Returns to Integrated Pest Management Research and Outreach for Soybean Aphid

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Abstract

Soybean aphid is a major invasive pest that has caused major yield loss and increased insecticide use in the United States since its discovery in 2000. Using the economic surplus approach, we estimate the economic benefits of U.S. research and outreach for integrated pest management (IPM) of soybean aphid. We calculate *ex ante* net benefits from adoption of an IPM action threshold (AT). The AT triggers insecticide application only if the value of predicted yield damage from pest scouting is expected to exceed the cost of pest control.

Our research finds that gradual adoption of AT-based IPM over the 15 years since soybean aphid IPM research began in 2003 generates a projected economic net benefit of $1.3 billion, for an internal rate of return of 140%. Lower and upper bound sensitivity analysis brackets the estimated net benefit to U.S. consumers and soybean growers in the range of $0.6 to 2.6 billion in 2005 dollars. If a 10% rate of return is attributed to IPM applied research and outreach on soybean aphid, that would leave nearly $800 million to compensate prior basic IPM research. Using benefit functions from two prior studies of consumer willingness to pay to avoid pesticide risk, we find that the nonmarket environmental and human health benefits of reduced insecticide use due to adopting AT-based IPM are less than five percent of the baseline market value estimate of economic net benefit.

Soybean aphid is a major invasive pest of soybean in North America. First detected in Wisconsin in 2000, it rapidly spread to over 20 north-central states within four years (Ragsdale et al. 2004). Heavy infestation of soybean aphid can reduce yield directly through plant feeding and indirectly through virus transmission and reduction in seed quality (Rutledge and Neil 2006, Ragsdale et al. 2007). In 2003, when most north-central states suffered from unprecedented soybean aphid infestations, yield losses were estimated to be 0.4 to 0.9 ton/ha (6 to 13 bu/ac) (Myers and Wedberg 2002, Hunt 2004, Rice et al. 2004). U.S national average yield fell by 11% compared to the previous 5-year average, and U.S. soybean prices exceeded $294/ton ($8/bu), 25% above the previous year (National Agricultural Statistics Service (NASS), 1998-2003).

Traditional broad-spectrum insecticide can be used to protect soybean from yield loss. In China, where soybean aphid has long been present, soybean growers were observed to apply insecticide as many as four times in one season to avoid yield loss (Dai Z. L. and J. 1991). According to USDA agricultural chemical usage reports (NASS, 1998-2006), the insecticide treated soybean area in mid-west states including Iowa, Illinois, Indiana, Minnesota, Michigan and Ohio leaped to 20% in 2005, compared to less than 1% before 2000. Prophylactic treatment with insecticides can protect soybean from yield loss. However, it increases production costs, and the yield protection benefit from a prophylactic treatment may fail to cover its cost. Moreover, the most commonly used soybean aphid insecticides (esfenvalerate, lambda-cyhalothrin and zeta-cypermethrin) are moderately or highly toxic to humans (World Health Organization, 2004), so they pose environmental and human health risks in addition to their monetary costs (Fernandez-Cornejo, 1998).

To reduce the environmental and human health risks associated with pesticide use, the U.S. Department of Agriculture (USDA) and many agricultural universities have promoted integrated pest management (IPM) for many years (Fernandez-Cornejo and Jans 1999). IPM is a systematic approach to crop protection integrating various pest suppression technologies including biological, chemical and cultural controls (Allen and Rajotte 1990, Kogan 1998). Action threshold (AT) based IPM uses scouted pest population densities and treats only when an economically damaging pest level is forecast to be reached by the time that spraying could take place. The threshold ideas was introduced in 1959 (Stern et al. 1959), and AT-based IPM research and outreach was first federally supported in 1971 (Allen and Rajotte 1990).

An IPM AT for soybean aphid was rapidly developed. Between 2003 and 2005, entomologists adopted a common experimental protocol at 6 sites distributed across 6 states (Iowa, Michigan, Minnesota, Nebraska, North Dakota, and Wisconsin). The researchers identified soybean aphid population growth rates and the relationship between soybean aphid density and yield loss, allowing them to establish an action threshold at 250 aphids per plant (Ragsdale et al. 2007). Subsequent research has validated the profitability of that action threshold for soybean aphid (Song et al 2006; Ragsdale et al. 2007). IPM for soybean aphid has been promoted among soybean growers through various outreach activities.

The rapid development of an AT to manage soybean aphid was enabled by a body of IPM principles, theories and experience developed over four decades and applied to a wide range of pests. In order to avoid exaggerating the returns to recent applications of IPM research methods to soybean aphid, it is important to attribute a suitable level of benefits to prior basic IPM research (Alston and Pardey 2001).

The goal of this study is to estimate the returns to research and outreach for soybean aphid management, especially AT based IPM. We make three contributions here. First and foremost, we estimate the economic impact of U.S. public research and outreach for AT-based IPM of soybean aphid, using the economic surplus approach. Although IPM impacts on farm-level productivity, profitability and pesticide use have been studied extensively (Hall 1977, Hall and Duncan 1984, Fernandez-Cornejo et al. 1994a, Fernandez-Cornejo 1996, Fernandez-Cornejo and Jans 1996, Fernandez-Cornejo 1998), there exist few evaluations of economic impact on overall social welfare (Napit et al. 1988). Second, we estimate the environmental economic value of reduced pesticide risk due to IPM adoption using benefit transfer methods. Third we divide the attribution of soybean aphid IPM research and outreach benefits between the soybean aphid IPM application and previous basic IPM research.

MATERIALS AND METHODS

Economic Surplus Analysis and Conceptual Framework

A well accepted approach to evaluate economic returns to research is economic surplus analysis. Economic surplus is a measure of economic welfare equal to the sum of producers' earnings over their marginal costs and consumers' willingness to pay above and beyond the market price. These ideas can be illustrated with supply and demand curves, as in Figure 1. The soybean supply curve (the quantities that growers would be wiling to supply at different prices) is represented by line S_0; D represents soybean demand curve (the quantities that consumers would be willing to buy at different prices). The consumer surplus is the area e_0p_0b, the value of consumers' added satisfaction gained by being able to purchase soybean for a price that is less than they would be willing to pay. The producer surplus is measured by area $e_0p_0a_0$, the added income above cost that producers earn by selling soybean at a market price that is higher than they would be willing to sell for. Economic surplus is equal to the sum of producer and consumer surplus, as shown by area FO_0E_0.

We use the change of economic surplus in U.S. soybean market to estimate the annual loss associated with soybean aphid invasion and project the benefits of controlling it for a period from 2000 to 2017. Then we calculate the net present value (NPV) of the annual loss and benefits with a real discount rate of 5% in 2005 dollars. The analysis starts with a benchmark estimate of the potential damage that soybean aphid could have caused if left uncontrolled during this period. The "no control" scenario establishes the counterfactual baseline for evaluating two management alternatives for damage mitigation. This scenario attempts to capture the value of economic losses from soybean aphid if no pest management tactics had been available. Since the supply curve represents marginal costs, uncontrolled yield loss due to soybean aphid will increase marginal costs and shift supply upward and to the left from S_0 to S_1 (Figure 1). The consumer surplus shrinks to area e_1p_1b, because soybean consumers now pay a higher price and some who consumed at the original price can no longer afford to do so. The change of soybean producer surplus is measured by area $e_0p_0a_0$- $e_1p_1a_1$. In general, the net welfare effect to producers may be positive or negative because there are two opposite effects. The producers sell fewer soybeans, but at a higher price. The sum of soybean consumers' and producers' surplus changes measures the net welfare loss associated with uncontrolled soybean aphid and can be represented by area $e_0e_1a_1a_0$.

