRM program imposes costs in the short run in order to generate benefits in the longer run that are worth more than the short-run costs. If we were to consider the short-run costs, we ought also to take into account the long-run benefits, and to do this would require a full dynamic analysis of the impacts of the technology over time, factoring in the role of resistance. In the analysis below we look at the impacts of adoption of the technology in one year, in a static analysis, without any consideration of the impacts over time of either increasing pest resistance or of

[6] In a companion study we documented the evidence in the literature on the farm-level benefits from the adoption of transgenic crop technologies (e.g., Marra; Marra, Pardey, and Alston). That companion study provides a set of benchmarks for the consideration of the results of the work undertaken here, as well as guidance to related literature and methodological approaches.

IRM programs that might be introduced to reduce the losses resulting from resistance build-up. Until IRM plan elements are delineated, it is difficult to estimate the financial impact of IRM on growers in the static analysis. Even with knowledge of the plan elements, the full dynamic analysis would remain difficult.[7]

Our analysis also does not allow for responses by suppliers of competing technologies. A profitable innovation provides impetus for both the current supplier and other companies to continue the development of competing technologies. Several players currently involved in this industry are devoting resources toward developing improved transgenic technologies in corn and in many other crops. Progress is sure to continue at a rapid pace. At the same time, companies selling conventional control products will respond to their loss of market share by lowering their products' prices or offering non-price incentives. We observed this response with the previous transgenic introductions. These competitive responses will benefit all corn growers and, in some instances where products are labeled for other crops, other farmers, as well. It is difficult to predict, given these market forces, precisely how the total benefits from the CRW-resistant transgenic corn technology will change over time.

4. Evaluation Concepts

A key element in the evaluation of the benefits from the adoption of a particular varietal technology, such as the CRW-resistant varieties of corn, is to estimate the adoption pattern—the numbers of acres (or percentages of total corn acres) annually planted to CRW-resistant transgenic corn for each of a range of different agroecologies.

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[7] Recent articles that have examined elements of the economics of refuge requirements for transgenic crops include Hurley, Babcock, and Hellmich; Hurley, Secchi, Babcock, and Hellmich; Laxminarayan and Simpson; Marra, Hubbell, and Carlson; and Livingston, Carlson, and Fackler.

In each relevant agroecology, the projected adoption paths can be defined as a function of estimates of the expected agroecology-specific yields and costs (and hence profitability) of growing CRW-resistant transgenic corn relative to the next-best alternative corn variety. We assume that all of the farmers in agroecology *i* will adopt CRW-resistant transgenic corn in year *t* if it is expected to be more profitable than the next-best alternative technology (with suitable allowance for a risk premium and for other differences including non-pecuniary aspects), which includes the option of not applying any treatment for CRW control. Algebraically, we can represent this behavior as:

$$(1) \qquad a_{it} = \left\{ \begin{matrix} 1 & \text{if} & \pi_{it} \geq c_{it} \\ 0 & \text{if} & \pi_{it} < c_{it} \end{matrix} \right\} \text{where } \pi_{it} = (1-\rho_{it})(P_{it}\Delta Y_{it} - Y_{it}\Delta P_{it} - \Delta VC_t - \Delta S_{it})$$

where, in agroecology *i* in year *t*,

- a_{it} is a dichotomous indicator variable that is equal to 1 if farmers in agroecology *i* adopt CRW-resistant transgenic corn in year *t*;
- c_{it} is the fixed cost per acre associated with CRW-resistant transgenic corn technology;[8]
- π_{it} is the total difference in variable profit in dollars per acre between CRW-resistant transgenic corn technology and the next-best alternative corn technology;
- ρ_{it} the fraction of CRW-resistant transgenic corn acreage that must be planted to the next-best alternative (i.e., non-transgenic corn or other crops) to provide a refuge for non-resistant corn rootworm;

[8] This could entail fixed benefits from enhancements to farmer and farm-worker safety associated with the use of the technology as well as costs of risk or information costs associated with learning about the new technology (which could decline with experience with the CRW-resistant transgenic corn technology, giving rise to progressive adoption at the level of the agroecology). In the case of CRW-resistant transgenic corn the costs of risk are expected to be close to zero, since the estimated distribution of yield benefits has more probability mass associated only with benefits *higher* than the conventional CRW technology. Therefore, even though the variance of benefits is higher, it is higher only because there is a higher probability of superior outcomes relative to the conventional CRW technology.

- P_{it} is the price per bushel of corn in year t, and ΔP_{it} is the price discount per bushel for corn grown using CRW-resistant transgenic corn technology, compared with conventional (non-transgenic) corn;
- Y_{it} is the average yield, and ΔY_{it} is the difference in yield in bushels per acre between CRW-resistant transgenic corn technology and the next-best alternative corn technology;
- ΔVC_{it} is the difference in variable cost of production, in dollars per acre, between CRW-resistant transgenic corn technology and the next-best alternative corn technology;
- ΔS_{it} is the difference in seed price per acre between CRW-resistant transgenic corn technology and the next-best alternative.