We model the benefits of soybean aphid management in two stages. In the first, farmers adjust to soybean aphid by practicing prophylactic control. In so doing, they reduce the damage but sometimes spray unnecessarily. In a second stage, after exposure to the IPM action threshold idea, farmers begin to spray only when the value of expected yield loss exceeds the cost of control. The two stages are captured in two analytical scenarios. First is a prophylactic management scenario where a single insecticide treatment is applied regardless of the level of soybean aphid pressure. Compared to the "no control" scenario, the new supply curve (S_2 in Figure 2) will shift rightward because prophylactic control can protect against yield loss. However, it will not return to the original market equilibrium because the control costs incurred raise production costs above the level prior to arrival of soybean aphid. The benefits of prophylactic control of soybean aphid are measured by the reduced economic loss compared to no control. In the second stage, AT-based IPM and prophylactic management coexist as IPM gradually replaces prophylactic control. Since IPM is a newly proposed management alternative, it takes time for soybean growers to adopt it. We assume that it takes 15 years from when IPM research on soybean aphid began in 2003 for IPM to be adopted by all soybean aphid growers in the susceptible area, an area accounting for roughly 75% of U.S. soybean production. The averted pest control costs when soybean aphid pressure is low will result in a rightward supply curve shift (S_3) compared to the prophylactic control scenario curve at S_2. The gross benefits of IPM research and outreach are measured by the reduced economic loss compared to the prophylactic control scenario.

Factors that determine the surplus change

Formulas in Alston, Norton and Pardey (1998) are employed to estimate the change of surplus (see appendix I) for each individual year, and then they are summed up. We assume linear supply and demand, parallel supply shift and large open economy in which U.S soybean exports can influence international market price. By solving the equilibrium conditions before and after soybean aphid invasion and converting them to elasticity forms, the changes of the U.S. consumer surplus and producer surplus can be calculated as following:

$$\Delta CS_{US} = P_0 C_{US} Z(1 + 0.5Z\eta_{US}) \quad [1]$$

$$\Delta PS_{US} = P_0 Q_{US}(K - Z)(1 + 0.5Z\varepsilon_{US}) \quad [2]$$

$$\Delta TS_{US} = \Delta CS_{US} + \Delta PS_{US} \quad [3]$$

where ΔCS_{US} is the change in consumer surplus in the U.S., ΔPS_{US} is the change of production surplus in the U.S., and ΔTS_{US} is the change of the total economic surplus in the U.S. P_0, Q_{US} and C_{US} are soybean market price, U.S. production and U.S. consumption. ε_{US} is U.S. domestic supply elasticity and η_{US} is U.S. domestic demand elasticity, which can be represented by the slope of the demand and supply curves, are obtained from existing literature. K is the vertical supply shift, and Z is the percentage change in equilibrium price, which can be expressed as

$$Z = K * \frac{\varepsilon_{US}}{\varepsilon_{US} + \eta_{US} * S_{US} + (1 - S_{US}) * \eta_{ROW}} \quad [4]$$

where S_{US} is the proportion of soybean consumed domestically. K is the key value to be estimated. It depends on change of marginal production costs, which differ among management alternatives. For any given management alternative, K also varies across years because aggregate yield loss and control costs vary from year to year with the spread of soybean aphid and adoption rates for prophylactic control and IPM. The methods used to obtain each element in the formula are explained below in more detail.

Estimated yield change and control costs to project supply shifts

The vertical supply shift K is equal to the net change in production costs, which is the sum of the equivalent cost increase converted from yield loss and the control cost. The yield loss caused by soybean aphid is estimated by an econometric model using experimental data at two sites in each of three states, Michigan, Iowa and Minnesota, between 2005 and 2007. At each site, three treatments were established, representing no control, prophylactic control and IPM control. We specify the model as

$$y_{it} = a_0 + a_1 EET + a_2 TR + a_3 EET * TR + \sum_{i=1}^{2} b_i S_i + \sum_{t=1}^{2} c_t YR_t + \sum_{i=1}^{2}\sum_{t=1}^{2} d_{it} S_i YR_t + u_{it} \qquad [5]$$

Where y_{it} is the yield at location i in year t, variable EET is ‘exceeds economic action threshold’, a binary variable to indicate if the soybean aphid infestation exceeded the threshold at location i in year t. TR is a binary variable indicating whether the field was treated (whether due to prophylactic or IPM strategy). S_i are location variables (Iowa and Minnesota; Michigan is the base) to capture the effects of geographic factors, YR_t are binary variables indicating year (2006 or 2007; 2005 is the base) to capture annual effects, and u_{it} is the error term. Since we have three years of yield observations for the same set of sites, there is a possibility that unobserved factors, such as site attributes, could be correlated, leading to coefficient estimates to be statistically biased. Fixed effect or random effect estimation can solve this problem, depending on whether the unobserved effects are correlated with other explanatory variables. We use fixed effects estimation favored by a Hausman test instead of random effects estimation (see Wooldridge 2002, p. 288).

As Table 1 shows, when the soybean aphid population is over threshold it causes 0.66 ton/ha (9.7bu/ac) yield loss if not controlled. However, if treated when above threshold, both prophylactic and IPM treatments can fully protect against yield loss. Although straight analysis of variance shows that there is no significant difference in yield effect between IPM and prophylactic treatments (Song et al 2006), the treatments differ in control costs, which consist of spraying cost and insecticide cost. The spraying cost is \$8.00/ha (\$3.20/ac) from Doane's Agricultural Report (Schnitkey and Lattz 2005). The insecticide cost is \$17.40/ha (\$6.98/ac) for lambda-cyhalothrin at the recommended rate of 3.2 oz/acre. Thus prophylactic control costs were \$25.45/ha (\$10.18/ac) in 2005. Ragsdale et al. (2007) also estimated the soybean aphid control costs and derived three cases (low, middle and high cost) by combining spraying cost estimated from different sources and insecticide costs at various pesticide expenses. Our prophylactic control estimate is similar to their mid-range control costs at \$ 24.95/ha (\$9.92/acre). IPM costs have two cases, when threshold is exceeded, it is \$ 29.95/ha (\$12.18/ac) because there are \$5.00/ha (\$2.00/ac) more scouting compared to prophylactic control cost[1]. If the threshold is not exceeded, scouting costs are only \$5.00/ha (\$2.00/ac). The average IPM control costs depend on whether the soybean aphid infestation exceeds the action

[1] Scouting costs of \$2/acre come from personal communication, a telephone conversation by Scott Swinton with Matt Duchrow of Agri-Business Consultants, Inc. on 18 Jan, 2006. His conservative estimate of a per-visit rate is \$1. Most of Mr. Duchrow's clients had him scout their fields 2 times.

threshold for control. Assuming it does so on a proportion $\alpha \in (0,1)$ average IPM costs would be \$(α*24.95 + 5), so when the AT is exceeded less than 80% of the time, IPM has a cost advantage over prophylactic control, which always costs \$24.95/ha.

The vertical supply shift K is equal to the net change in production costs per ton of soybeans with respect to the base case of uncontrolled soybean aphid. Production cost changes per ton are calculated as the sum of the equivalent combined cost increases from yield loss and pest management cost. In order to convert yield loss to vertical supply shift, per-hectare yield loss is converted to an equivalent cost increase by dividing the yield changes by the U.S. soybean supply elasticity[2] (Falck-Zepeda et al 2000; Alston et. al 1998). Changes in the per-hectare control costs are converted to a per-ton basis by dividing them by one plus the per-hectare yield change caused by soybean aphid and associated management.

Supply and demand elasticities

Soybean supply and demand elasticities were obtained from existing literature (see Table 2). The U.S supply of soybean land has historically been price inelastic, meaning that when price changes, soybean planted area changes proportionately less. U.S. supply elasticity estimates range widely, from 0.2 to 0.9, which can result in great difference in

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[2] To see this point, we can make some manipulation on supply elasticity, which is defined as ε=dp/dq*q/p. Since the supply curve represents marginal production costs, the slope of it can be expressed as dp/dq=dMC/dq. After substitute it into supply elasticity ε=dp/dq*q/p= dMC/dq*q/p and rearrange, we can get dq/q= (dMC/p)/ ε. Left hand side is yield change and right hand side is equivalent change in marginal production costs.

the estimation of K and subsequently economic surplus. We used the 0.8 value in our baseline scenario, which results in a more conservative, smaller price effect on estimated economic surplus than the mean value of 0.55. Sensitivity analysis on this assumption is described in the following section. For the rest of the elasticity assumptions, we select the value most common in the literature or failing that, the median. Parameter values for the baseline scenario were a U.S domestic demand elasticity of -0.4, U.S export elasticity of -0.6, the rest-of –world (ROW) demand elasticity of -0.25 and rest-of-world supply elasticity of 0.3 (Table 2).

Diffusion of IPM

The IPM adoption process can be represented by the logistic "S" shaped curve first estimated statistically by Griliches (1957). The curve describes an adoption path in which adoption begins slowly followed by a period of rapid growth and then reaches a plateau adoption level. The level of adoption at a particular year is estimated by

$$P_t = \frac{P_{\max}}{1+e^{-(a+bt)}} \qquad [6]$$

where P_t is proportion of adopted area in year t; $P_{\max}$ is a maximum adoption rate; a and b are adoption parameters to be estimated. If $P_{\max}$ is given, the logistic adoption function can be expressed as a linear function of the logarithmic odds ratio:

$$\ln\left(\frac{P_{\max}}{1+e^{-(a+bt)}}\right) = a+bt \qquad [7]$$

A natural upper bound for the IPM adoption rate is the planted area of the northern states potentially infested with soybean aphid, roughly 75% of the nation's total planted area. According to USDA's pest management practices reports, scouting for weed, disease and insect pests (chiefly the first two) was practiced on an average of 16%

soybean planted area in major producing states in 1997-99 (NASS, 1998-2001), indicating that the idea of AT-based IPM was already well established before soybean aphid appeared. Therefore, we can reasonably assume that 1) the soybean aphid IPM adoption rate reached 1% in 2004, the first year that IPM for soybean aphid was proposed, and 2) the adoption rate can achieve the maximum of 75% of soybean growers in 2017. These assumptions imply two equations in two unknowns, which yield the solutions a = -5.00 and b = 0.73. These estimates are similar to those of Fernandez-Conejo and Castaldo (1998) who used a logistic form to examine the adoption path of several IPM practices in U.S. fruit. The predicted spread of IPM adoption is accompanied by the disadoption of prophylactic control, so that two methods sum to the total area susceptible to soybean aphid, as illustrated in Figure 3.

Because the soybean area infested area is still expanding, we also modeled its spread within the potentially susceptible temperate soybean production areas of the northern United States. The total susceptible area expands with the spread of soybean aphid and stabilizes at 75% of national planted area, as noted above. We use another logistic curve to project the growth path of total susceptible area, based on USDA reported chemical usage data of soybean crop from 2000 to 2006 (NASS 2001 to 2007)[3].

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[3] The logistic curve in Equation [6] and linear transformed function in Equation [7] are used, where P_t is percentage of soybean area treated due to soybean aphid infestation. USDA Chemical Usage Report (NASS 2001 to 2007) reported the percentage of soybean treated area in most soybean planting states for year 2000 to 2006 except 2003. P_t is calculated as the average reported percentage in soybean aphid infested states in the same period. $P_{\max}$ is 75%, as assumed above. The linear transformed function [7] is estimated by

The predicted rate of IPM diffusion is a function of both time and the spread of soybean aphid. Before IPM was introduced in 2004, prophylactic control is assumed to dominate all infested area. IPM adoption begins slowly during 2005-07, its early promotion years, speeding up after 2008, surpassing the adoption level for prophylactic control in 2010, and tapering off at the maximum of 75% in 2017. The patterns for prophylactic control, IPM adoption rate and total treated area associated with soybean aphid are illustrated in Figure 3.

Research and outreach costs

The public program costs of developing AT-based IPM for soybean aphid are a combination of research and diffusion costs. We estimate the research costs by synthesizing data from federally funded research projects that included AT based IPM for soybean aphid and associated costs covered by state and industry sources. Details are presented in Appendix II. Since 2000, there have been three major federal research projects focusing on soybean aphid AT based IPM. Two were funded by North Central Soybean Research Program (NCSRP) during 2003-06 and 2006-09. The soybean aphid AT was developed under the first NCSRP project. The third major project was funded by the U.S. Department of Agriculture's Risk Avoidance and Mitigation Program (RAMP). The total research grants devoted to AT-based IPM for soybean aphid come to $2.1 million between 2003 and 2009. For each project, we also identify the participating states and the principal investigators (PI), and we assume that for each state, there was one

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ordinary least squares regression and the estimated intercept a is -1112 with a t value -3.55, parameter b is 0.55 with a t value 3.54. Both parameter estimates are significant at the 5% level.

technician and one graduate assistant (GA) to assist the PI implementing the project. In a survey of research participants' time allocation in 2005, soybean aphid RAMP project personnel involved in AT-based IPM reported devoting one third to half time to the project. This time allocation style is used to estimate the full time equivalents, which include 3 PIs, 3 technicians and 3 GAs per year between 2003 and 2009 (see details in Appendix II). The associated costs of research time are \$1.2 million per year, estimated by multiplying full-time equivalents by representative salary and adding fringe benefit costs, nonpersonnel costs (at 30% of personnel) and adding indirect costs (at 50% of direct costs. We estimate the outreach costs by assuming 20 agents in 20 soybean infested states and each devoting 5% time from 2004 to 2017. The outreach costs are estimated to be \$2.2 million per year. The estimated present value of direct research and extension costs dedicated to soybean aphid between 2003 and 2017 is \$31 million. Because research costs are assumed to be end in 2009, 74% of the total is devoted to outreach activities and 26% to research.

Prices and discount rate

The value of soybean aphid management depends importantly on soybean price assumptions. We use historic soybean prices for the period 2000-06, with prices for 2007-17 from the USDA (2007) predictions that vary year to year with a conservative mean of \$254/ton (\$6.90/bu) (see Appendix III for full price series). We assume no inflation, reporting present values of results in 2005 dollars using a real discount rate of 5 percent.