Total benefits are given by combining information on the per acre benefits from adoption and the implied number of acres on which adoption is profitable. The area planted to CRW-resistant transgenic corn in agroecology i in year t, A_{it}, is equal to the value of the indicator variable (i.e., a_{it} = 1 or 0), multiplied by the total relevant corn acreage in agroecology i in year t, TA_{it} (corn acreage that was or would be treated for CRW). Thus, $A_{it} = TA_{it}$ if $a_{it} = 1$, and $A_{it} = 0$ if $a_{it} = 0$. The aggregate farmer benefit within agroecology i (FB_{it}) is equal to the benefit from adoption times the total area of adoption:

(2) $$FB_{it} = \pi_{it} A_{it} = \pi_{it} a_{it}(\cdot) TA_{it}$$

And, summing these benefits across all agroecologies in the nation, we can obtain a measure of the national aggregate farmer benefit from adoption in year t (FB_t):

(3) $$FB_t = \sum_{i=1}^{I} FB_{it} = \sum_{i=1}^{I} \pi_{it} a_{it}(\cdot) TA_{it}$$

The only missing element, for measuring the full net economic impact, is a measure of the profits of seed companies and technology suppliers, given the pricing strategy that drove the assumed pattern of adoption. The gross, non-farmer benefit ($GNFB_t$) can be estimated as the seed price premium per acre, ΔS_{it}, multiplied by the number of relevant acres and added up across agroecologies. This is a gross rather than net benefit to the extent that, as well as the costs of license fees and royalties paid by seed companies (a transfer), it might have to cover additional marketing costs that may be incurred in developing and marketing the new seed relative to the benchmark alternative.

(4) $$GNFB_t = \sum_{i=1}^{I} \Delta S_{it} A_{it} = \sum_{i=1}^{I} \Delta S_{it} a_{it}(\cdot) TA_{it}$$

Summing the farmer and non-farmer benefits provides a measure of the total, national benefits from the adoption of the technology ($TNB_t = FB_t + GNFB_t$), the elements of which have been derived under an assumption that there are no substantial effects on the total quantity of corn produced and thus on the price of corn. If the adoption of CRW-resistant transgenic corn technology led to an increase in the total quantity of corn, and this caused a significant reduction in price of corn, there would be effects on the welfare of corn consumers (positive) as well as corn growers (negative effects on adopters and non-adopters alike, if we assume no segregation costs and no price discounts for transgenic varieties). These distributional effects would probably not mean a significant change in the overall national impact, but the distributional story might be of interest nevertheless.[9]

As noted in the introduction, we adopted a strategy here of using data for a particular past year, 2000, to evaluate what would have been the benefits if CRW-resistant transgenic corn technology had been commercially available in that year and was priced such that it

[9] This measure does not account for any impacts on the suppliers of agricultural chemicals and others whose business may be reduced as a consequence of farmers shifting to the new technology. If the industries in question could be regarded as competitive and only earning "normal" economic profits, then there would not be any net welfare impacts to consider. On the other hand, if the affected firms had been earning more than "normal" economic profit, such as they would if they were exercising some market power in a patented technology, then they would experience net economic losses as a result of farmers adopting the new technology, which ought to be considered in the estimate of net national benefits. Moschini, Lapan, and Sobolevsky present a model of this kind of situation. We do not have access to any information to begin to estimate such impacts.

would have been fully adopted by those farmers who treated their corn crop for CRW. Having made these assumptions, the adoption outcome was clearly defined: i.e., a_{it} = 1 for every acre in every agroecology that was treated for CRW in year t, and hence $A_{it} = TA_{it}$ (i.e., it is assumed that every acre treated for CRW would have adopted the new technology). This measure leaves out those acres that were not treated using conventional CRW-control technology (because it was not profitable to do so) but would be treated using the new technology (because it is more profitable than the conventional technology). On the other hand it includes some conventionally treated acres on which the transgenic alternative might not be adopted under any circumstances.

To implement this approach and estimate the benefits from having the CRW-resistant transgenic corn technology available for adoption (and adopted) in the year 2000, as described above we assumed that the new technology would be priced such that the variable costs of pest control per acre, including the seed premium in the case of CRW-resistant transgenic corn technology, would be equal between the new technology and a benchmark technology. That is, for the analysis, the premium for the transgenic seed was set equal to the additional variable costs per acre associated with insect control for the conventional technology (i.e., material and application costs). In addition, we assumed that there would not be any premium or discount for transgenic corn ($\Delta P_{it} = 0$) and that the fixed cost of adoption was negligible ($c_{it} = 0$), and we assume away refuge requirements (i.e., $\rho_{it} = 0$ for all i and t).

5. Measurement of Benefits

As described in section 2, we identified a total of 11 distinct corn production regions, which we would treat as different agroecologies for the purposes of this analysis. We used a partial budgeting approach to estimate the per acre net benefits of CRW-resistant transgenic corn, relative to soil insecticide control for CRW, on a representative acre for each agroecological region, and then we scaled these per acre benefits by the relevant number of acres in each region to obtain an estimate of total regional benefits. Yields, harvest costs, and (possibly) control costs were assumed to be affected by the technology choice. Yields may differ because the CRW-resistant transgenic corn technology is more effective than chemical applications in controlling CRW. Harvest costs, $0.375 per bushel, are a direct function of yields (harvest cost based on enterprise budgets from several universities—e.g., Duffy and Smith). Finally, the seed price premium may differ from the regional average chemical control cost, so it is included.[10]

Variation in the benefit per acre across regions is determined primarily by variation in the yield gain from using the new CRW-control technology relative to the conventional (non-transgenic) alternative. In turn, this depends on the yield potential of the crop in that region in conjunction with weather conditions and pest pressure (which in turn depends on weather, past cropping patterns within the same field, and the extent of infestations in neighboring fields). An advantage of conducting a counterfactual analysis is that we can use observations of corn production in the field, under different treatments—conventional pest-management strategies and CRW-resistant transgenic corn technology—, which reflect the actual situation in terms of yield potential, pest pressure, weather conditions, and so on. However, data are not available directly on the untreated (base) yields for the different agroecologies, and data are available only for root damage assessments, rather than corn yield, associated with the

[10] We assume that an explicit, separate "technology fee" as such would not be applied in this case of. Rather the equivalent of a technology fee would be incorporated in the seed price. Hence, we refer to the "seed premium" rather than the "technology fee."

different treatments. We estimated the untreated corn yield and corn yield gain associated with the different degrees of root damage and the different treatments by combining actual region-specific average yield data for the year 2000 with information from Mitchell, who has estimated the relationship between corn yields and root damage ratings.

A partial budget was developed for each of the 11 regions to calculate the net benefits from CRW control: soil insecticide application relative to no control, CRW-resistant transgenic corn relative to no control, and CRW-resistant transgenic corn relative to soil insecticide application. For each analysis, values were specified for a base (untreated) yield and price (USDA/ERS). To calculate the yield, given CRW control, the base yield was adjusted upward by the average yield increase, based on estimates from Mitchell of the "yield saved," associated with each type of control (CRW-resistant transgenic corn or chemical treatment).[11] The (net) farmer benefit ($FB_{A\text{-}B}$) from control using control strategy A relative to an alternative control strategy, B, could then be calculated as follows:

(5) $$FB_{A-B} = (P - H)(Y_A - Y_B) - (CC_A - CC_B),$$

where *A* indicates the control treatment of interest (using insecticide or CRW-resistant transgenic corn) and *B* indicates the comparison treatment (applying insecticide or not applying any treatment), *P* is the corn price, taken from USDA/ERS, and which varies among regions, *Y* is yield, *H* is harvest cost, and *CC* is control cost (Doane's Market Research), which is zero in untreated corn.[12] The net benefits of CRW-resistant transgenic corn relative to soil insecticide applications were found by setting each yield increase (for soil insecticide

[11] It should be noted that all of these calculations used the "average" yield saved reported by Mitchell. However, his estimates include a relatively wide 95 percent confidence interval. Further research by corn entomologists and agronomists is needed to refine these estimates.

[12] More complete details on the data and computations can be found in the longer report by Alston, Hyde, and Marra, in particular in the appendix. Separate tables are presented for each region.

application and for CRW-resistant transgenic corn) to the average level associated with a given root rating. [13]

We calculated three important factors pertaining to the benefits from adopting the alternative CRW control methods, and therefore the adoption decision: namely, (a) economic root rating thresholds for CRW control (using both the CRW-resistant transgenic corn control strategy and the soil insecticide application strategy), (b) net benefits from CRW-resistant transgenic corn at the soil insecticide application threshold, and (c) net benefits from CRW-resistant transgenic corn relative to soil insecticide application. The economic threshold root rating is the observed root rating at which the additional control costs just equal the additional benefits of control. Analytically, the root rating threshold for treatment *i*, RR_i^* is derived as follows. First, in equation (5), setting the net benefits from control strategy *i* relative to no control equal to zero implies:

(6) $$CC_i = (P - H)(Y_i - Y_i^*),$$

where CC_i is the control cost for control strategy *i* (either soil applied insecticide or CRW-resistant transgenic corn), *P* is the expected corn price, *H* is the harvest cost per bushel and Y_i^* is the untreated yield in bushels per acre at the economic threshold for treatment *i*. Then we can substitute for yield, using $Y_i = \gamma RR_i$, where γ is the factor that converts root rating into yield, RR_i is the root rating associated with control strategy *i* and RR_i^* is the root rating at the economic threshold for control strategy *i*, to obtain

[13] The net benefits from the adoption of the CRW resistant transgenic corn technology if the root damage rating were at the threshold value at which it would be just profitable to apply the insecticide control technology correspond to both the *minimum* benefits from adopting CRW resistant transgenic corn for those who had opted to apply insecticide (since at best their root rating would have been just above the threshold), and at the same time they represent the *maximum* potential benefits for those who opted not to apply insecticide (since at worst their root rating could have been just below the threshold).

(7) $$CC_i = (P - H)(\gamma RR_i - \gamma RR_i^*),$$

Rearranging terms in (7) gives:

(8) $$RR_i^* = RR_i - \frac{CC_i}{\gamma(P - H)}$$

Note that the threshold root rating increases with an increase in harvest cost or control cost and decreases with an increase in the expected corn price. The threshold decreases with an increase in the root rating associated with the control strategy because an increased root rating after implementing the control strategy implies the strategy is not as effective (i.e., it cannot achieve as much yield increase relative to untreated yield). This implies, as well, that the threshold root rating for the insecticide control strategy will be above the threshold root rating for the CRW-resistant transgenic corn control strategy. We estimated threshold root ratings under different values for (a) the untreated yield, and (b) the seed premium for CRW-resistant transgenic corn technology (one corresponding to the national average cost of conventional spray treatment).