RESULTS

Results of the baseline calculations establish estimated economic loss due to soybean aphid under three scenarios, uncontrolled, prophylactic control and gradual adoption of AT-based IPM. If left uncontrolled, the present value of economic loss for the period 2000-17 would have an estimated value in 2005 dollars of $7.16 billion, or 3% of the total soybean production value during that period (Table 3). The incidence of loss would be greater for consumers, who suffer 61% of the loss, with producers suffering the other 39%.

Prophylactic control can protect yield loss caused by soybean aphid, but it increases control costs compared to the uncontrolled scenario, reducing the estimated loss from $7.16 to $3.33 billion (Table 3). IPM has an apparent cost advantage over prophylactic control when soybean aphid pressure is low. Using the logistic adoption curve in Figure 3 to simulate a gradual process of IPM replacing prophylactic control between 2004 and 2017, the loss would fall to $1.99 billion. The $1.34 billion of reduced loss is the gross benefit of soybean aphid research and extension. Based on the direct research and extension costs of $31 million, the internal rate of return to investment in AT-based IPM for soybean aphid control is 140% (attributed exclusively to the direct costs of research and outreach).

Sensitivity Analysis

Economic impact analyses are built on many assumptions. We evaluate the sensitivity of these results to changes in four key parameter assumptions: over-threshold infestation level, supply elasticity, speed of IPM adoption and soybean price. For simplicity, we develop two sensitivity analysis cases by varying all four key parameters. The conservative case has lower estimated IPM research benefits, by assuming lower over-threshold infested level, more elastic supply, slower IPM adoption, and lower soybean prices. By contrast, the optimistic case has higher estimated IPM research benefits, by assuming higher over-threshold infestation level, less elastic supply, quicker IPM adoption and higher soybean prices based on 2008 estimates. Table 4 reports the parameter assumptions for the different cases and the corresponding estimated results.

The benefits of AT-based IPM come chiefly from its cost advantage over prophylactic control, since both of them can effectively protect against yield loss. The incidence of infestations over-threshold affects the cost difference between IPM and prophylactic control. More infestation over-threshold means more fields need to be treated under the IPM regime and increases the control costs, reducing the benefits generated by IPM. For our conservative case, we assume double the baseline area of soybean fields over threshold. For the optimistic scenario, we assume half the baseline area.

Both demand and supply elasticity can affect the IPM research benefits. The -0.4 demand elasticity is widely accepted on the literature, so we adhere to this assumption. Supply elasticity estimates are more varied. For a given yield loss, higher price elasticity of supply means smaller vertical supply shift K and equilibrium price change Z and thus a smaller economic surplus change. For our conservative case, we use 0.9. For the optimistic scenario, we use 0.2, the lowest estimate in the literature.

Quicker IPM adoption will boost IPM benefits. We let the logistic adoption parameter b vary by ±20% to evaluate the impact of adoption speed.

Another factor that can affect the soybean aphid economic impact and benefits of its control is the surging soybean price in the current biofuel production context. Our baseline soybean prices between 2000 and 2017 are obtained from observed prices for 2000-06 and USDA baseline projections made in early 2007. However, the recent ethanol expansion not only pushes up the price of corn, which is the main ethanol production feedstock, but also raises the price of soybean by competing with corn for crop land. The national average farm price for soybean in January 2008 was $404/ton ($11.00/bu), 40% higher than historical record $287/ton ($7.80/bu) in 1983 and more than double of the average price $184/ton ($5.00/bu) since 1960. The USDA 2008 soybean price projections over the next ten years were adjusted much higher than previous two years. We use the 2008 USDA's projections averaging $326/ton ($8.90/bu) for the optimistic scenario and the 2006 projections averaging $218.60/ton ($5.90/bu) for the conservative case (Appendix III).

Results of the sensitivity analysis bracket the base case estimate of net benefits to AT-based IPM research and outreach for soybean aphid over 2003-17 of $1.32 billion (Table 4). The conservative estimate of net benefits equals $0.56 billion, a 58% reduction from the base. The optimistic case yields an estimate of net benefits of $2.63 billion or 100% above the base case.

DISCUSSION

Context for findings

Two prior bodies of research offer comparative frames of references for these findings on impact of soybean aphid and the returns to research and outreach into IPM to control it. The first body estimates damages from another invasive pest in soybean, Asian soybean rust. These estimates provide contest for our counterfactual estimate of potential economic losses due to soybean aphid if left uncontrolled. Livingston et al. (2004) and Johansson et al. (2006) studied the economic impact of the Asian soybean rust disease. They reported an estimated loss only for soybean producers ranging from $623 million to 1.4 billion for the year 2010 depending on the management regime. Our estimates of loss from soybean aphid in 2010, borne by both producers and consumers, range from $274 to $698 million, in the lower end of the possible loss caused by Asian rust. The difference can be explained by the facts that Asian rust has higher yield impact and the treatment costs are much higher than soybean aphid (over $75/ha vs under $33/ha).

The second relevant body of findings bears on the returns to a major IPM extension program over time in different crops. Napit et al (1988) evaluated the economic impact of nine IPM extension programs in several states. For seven programs, they found no significant profitability impact from IPM. For two, cotton in Texas and Mississippi, adopting IPM for cotton made a significant net revenue difference. They reported annual internal rates of return of 452% for Texas and 300% for Mississippi respectively, much higher than our regional estimation of 140% for soybean aphid. Their higher rate of return estimate may be explained by at least three factors, 1) they covered more IPM practices including not only scouting but also biological control and change in cultural practices and, 2) their study embraced all target pests for a particular crop, where ours focuses only on AT-based IPM for soybean aphid, and 3) cotton has been a particularly successful crop for IPM programs historically.

Extending the analysis to include health and environmental values

The economic impact estimated so far captures market values, but environmental benefits can be expected as well. IPM can reduce pesticide use and associated risks to environment and human health, such as contaminating water, poisoning farmers or killing nontarget animals (Pimentel et al 1992, Brethour and Weersink 2001). The value of these benefits is not directly revealed through the soybean market, but a complete welfare analysis should account for them in total benefits of soybean aphid IPM research and outreach. Several research methods can be used to elicit consumers' willingness-to- pay (WTP) for such nonmarket benefits as reduced exposure to pesticide risk. These nonmarket valuation methods include contingent valuation, cost of illness, and averting expenditures (interested readers are referred to Champ et al 2003). To calculate likely environmental benefits of AT-based IPM for soybean aphid, we use reported environmental and human health benefits of reduced pesticide use from the published literature, a technique called benefit transfer. Benefit transfer is defined as 'the transfer of existing estimates of non-market values to a new study which is different from the study for which the values were originally estimated' (Boyle and Bergstrom 1992).

Our calculation of environmental benefits of soybean aphid IPM involves five steps:

1) assigning a risk level to the commonly used pesticides for soybean aphid to environmental and human health, because consumers have different WTP for avoiding different level of risks;
2) estimating society's total annual WTP for avoiding a given agricultural pesticide risk level, based on the WTP values transferred from previous studies;

3) assessing the impact of replacing prophylactic control by IPM on the pesticide [4] risk exposure from year 2003to 2017;
4) calculating the annual economic value of the environmental benefits of the soybean aphid IPM program from when it began in 2003 to 2017 by multiplying the total annual WTP to avoid a given level pesticide risk by the degree of pesticide risk reduction due to IPM; and
5) calculating discounted net present values (NPV) from the annual risk reduction calculations.