To complete the analysis, we require an estimate of the number of acres in each region, corresponding to each combination of untreated yield and root damage rating, for each class of potential adopters of the CRW-resistant transgenic corn technology in that region Unfortunately these data are not available. Corn rootworm pressure within a given region can vary greatly from year to year. The variance is also very high among fields within a region for any given year. This is attributable to many factors, including cultural practices and environmental factors. As an approximation we used an average root damage rating for each region. To examine the sensitivity of the results to the regional average values for root damage ratings, as well as “moderate” estimates for root damage ratings, which apply in a “most-likely” scenario, we also evaluated the benefits assuming “high” and “low” rates of corn rootworm pressure for each region. Table 3 lists the region-specific root damage ratings under the "high," "moderate," and "low" scenarios, which are assumed to apply with probabilities of 15 percent, 70 percent, and 15 percent, respectively.[14] Table 4 lists the corresponding values of untreated base yields, derived from the combinations of actual yields and root damage ratings.

[Table 3: *Actual Average Regional Yield in 2000, and* . . .]

[Table 4: *Estimates of Average Yield Increase Factor* . . .]

In table 5, for each region we report estimates of regional average benefits per acre from adopting CRW-resistant transgenic corn technology for both continuous and first-year corn, under our three different scenarios of "low," "moderate," and "high" CRW pressure. Total annual regional benefits, computed by multiplying the region-specific benefits per acre by the relevant number of acres in the region, are also reported in table 5 for each scenario. The sum across regions is the total national benefit to producers, and dividing this total by the number of base acres treated gives an estimate of the overall average benefit per acre. These aggregate figures are shown in the last row of table 5. In the moderate scenario, the total annual benefits across the 11 regions amounted to $231 million, spread across 13.8 million acres, an average of about $16.49 per acre treated. Between the "low" and "high" scenarios, the estimates of total benefits ranged from $111 million to $406 million (or from $8 to $29 per acre). Finally, the last column in table 5 shows the "average" estimate of total regional benefits, obtained by weighting the benefits under the "low," "moderate," and "high" scenarios by their assumed probabilities. Since the probability distribution is symmetric, with

[14] The ranges established and probabilities assumed were primarily based on personal communication with university scientists (Dr. L. Meinke, University of Nebraska; Dr. M. Rice, Iowa State University; and Dr. K. Steffey, University of Illinois).

a high weight on the “moderate” scenario, the “average” estimates are generally similar to their “moderate” counterparts—a total benefit of $239 million, about $17 per acre treated.

[Table 5: *Farm Level Benefits from Adoption*…]

The estimates in table 5 are based on the regional prices of corn in 2000, which averaged $1.85/bushel.[15] In table 6 we compare estimates based on those prices with alternative estimates made under the assumption of a corn price equal to the ten-year average U.S. corn price ($2.32/bushel), for the moderate scenario. Summing across regions, the total annual benefits increased from $231 million ($16.50 per acre treated), using the year 2000 regional corn price to $319 million (just over $23 per acre treated), using the U.S. ten-year average corn price. Figure 2 shows the frequency distribution of national average corn prices for the decade 1991–2000 to give some perspective on our alternative price assumptions.

[Table 6: *“Moderate” Farm Level Benefits under Alternative Corn Prices*]

Comparing across the regions, the measures of benefits vary from negligible amounts in Mississippi Portal or Southern Seaboard up to $54 million in the Heartland, Remaining region (up to $76 million in the Heartland, Remaining region using the ten-year average U.S. corn price assumption). Some of this variation is attributable to variation in benefits per acre, but variation in the number of acres treated for CRW is a much more important factor. The four regions that account for most of the benefits, the Northern Crescent, Prairie Gateway, Heartland, Remaining, and Heartland, SBV, also account for most of the acreage treated.

In addition to the farm-level benefits, non-farm benefits are given by multiplying the seed premium ($12.43 per acre) by the number of acres to which it applies (13,796,901 acres), a total benefit of $171 million. If the seed premium increases by one dollar per acre, this

[15] The year 2000 corn price average was more than 20 percent below the 10-year average (not adjusted for inflation), so we report the regional and aggregated results using both price scenarios in table 6.

simply reduces the farmers' net benefits by one dollar per acre, which is exactly offset by an increase in the non-farm benefits of one dollar per acre. So long as this hypothetical price change would not result in any changes in farmers' decisions about adopting the technology (i.e., so long as the premium was initially low enough such that the adoption decision would not be marginal) the seed premium affects only the distribution of benefits. Accordingly, even if there is an adoption response, the main impact of varying the seed premium would be for the distribution of benefits, with less-important implications for the total.

Combining the annual farmer benefits of $231 million in the "moderate" scenario ($319 million with the ten-year U.S. average corn price assumption) and the annual nonfarmer benefits ($171 million), we estimate that the total annual national benefits from the adoption of CRW-resistant transgenic corn technology in the year 2000 would have been equal to $402 million ($490 million with the alternative corn price assumption).

6. Non-Pecuniary Benefits

In addition to the benefits computed above farmers may receive other benefits that do not show up in the corn production budget. A computer-assisted telephone survey of corn farmers was conducted in late March and early April of 2002 by Doane Marketing Research, Inc., under the direction of the authors, with a view to assessing these non-pecuniary benefits. The survey sample was randomly selected from Doane's list of corn farmers.

To qualify for the survey, a respondent must have planted a minimum of 250 acres of corn in 2001 and must be the primary decision maker for purchases of insecticides and seed in their farm operation. Qualifying farmers must have also used a soil-applied insecticide for corn rootworm control on at least some of their corn acreage in 2001. The sample was weighted toward the regions with the most acreage planted to corn. Numbers of respondents by region were: Heartland-Remaining (100), Northern Crescent (100), Northern Great Plains (100), Prairie Gateway (101), Heartland-EDV (50), Heartland-SBV (50), and all other regions combined (100). The survey respondents treated 93 percent of their continuous corn acres and 62 percent of their first year corn acres at least once in 2001 for corn rootworm. The average price paid for all soil-applied insecticides targeted at corn rootworm on both continuous and first-year corn acres ranged from $10.56 to $11.84 per acre.

Respondents were asked a series of questions designed to elicit the value they would place on a set of "nonpecuniary" benefits from adopting the product, in addition to the benefits associated with increases in their average yields, including savings in handling and labor time, human safety benefits (operator and worker safety), environmental quality benefits, and more consistent control (less yield risk). First they were asked if they agree or disagree with a statement that a particular benefit would be gained by adopting the product. An overwhelming percentage of respondents agreed that at least some of each non-pecuniary benefit could be gained by adoption (92 percent agreed it would be safer for humans and 82 percent agreed it would be safer for the environment than soil-applied treatment). They were then asked to place a separate value per acre on each of the benefits. In addition, they were asked to place a separate value on savings in equipment costs that might be gained by adoption and another on an increase in standability (less lodging, resulting in more harvested yield) of between two and five percent. They were then asked to give a value per acre for the *total package* of non-pecuniary benefits plus equipment cost savings and then an additional value for the non-pecuniary, equipment cost and standability benefits. Table 7 presents the average values placed on the benefits listed above by likely adopters, unlikely adopters, and the total sample. Perhaps the most important elements of these are the value of time saved and the yield-risk reduction associated with CRW-resistant transgenic corn. [16]

[Table 7: *Values Placed by Respondents on Various Characteristics* …]

The survey results indicate the value of time saved would be $1.60 per acre for unlikely adopters, or $1.94 for likely adopters, with an overall average of $1.87 per acre. The respondents' valuation of the potential yield risk reduction from consistent insect control ranges from $1.25 per acre for unlikely adopters to $4.03 for likely adopters with an overall average of $3.80 per acre. These are reported values when the respondents were asked to value each of the benefits separately. When they were asked to value the benefits as a package, including potential equipment cost savings, the range is from $2.55 per acre for the unlikely adopters to $4.55 for the likely adopters, with an overall average value of $4.18 per acre. Notice that the values placed on the total package of benefits together (both with and without standability benefits) are less than the sum of the separate values. We believe the values the respondents placed on the total packages of benefits are probably closer to their true willingness to pay for these benefits, since they were asked to value the benefits packages after they had had a chance to think further about the individual components. Applying these average benefits per acre to the 13,796,901 acres treated for corn rootworm in the year 2000 would imply a total additional farmer benefit of $58 million if CRW-resistant transgenic corn had been made available and was adopted on 100 percent of the treated acres.

7. Summary and Conclusion

We have examined the potential impact of the introduction of a new transgenic technology for control of corn rootworm. Under a reasonable set of assumptions, and using production and

[16] Research in progress includes a more comprehensive exploration of the valuation portion of the survey.

price data for 2000, we found that if the technology had been available in the year 2000, and priced equivalent to the benchmark pesticide technology so that it would be adopted comprehensively, the benefit for farmers in the United States would have been $231 million in that year. Adding the annual non-farmer benefits of $171 million (the benefits accruing to the technology developer and seed companies), the total benefits in the United States in 2000 would have been $402 million ($490 million, if the ten-year average corn price is used, instead of the actual price in 2000, to place a value on the yield increase). The total (farm and non-farm) benefit is 2.36 percent of the value of the year 2000 corn crop. These estimates may be understated for several reasons. First, we estimated all of the benefits using an average root-rating index. It is clear that acres with above-average root damage ratings would realize greater benefits from the technology. It is also true, as discussed earlier, that some acres below the root-rating threshold for insecticide treatment would realize a small net benefit from the new technology. Perhaps more importantly, however, the technology provides further, non-pecuniary benefits to farmers, in addition to those associated with yield gains. We estimated non-pecuniary farmer benefits of $58 million if CRW-resistant transgenic corn had been made available and was adopted on 100 percent of the treated acres. Adding this additional $58 million to the farmer benefit from yield improvement ($231 million) increases the total farmer benefit to $289 million, and the total farmer plus non-farmer benefit to $460 million. Table 8 summarizes the alternative estimates of the total benefits, the forms of benefits, and their distribution among farmers and others.