We report the major results here and the details of the procedures in Appendix IV. The estimated NPV, based on WTP values adapted from benefit functions reported in two past studies literature range from $4 million to $55 million. Compared to the market benefits of soybean aphid IPM program, the estimated monetary value of the environmental benefits of soybean aphid IPM is relatively small, partly because the pesticides used for soybean aphid represents only 0.05%[5] of total U.S. agricultural pesticide use.

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[4] Pesticide includes herbicide, insecticide, fungicide and other chemicals. IPM for soybean aphid directly reduces the insecticide use and thus total pesticide use.

[5] Fishel (2007) estimated 675 million pounds pesticide used in U.S. in 2001. USDA reported 272 thousand pounds insecticide used for soybean in 2001, but only for the surveyed states which covered 71% of the total soybean area. Based on that, we estimate 345 thousand pounds insecticide used for total soybean area. Therefore we can estimate that the insecticide use for soybean is about 0.05%.

Attribution of benefits from IPM for soybean aphid

A broader issue is how much of the AT-based soybean aphid IPM benefits should be attributed to the indirect effect of basic IPM research, rather than the direct effect of research and outreach applied to the specific case of soybean aphid. Previous IPM research expenditure over the past four decades is difficult to tally, but the total would likely come to over $1 billion. We approach this question indirectly by calculating the residual benefits after subtracting the direct returns to the soybean aphid research and outreach efforts by assuming a rate of return. Ascribing a reasonable rate of return of 10% to direct effects would leave $790 million in benefits to compensate the indirect costs of prior IPM research. Even at a very high rate of return of 25% to direct costs, $210 million would remain to cover indirect costs of prior IPM research.

IPM research and extension have received federal support for nearly a half century. The high ex ante rate of return to IPM threshold recommendations for soybean aphid illustrates how that research investment has established the capability to conduct rapid adaptive research to combat a new invasive pest species. Reasonably conservative assumptions lead to an estimated welfare gain of $1.1 billion in 2005 dollars, enough to generate a 10% inflation-free internal rate of return and leave $790 million toward compensating prior basic research into action threshold IPM.

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Table 1: Fixed effects estimation of soybean yield response to aphid infestation at six sites in Michigan, Iowa and Minnesota from 2005 to 2007 (in tons/ha).

Explanatory Variables	Coefficients	Std. Error	P>|z|
Year 2006	1.51	0.30	0.00
Year 2007	0.66	0.30	0.03
Minnesota	1.38	0.31	0.00
Iowa	2.20	0.31	0.00
Exceed threshold	-0.66	0.41	0.11
Treated	0.05	0.14	0.71
Treated when above threshold	0.76	0.33	0.02
Minnesota*2006	-1.72	0.39	0.00
Minnesota*2007	-1.99	0.39	0.00
Iowa*2006	-1.51	0.39	0.00
Iowa*2007	-1.46	0.39	0.00
Constant	2.20	0.27	0.00

Note: Number of observations is 54, number of groups is 18 (3 treatments at 6 sites), Overall R^2 is 77%, within R^2 is 77% and between R^2 is 77%.

Table 2: U.S. and rest-of-world soybean supply and demand elasticities used in previous studies

Elasticities	Falck-Zepeda et al (2000)	Moschini et al (1999)	Piggott et al (2003)	Price et al (2003)
U.S. domestic supply elasticity	0.22 and 0.92	0.80		0.28
U.S. domestic demand elasticity	-0.42	-0.40	-0.29	-0.50
U.S. export demand elasticity	-0.61		-0.63	-1.21
U.S total demand elasticity			-0.38	
R.O.W. demand elasticity	-0.07	-0.40		-0.25
R.O.W. supply elasticity	0.30	0.60		0.30

Table 3: Estimated U.S. gross economic impact of soybean aphid since arrival (2000-17) and its management since IPM research began (2003-17) (in million $)

Management scenario	Change in U.S. producer surplus	Change in U.S. consumer surplus	Change in U.S. total economic surplus
No control (2000-17)	-2,791 m	-4,368 m	-7,159 m
Prophylactic control only (2003-17)	-1,279 m	-2,052 m	-3,331 m
IPM displacing prophyl. (2003-17)	-768 m	-1,217 m	-1,985 m

NB: IPM introduced in 2004 after research initiated in 2003.

Table 4: Sensitivity analysis for net return to U.S. research and outreach for AT based IPM for soybean aphid, 2003-17 (in millions $)

	Case considered:	Conservative	Baseline	Optimistic
	Gross benefits	$ 589 m	$1,346 m	$2,657m
	Research Costs	$31 m	$31 m	$31 m
	Net Benefits	$558 m	$1,315 m	$2,626 m
	Sensitivity[1]	-58%		+100 %
Parameters	infestation level	40%	20%	10%
	Supply elasticity	0.9	0.8	0.2
	Adoption pattern	Slow (b=0.58)	Base (b=0.73)	Quick (b=0.88)
	Soybean price (2007-2017)	2006 USDA projection[2]	2007 USDA projection[3]	2008 USDA projection[4]
	Average soybean price (2007-2017)	$218.60/ton	$254.00/ton	$325.98/ton

1 Compared to baseline

2 USDA Agriculture Baseline Projection to 2015 (http://www.ers.usda.gov/Publications/OCE061/)

3 USDA Agriculture Baseline Projection to 2016 (http://www.ers.usda.gov/Publications/OCE071/)

4 USDA Agriculture Baseline Projection to 2017 (http://www.ers.usda.gov/publications/OCE081)

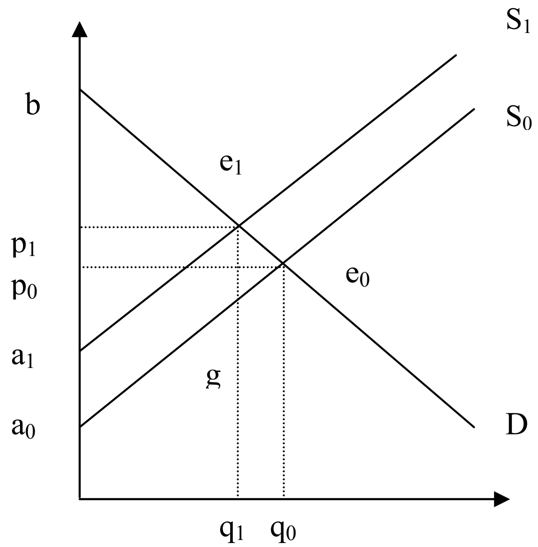
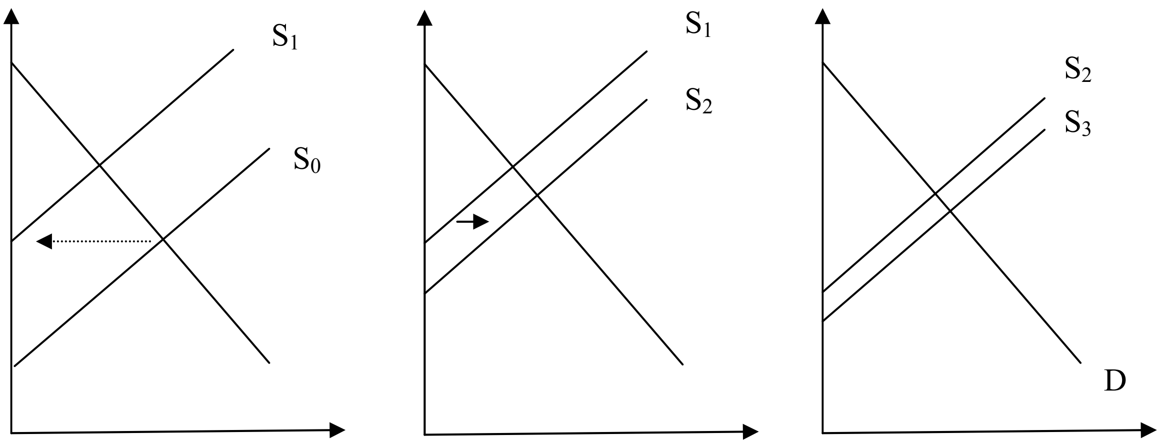