[Table 8: *Estimated Aggregate Benefits from Adoption* . . .]

These estimates of pecuniary and non-pecuniary benefits to farmers and others are based on the assumption of 100 percent adoption—that all corn acres currently treated with conventional control methods would be switched to the new technology, instantaneously and completely. This is an extreme assumption and for that reason probably unreasonable—even under our assumption about the pricing of the CRW-resistant transgenic corn technology, which meant that it would entail lower pest-control costs and higher yields and would clearly dominate conventional pest-control technology—since some farmers have said they would not plant a crop with a biotech trait under any circumstances. Our survey results indicate that this proportion of farmers may be significant, although the number of farmers in this category will probably decrease after product commercialization and adoption begins to take place. The survey results indicated that adoption might be only 30 percent in the first year, which would imply that the benefits in the first year would be 30 percent of the figure implied by 100 percent adoption (the relationship is linear under our assumptions unless we use a more-sophisticated analysis in which the farmers identified as those who choose to adopt are those who are likely to obtain higher-than average benefits per acre).

Table 8 shows the effects of this lower adoption rate on the pattern of benefits as well as the total. Using an adoption rate of 30 percent, instead of a total benefit of $460 million in the year 2000, a conservative estimate of the benefits is $138 million. This might not be the maximum annual benefit, since adoption would evolve over time with the development of information and knowledge of the technology and its impacts. Other conditioning factors on adoption and on the benefits from adoption, which have not been addressed directly, include the potential effects of refuge requirements, price discounts, or identity preservation costs, if they become a reality. It is important to remember also that the pace of technological innovation in agricultural biotechnology and other pest management systems will likely place an upper limit on the amount of time over which the maximum benefits can be realized.

Additional work could be done, both to refine the estimates of this ex ante study and to estimate the benefits after commercial introduction, as well as to compare the two. One of the more crucial pieces of information we need, to improve on our ex ante estimates, is information about the distribution of corn rootworm damage within each production region. This would allow us to calculate the benefits associated with the acres experiencing higher-than-average rootworm pressure, and also to identify those acres that are not now treated but for which the technology would provide a net benefit. The relationship between root damage as measured by the root rating and ultimate yield should receive more attention, as well.

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Table 1: *Corn Acreages and Shares Treated for CRW, by Region in 2000*

Region	Total Area Planted to Corn	Share Treated for CRW	Total Area of Continuous Corn	Share Treated for CRW	Total Area of First Year Corn	Share Treated for CRW
	acres	*percent*	*acres*	*percent*	*acres*	*percent*
Mississippi Portal	1,347,885	1.0	502,916	0.0	844,969	1.5
Southern Seaboard	2,136,491	7.7	706,933	8.3	1,429,558	7.3
Fruitful Rim	882,273	50.5	432,626	52.0	449,646	49.1
Eastern Uplands	1,705,355	11.6	733,404	18.4	971,951	6.5
Northern Crescent	11,288,731	14.7	4,536,048	25.6	6,752,683	7.5
Heartland, Remaining	34,516,415	13.8	6,601,637	44.5	27,914,778	6.6
Heartland, EDV	2,788,455	5.2	265,913	12.7	2,522,542	4.4
SBV Sub-Region	8,951,127	33.0	936,815	47.6	8,014,312	31.3
Northern Great Plains	4,867,966	8.7	1,442,112	26.4	3,425,855	1.3
Prairie Gateway	9,931,175	29.7	5,506,741	45.5	4,424,434	10.1
Basin and Range	211,827	33.7	112,420	55.8	99,407	8.6
TOTAL	79,579,030	17.3	22,268,847	35.7	57,310,183	10.2

Source: Doane’s Market Research.

Table 2: *Treated Acres, Expenditure on CRW Insecticides, and Average Cost per Acre, by Region*

Region	Total Acres Treated for CRW	Total Expenditure on CRW Insecticides	Continuous Corn Acres Treated for CRW	Expenditure on CRW Insecticides, Continuous. Corn	First-Year Corn Acres Treated for CRW	Expenditure on CRW Insecticides First-Year Corn	Average CRW Insecticide Cost per Acre
	acres	*Dollars*	*Acres*	*dollars*	*Acres*	*dollars*	*dollars/acre*
Mississippi Portal	13,115	117,283	36	361	13,079	116,922	8.94
Southern Seaboard	163,442	1,879,948	58,497	626,588	104,945	1,253,360	11.50
Fruitful Rim: Target	445,505	5,337,143	224,830	2,758,341	220,675	2,578,802	11.98
Eastern Uplands	198,413	2,247,484	135,204	1,572,652	63,208	674,833	11.33
Northern Crescent	1,680,410	20,992,361	1,159,901	14,265,651	520,509	6,726,710	12.63
Heartland, Remaining	4,820,048	57,537,615	2,984,335	36,527,083	1,835,713	21,010,532	12.07
Heartland, EDV	145,594	1,819,104	33,640	449,777	111,954	1,369,327	12.49
Heartland, SBV	2,992,309	39,935,790	445,725	6,634,121	2,546,584	33,301,669	13.52
Northern Great Plains	532,094	5,355,880	486,724	4,983,995	45,369	371,885	12.59
Prairie Gateway	3,134,778	35,695,939	2,679,506	30,482,413	455,272	5,213,527	12.09
Basin and Range	71,282	590,972	62,719	509,743	8,563	81,229	8.29
TOTAL	14,196,990	171,509,520	8,271,117	98,810,724	5,925,871	72,698,796	12.43

Source: Doane’s Market Research.

Table 3: *Actual Average Regional Yield in 2000, and Subjective Distributions of Regional Average Root Damage Ratings*

Region	ActualYield[a] (bu/ac)	Regional Average Root Rating		
		Low	Moderate	High
Mississippi Portal	113	1	2	3
Southern Seaboard	106	1	2	3
Fruitful Rim	175	3	4	5
Eastern Uplands	128	2	3	4
Northern. Crescent	127	2	3	4
Heartland, Remaining	148	2.5	3.5	4.5
Heartland, EDV	148	2	3	4
Heartland, SBV	148	2.5	3.5	4.5
Northern Great Plains	97	2	3	4
Prairie Gateway	127	2.5	3.5	4.5
Basin and Range	128	3	4	5

[a]Yield taken for ERS budgets except for Mississippi Portal (LA, MS, TN, AR), Fruitful Rim (AZ, CA, WA, ID), and Basin and Range (UT, CO, NV, MT, WY, NM). These were calculated using NASS data and represent total production divided by acres harvested in the states indicated.

[b]The range of root damage ratings, corresponding to "low", "moderate," and "high" CRW pressure was established for each region, based primarily on personal communication with university scientists (Dr. L. Meinke, University of Nebraska; Dr. M. Rice, Iowa State University; and Dr. K. Steffey, University of Illinois).

Table 4: *Estimates of Average Yield Increase Factor with "Low," "Moderate," and "High" CRW Pressure, and Untreated Base Yield*

Region	ActualYield[a] (bu/ac)	Average Yield Increase Factor			Untreated Base Yield[a] (bu/ac)
		"Low" CRW Pressure	"Moderate" CRW Pressure	"High" CRW Pressure	
Mississippi Portal	113	1.000	1.076	1.164	113
Southern Seaboard	106	1.000	1.076	1.164	105
Fruitful Rim	175	1.164	1.269	1.393	154
Eastern Uplands	128	1.076	1.164	1.269	126
Northern. Crescent	127	1.076	1.164	1.269	124
Heartland, Remaining	148	1.119	1.214	1.328	144
Heartland, EDV (cont)	148	1.076	1.164	1.269	145
Heartland, EDV (first)	148	1.076	1.164	1.269	147
Heartland, SBV (cont)	148	1.119	1.214	1.328	134
Heartland, SBV (first)	148	1.119	1.214	1.328	139
Northern Great Plains	97	1.076	1.164	1.269	96
Prairie Gateway	127	1.119	1.214	1.328	119
Basin and Range	128	1.164	1.269	1.393	117

[a] Untreated base yield computed based on "moderate" CRW pressure.

Table 5: *Farm Level Benefits in 2000 from Adoption Under Low, Moderate, or High Corn Rootworm Pressure*

Region	Continuous (C) or First-Year (F) Corn	Base Acres Treated[a]	Benefits per Acre[b]			Total Regional Benefits[b]			
			"Low"	"Moderate"	"High"	"Low"	"Moderate"	"High"	"Average"[c]
		acres	*dollars per acre*			*dollars*			
Mississippi Portal	C	36		1.91	8.22		69	296	93
	F	13,079		0.82	7.13		10,725	93,253	21,495
Southern Seaboard	C	58,498		2.80	9.42		163,794	551,051	197,314
	F	104,944		4.03	10.66		422,924	1,118,703	463,852
Fruitful Rim	C	224,830	14.31	26.42	44.91	3,217,317	5,940,009	10,097,115	6,155,171
	F	220,676	13.73	25.84	44.33	3,029,881	5,702,268	9,782,567	5,913,455
Eastern Uplands	C	135,205	4.35	11.89	22.51	588,142	1,607,587	3,043,465	1,670,052
	F	63,208	3.39	10.94	21.55	214,275	691,496	1,362,132	720,508
Northern Crescent	C	1,158,988	4.74	11.87	21.89	5,493,603	13,757,188	25,370,247	14,259,609
	F	503,397	5.80	12.92	22.95	2,919,703	6,503,889	11,552,961	6,723,622
Heartland, Remaining	C	2,936,189	9.03	18.40	32.14	26,513,787	54,025,878	94,369,114	55,950,549
	F	1,829,706	8.08	17.44	31.19	14,784,024	31,910,073	57,068,530	33,114,934
Heartland, EDV	C	33,640	6.39	14.37	25.61	214,960	483,407	861,520	499,857
	F	111,954	5.32	13.42	24.81	595,595	1,502,423	2,777,579	1,557,672
Heartland, SBV	C	445,725	10.85	19.56	32.36	4,836,116	8,718,381	14,423,661	8,991,833
	F	2,507,346	9.56	18.60	31.87	23,970,228	46,636,636	79,909,117	48,227,547
Northern Great Plains	C	381,016	4.02	8.96	15.91	1,531,684	3,413,903	6,061,965	3,528,780
	F	44,431	(0.69)	4.25	11.20	(30,657)	188,832	497,627	202,228
Prairie Gateway	C	2,505,954	7.90	16.36	28.80	19,797,037	40,997,407	72,171,475	42,493,462
	F	446,796	7.40	15.87	28.30	3,306,290	7,090,653	12,644,327	7,356,049
Basin and Range	C	62,720	6.70	15.89	29.94	420,217	996,605	1,877,807	1,042,327
	F	8,563	8.05	17.25	31.30	68.932	147,712	268,022	153,941
Total Across Regions		13,796,901	8.08	16.49	29.42	111,471,141	230,911,872	405,902,565	239,244,367

[a]Base Acres Treated from Doane's Market Research.