Figure 1: Illustration of Economic Surplus Analysis



S_0: soybean market supply curve before soybean aphid arrived

S_1: soybean market supply curve under no control scenario

S_2: soybean market supply curve under prophylactic management scenario

S_3: soybean market supply curve under prophylactic and IPM co-existing

management scenario

Figure 2: Hypothetical U.S Soybean Supply Shifts under Different Management Scenarios

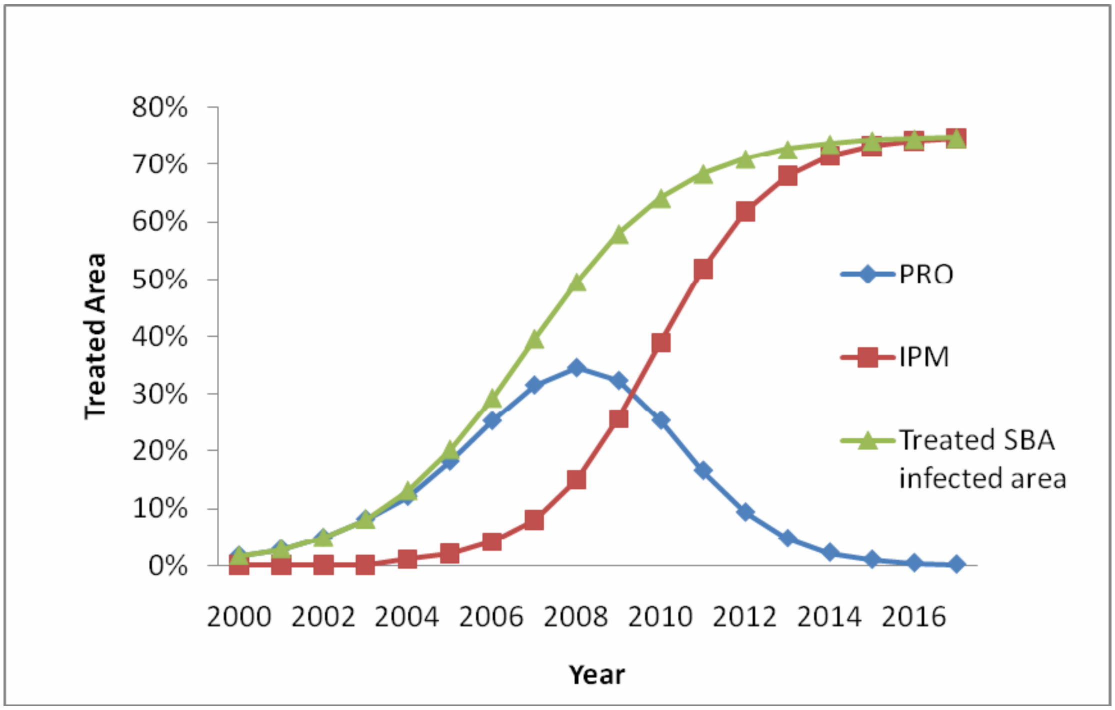


Figure 3: Adoption of IPM and Disadoption of Prophylactic Treatment

Appendix I

The quantitative estimation of the size and distribution of the welfare loss associated with the different management scenarios can use the well-established method for estimating the welfare gain from the introduction of a new technology.

In 2006, U.S. produced over one third of the world soybean and exported over 40% of the world's total exportation. Thus we estimate the impacts of soybean aphid in the context of a large open country which can influence world price through international trade. The linearity of supply-and-demand and a parallel shift were assumed. Following Alston et Al. (1998), US and rest of the world (ROW) can be modeled as:

U.S. supply: $Q_{US} = \alpha_{US} + \beta_{US}(P+k)$ [1]

U.S demand: $C_{US} = \gamma_{US} - \delta_{US} P$ [2]

ROW supply: $Q_{ROW} = \alpha_{ROW} + \beta_{ROW}(P+k)$ [3]

ROW demand: $C_{ROW} = \gamma_{ROW} - \delta_{ROW} P$ [4]

Where k is the vertical supply shift due to the soybean aphid infestation. P is the world price of soybean. Q_{US} and C_{US} are soybean quantities produced and consumed in the United States while Q_{ROW} and C_{ROW} are quantities produced and consumed in the rest of the world. In equilibrium,

$$Q_{US} + Q_{ROW} = C_{US} + C_{ROW} \quad [5]$$

The percentage change of price Z is defined as $\frac{P_1 - P_0}{P_0}$ where P_0 is the initial price and P_1 is the price after supply shift. Solve the above system of demand-and supply equations for P by setting $Q_{US} + Q_{ROW} = C_{US} + C_{ROW}$, we can obtain:

$$P=\frac{\gamma_{US} + \gamma_{ROW} - \alpha_{US} - \alpha_{ROW} - \beta_{US} k}{\beta_{US} + \gamma_{US} + \beta_{ROW} + \delta_{ROW}} \quad [6]$$

When k=0, $P = P_0 = \frac{\gamma_{US} + \gamma_{ROW} - \alpha_{US} - \alpha_{ROW}}{\beta_{US} + \gamma_{US} + \beta_{ROW} + \delta_{ROW}}$ [7]

When k=KP$_0$, $P = P_1 = \frac{\gamma_{US} + \gamma_{ROW} - \alpha_{US} - \alpha_{ROW} - \beta_{US} KP_0}{\beta_{US} + \gamma_{US} + \beta_{ROW} + \delta_{ROW}}$ [8]

where K is the percentage price reduction due to soybean aphid.

The P_0 and Z can be converted to the elasticity form as following:

$$P_0 = P_1 / \{1 - \frac{\varepsilon_{US} K}{\varepsilon_{US} + S_{US}\eta_{US} + (1 - S_{US})\eta_{ROW}}\} \quad [9]$$

$$Z = \frac{P_1 - P_0}{P_0} = \frac{\varepsilon_{US} K}{\varepsilon_{US} + S_{US}\eta_{US} + (1 - S_{US})\eta_{ROW}} \quad [10]$$

where ε_{US} is U.S. domestic supply elasticity, η_{US} is US domestic demand elasticity, η_{ROW} is the U.S. export demand elasticity, S_{US} and is the share of US production consumed domestically. After manipulation, we can obtain P_0, which we can't observe, as follows:

$$P_0 = \frac{P_1}{1 - Z} \quad [11]$$

The formulas for U.S. welfare effects caused by soybean aphid are given by

$$\Delta CS_{US} = P_0 C_{US} Z(1 + 0.5Z\eta_{US}) \qquad [12]$$

$$\Delta PS_{US} = P_0 Q_{US}(K - Z)(1 + 0.5Z\varepsilon_{US}) \qquad [13]$$

$$\Delta TS_{US} = \Delta CS_{US} + \Delta PS_{US} \qquad [14]$$

Where ΔCS_{US} is the change in consumer surplus in the US, ΔPS_{US} is the change of production surplus in US, and ΔTS_{US} is the change of the total economic surplus in the United States.