[b]Based on data in Alston, Hyde, and Marra, table 4 and tables B.1 through B.11.

[c]Average is the weighted average of "low," "moderate," and "high" using weights of 0.15, 0.70, and 0.15, respectively.

Table 6: *"Moderate" Farm Level Benefits in 2000 under Alternative Corn Prices*

Region	Continuous (C) or First-Year (F) Corn	Base Acres Treated[a]	Year 2000 Corn Price[b]		10-Year Average Corn Price ($2.32/bu.)	
			Per Acre Benefits	Regional Benefits	Per Acre Benefits	Regional Benefits
		acres	*$/acre*	*dollars*	*$/acre*	*dollars*
Mississippi Portal	C	36	1.91	69	3.60	130
	F	13,079	0.82	10,725	2.52	32,959
Southern Seaboard	C	58,498	2.80	163,794	3.86	225,802
	F	104,944	4.03	422,924	5.09	534,165
Fruitful Rim	C	224,830	26.42	5,940,009	36.90	8,296,227
	F	220,676	25.84	5,702,268	36.31	8,012,746
Eastern Uplands	C	135,205	11.89	1,607,587	15.72	2,125,423
	F	63,208	10.94	691,496	14.76	932,950
Northern Crescent	C	1,158,988	11.87	13,757,188	16.13	18,694,476
	F	503,397	12.92	6,503,889	17.18	8,648,360
Heartland, Remaining	C	2,936,189	18.40	54,025,878	26.02	76,399,638
	F	1,829,706	17.44	31,910,073	25.06	45,852,432
Heartland, EDV	C	33,640	4.37	483,407	19.94	670,782
	F	111,954	13.42	1,502,423	19.07	2,134,963
Heartland, SBV	C	445,725	19.56	8,718,381	26.66	11,883,029
	F	2,507,346	18.60	46,636,636	25.96	65,090,702
Northern Great Plains	C	381,016	8.96	3,413,903	13.23	5,040,842
	F	44,431	4.25	188,832	8.52	378,552
Prairie Gateway	C	2,505,954	16.36	40,997,407	21.23	53,201,403
	F	446,796	15.87	7,090,653	20.73	9,262,081
Basin and Range	C	62,720	15.89	996,621	23.85	1,495,872
	F	8,563	17.25	147,712	25.21	215,873
Total				230,911,872		319,129,407

[a]Based on data in Alston, Hyde, and Marra, table A.1 and tables B.1 through B.11; Base Acres Treated From Doane's Market Research.

[b]Prices in 2000 by region were Heartland ($1.75), Northern Crescent ($1.81), Northern Great Plains ($1.66), Prairie Gateway ($1.88), Eastern Uplands ($1.87), Southern Seaboard ($1.95), and all others ($1.77).

Table 7: *Values Placed by Respondents on Various Characteristics of the New Technology Relative to Soil-Applied Insecticide Applications*

Product Characteristic	Respondent Adoption Category		
	Likely to Adopt	Unlikely to Adopt	Total Respondents
		($ per acre)	
1. Handling and Labor Time Savings	1.94	1.60	1.87
2. Human Safety	1.79	1.24	1.68
3. Environmental Safety	1.46	0.82	1.34
4. Consistent Control (Reduced Yield Risk)	4.03	1.25	3.80
Sum of 1 through 4	*9.22*	*4.91*	*8.69*
5. Equipment Cost Savings	1.57	1.00	1.46
Sum of 1 through 5	*10.79*	*5.91*	*10.15*
6. Better Standability (2-5% increase)	5.29	3.70	4.99
Sum of 1 through 6	*16.08*	*9.61*	*15.14*
Items 1 through 5 Valued as a Package	*4.55*	*2.55*	*4.18*
Items 1 through 6 Valued as a Package	*7.24*	*3.86*	*6.61*

Table 8: *Estimated Aggregate Benefits from Adoption of Transgenic Corn Rootworm Technology under Alternative Assumptions about Adoption Rates and Corn Prices*

Form of Benefits	Total Benefits (Million Dollars in Year 2000)			
	100 percent adoption		30 percent adoption	
	Actual Corn Price in 2000	10-Year Average Corn Price	Actual Corn Price in 2000	10-Year Average Corn Price
Farmer benefits from				
a. Yield Gains	231	319	69	96
b. Non-Pecuniary Benefits	58	58	17	17
Total Farmer Benefits	**289**	**377**	**86**	**113**
Total Non Farmer Benefits	**171**	**171**	**51**	**51**
Total Farmer and Non Farmer Benefits	**460**	**548**	**138**	**164**

Note: Column totals might not add exactly because of rounding.