Appendix II

This appendix provides details about calculations and assumptions for the research and outreach costs associated with AT-based IPM for soybean aphid.

Research Grants: Since 2000, there have been three major research projects focusing on soybean aphid AT based IPM. Two were funded by North Central Soybean Research Program (NCSRP) during 2003-06 and 2006-09. The soybean aphid AT was developed under the first NCSRP project. The other was funded by the U.S. Department of Agriculture's Risk Avoidance and Mitigation Program (RAMP). Table A1 presents the details about the participating states, number of PIs and research funds of these projects.

Time costs of research participants: We have limited information for the two NCSRP projects (2003-09), so we assume that all PIs working on soybean aphid AT based IPM, whereas for RAMP (2005-07) we can indentify 5 PIs working on it. As almost all of them were also PIs of NCSPR projects, we assume that between 2003 to 2006 there were 6 PIs and between 2006 and 2009 there are 9 PIs conducting soybean aphid AT based IPM. For each project, we assume that there are one technician and one graduate assistant (GA) to assist the PI(s) implementing the project.

In a survey of time allocation in 2005, the RAMP project personnel reported devoting one third to half time to the soybean aphid research. The soybean aphid AT was developed under the first NCSRP. The second NCSRP and RAMP have multiple research objectives, so they involve relatively less AT based IPM. We assume that the research participants of the first NCSPR devoted one half of their time to AT-based IPM, whereas research participants of the second NCSPR and RAMP projects devoted one third of their time to the soybean aphid AT based IPM research. Therefore, between 2003 and 2009 there are 3 PIs, 3 technicians and 3 GAs full time equivalents per conducting soybean aphid AT based IPM research. Annual opportunity costs of research participants' time are estimated by multiplying the FTE and their respective costs, as shown in Table A2. The opportunity costs of researchers' time are $1.2 million per year.

Outreach costs: We estimate the outreach costs by assuming 20 agents in 20 soybean infested states and each devoting 5% time from 2004 to 2017, which gives us 20 full time equivalents agents. Their personnel costs are $ 66,269, based on email from Sharon Jackson to Scott Swinton on average Extension Educator costs in Michigan (May 30, 2007). Nonpersonnel costs were assumed to be 30% of research personnel costs. Indirect costs were assumed to be 50% of total direct costs. The estimated annual outreach costs are $2.2 million.

Total research and outreach costs: The research grants are assumed to be distributed evenly each year during the project duration and added with the annual researchers' time costs and outreach costs. The estimated direct research and extension costs dedicated to soybean aphid are $26 million, 75% of which are devoted to outreach activities and 25% to research.

Table A1: Information on Soybean Aphid Action Threshold-based IPM Research Projects

Research project	Participating States	Number of PIs	Federal Grants	State Matching Grants	Total Research Grants
NCSRP (2003-06)	MN (lead), IA, IN, MN, ND, OH	6	$ 356,668	$958,666	$1,285,354
NCSRP (2006-09) [1]	MN (lead), IA, IL, IN, KS, MN, NE, SD, WI	9	$ 111,051	$ 333,154[2]	$ 444,205
RAMP (2005-07)	MI (lead), IA, MN WI	11	$376,363	0	$376,263

Note: 1. NCSPR (2006-2009) has multiple research objectives and less to do with soybean aphid AT based IPM. According to the lead PI, David Ragsdale, 1/6 of the total research grants are assumed to be devoted to soybean aphid AT based IPM.

2. The state matching grants for NCSPR (2006-09) are estimated by assuming one third of the federal grants, which is roughly equal to the proportion of NCSPR (2003-06).

Table A2: Research participants and their full time equivalents

	PI	Technician	GA	Time allocation	PI FTE per year	Technician FTE	GA FTE
2003	6	6	6	1/2	3	3	3
2004	6	6	6	1/2	3	3	3
2005	6	6	6	1/2	3	3	3
2006	9	9	9	1/3	3	3	3
2007	9	9	9	1/3	3	3	3
2008	9	9	9	1/3	3	3	3

Table A3: Annual researchers' time costs between 2003 and 2008 (in $)

	PI	Technician	GA
Number of person per year	3	3	3
Cost per person	123,681	51,600	27,373
Personnel costs	371,044	154,800	82,119
Non-personnel costs (@ 30% personnel)	111,313	46,440	24,636
Total direct costs	482,357	201,240	106,755
Indirect costs (@ 50% direct costs)	241,179	100,620	53,377
Total direct and indirect costs	723,536	301,859	160,132
Total costs	1,185,527		

Note: Costs per person for PIs, technicians and GAs were obtained from Michigan State University Office of Planning (OPB) and Budgeting.

Appendix III

Table A4: Price used in sensitivity analysis in $/ton ($/bu in parenthesis)

Year	Conservative 2006 USDA projection	Baseline 2007 USDA projection	Optimistic 2008 USDA projection
2007	198 (5.40)	257 (7.00)	331 (9.00)
2008	209 (5.70)	266 (7.25)	325 (8.85)
2009	215 (5.85)	268 (7.30)	327 (8.90)
2010	219 (5.95)	257 (7.00)	321 (8.75)
2011	222 (6.05)	254 (6.90)	323 (8.80)
2012	222 (6.05)	250 (6.80)	323 (8.80)
2013	222 (6.05)	250 (6.80)	323 (8.80)
2014	224 (6.10)	248 (6.75)	325 (8.85)
2015	224 (6.10)	248 (6.75)	327 (8.90)
2016	224 (6.10)	248 (6.75)	329 (8.95)
2017	224 (6.10)	248 (6.75)	331 (9.00)

Source: USDA Agriculture Baseline Projection to 2015 (http://www.ers.usda.gov/Publications/OCE061/)

USDA Agriculture Baseline Projection to 2016 (http://www.ers.usda.gov/Publications/OCE071/)

USDA Agriculture Baseline Projection to 2017 (http://www.ers.usda.gov/publications/OCE081)

Appendix IV Estimating the environmental benefits of soybean aphid IPM using benefit transfer

This appendix provides details on how we estimate the environmental benefits of soybean aphid IPM, which involves the following four steps.

Step 1. Much of the literature on pesticide risk reduction adopts the risk level classification of low, medium and high to reflect the difficulty of quantifying risk while recognizing that people have different WTP for avoiding different levels of risk. We assigned a medium risk level to the group of pesticides used for soybean aphid based on the method developed by Mullen et al (1997). They divided the environment into eight categories, including ground water, surface water, acute human health, chronic health, aquatic species, birds, mammals, and arthropods. They then assigned risk levels to each individual category according to a set of criteria they created. The risk levels of three major soybean aphid insecticides were obtained from Mullen [6] and presented in Table A5. Since the three insecticides have similar mixtures of high, medium and low risks across the eight categories, for purposes of benefit transfer, we treat all three soybean aphid insecticides as posing medium risk overall.

Step 2. Society's annual WTP for avoiding the medium risk from agricultural pesticides is estimated based on the WTP transferred from previous studies. We found two very relevant studies. One study is Mullen et al. (1997), who valued the annual

[6] Personal communication with Dr. Jeffrey M. Mullen, assistant professor at University of Georgia via email on March 4th, 2008.

environmental benefits of the peanut IPM program in Virginia. They conducted a national mail survey to ask the respondents' WTP to avoid a given level of agricultural pesticide risk including high, medium and low via an increase in their grocery bill. They reported a WTP of $22.8 per household per month for in 1992 U.S. dollars, which can be adjusted by 2% inflation rate (Economic Report to President, 2006) and converted to a $355 per household per year in 2005 U.S. dollars. Given that there were 113 million households in U.S in 2005, society's total WTP to avoid medium pesticide risk was $40 billion in 2005 U.S. dollars.

Another study is Florax et al. (2005), who conducted a meta-analysis[7] of previous studies valuing pesticide risk exposure. They regressed the mean WTP per person per year in 2000 U.S. dollars for avoiding a given level of pesticide risk on four types of variables: types of pesticide risk (e.g., human health and environmental degradation), level of risk reduction (e.g., low, medium, high), research characteristics (e.g., valuation technique used, survey types), and social-economic variables, such as income. In Table A6, we present their reported estimation results from two model specifications with different levels of detail on types of pesticide risks.. Then we tailor their model to fit our case. For types of pesticide risks, we exclude the variables associated with consumer risk because soybean aphid insecticides are not applied to the pods and very few soybeans are consumed directly by humans. We also exclude the chronic health effects, ground water

[7] Meta-analysis is a quantitative analysis of the summary finding of prior studies valuing the same environmental benefit (van den Bergh and Button 1999). It uses statistical tool to analyze the variation in the estimated WTP values.

effects, and birds because the soybean aphid pesticides have low risks to these categories as shown in Table A5. The overall level of risk reduction is medium as discussed in step 1. For research characteristics variables, we assume using state preference valuation method with a mail survey (these are baseline in the model and thus included in the constant) and bias control. The payment vehicle is yield loss (the baseline in the model) and the type of safety device is IPM. The income variable comes from U.S GDP in 2000. Based on their regression results, we can estimate the WTP for avoiding medium risk posed by agricultural pesticides to be $8.88 to $12.41 per person per year in U.S. 2000 dollars depending on model specification, which can be adjusted by 2% inflation and converted to a $9.80 to $13.70 per person per year in 2005 U.S. dollars. Given a population of 296 million in U.S in 2005, society's total WTP to avoid medium pesticide risk is $2.9 to 4.1 billion.

Step 3. The impact on the pesticide risk exposure of replacing prophylactic control by IPM is measured by the reduction in pesticide use. We use the amount of pesticides as a proxy of risk they pose and assume that the reduction of pesticide risk exposure is linear in the reduction of pesticide use. Insecticide use to control soybean pest is about 0.05% (see Footnote 7) of total agricultural pesticide use in U.S in 2001. Therefore, we can infer that if replacing prophylactic control by IPM reduces insecticide use for soybean aphid by 1%, it equivalently reduces total agricultural pesticide use by 0.0005% and subsequently reduces the pesticide risk exposure by 0.0005%. Assuming a 20% soybean aphid infestation over-threshold level, IPM can reduce the insecticide use by 80%. For any given year, the pesticide use reduction for soybean aphid at a national scale is calculated as 80% of prophylactic insecticide use * the predicted IPM adoption rate. The associated risk exposure reduction would be (80% * the IPM adoption rate)*0.0005%.

Step 4. The annual WTP to avoid a medium risk of agricultural pesticide is combined with the pesticide risks reduction to estimate the economic value of the environmental benefits of the soybean aphid IPM program. The annual economic value of the environmental benefits of the soybean aphid IPM program from its introduction in 2003 to 2017 is calculated by multiplying the total annual WTP to avoid a medium level pesticide risk by the degree of pesticide risk reduction due to IPM.

Step 5. The NPV over the period 2003-17 is calculated from the annual economic benefits of risk reduction. The estimated NPV based on WTP values reported by Mullen et al 1997 is $55 million while based on Florax et al 2005 is $ 4 to 11 million depending on their regression model specifications.

Table A5: Risk levels of three soybean aphid pesticides to environment and human health

Environmental and human health categories	esfenvalerate	lambda-cyhalothrin	zeta-cypermethrin
Ground water	low	low	low
Surface water	high	mid	mid
Aquatic species	high	high	high
Acute Human health	mid	mid	high
Chronic human health	low	low	mid
Avian species	low	mid	low
Mammalian species	mid	low	mid
Nontarget Arthropods	high	low	high

Note: for the detailed criteria on how to assign a risk level to an individual environmental and human health category, please refer to Mullen et al (1997)
Source: **Mullen, J. D., G. W. Norton, and D. W. Reaves. 1997.** Economic Analysis of Environmental Benefits of Integrated Pest Management. Journal of Agricultural and Applied Economics 29: 243-53.

Table A6: Predicted WTP based on Florax et al (2005) meta-analysis of pesticide risk reduction valuation studies ($ per person per year)

	Model 1	**Scenario 1**	**Model 2**	**Scenario 2**
Specification	Est. Coef.	Variables included in Prediction	Est. Coef.	Variables included in Prediction
Variable				
constant	4.31 (0.38)	V	2.85 (0.23)	V
Targets and targets type				
Farmers	0.96 (0.29)	V		
Acute effects			0.42 (0.12)	V
chronic effects			0.42 (0.12)	×
general			0.73 (0.21)	V
Consumers	omitted			
Acute effects			-0.06 (-0.04)	×
chronic effects			0.18 (0.12)	×
cancer risk			-0.15 (-0.40)	×
Aquatic ecosystem	1.21 (0.37)	V		
surface water			0.63 (0.18)	V
Ground water			0.68 (0.20)	×
aquatic organism			0.56 (0.16)	V
Terrestrial ecosystem	1.17 (0.36)	V		
Mammals			0.54 (0.16)	V
Birds			0.55 (0.69)	×
biodiversity			2.39 (0.69)	V
beneficial insects			0.56 (0.16)	V
Risk assessment and income				
medium risk	0.14 (2.19)	V	0.17 (2.76)	V
high risk	0.81 (12.77)		0.78 (12.58)	
log(GDP)	0.38 (0.43)	V	0.51 (0.54)	V
Valuation method				
choice experiments	-4.77 (-4.48)	×	-5.05 (-4.25)	×
revealed preference	-7.52 (-3.69)	×	-7.4 (-3.46)	×

Continue on next page

Table A6 continues

Type survey and sampling				
face-face- survey	6.06 (9.03)	×	6.23 (8.03)	×
bias control	-0.19 (3.42)	V	-0.18 (-3.50)	V
payment vehicle				
price premium	-7.57 (-3.32)	×	-7.4 (-3.07)	×
Separate billing	-3.16 (-19.02)	×	-3.15 (-18.75)	×
Type safety device				
IPM	-3.7 (-3.10)	V	-2.94 (-1.92)	V
pesticide ban	1.24 (3.64)	×	1.42 (2.79)	×
Health risk vehicle				
All fruits and vegetables	6.84 (5.73)	×	7.29 (4.91)	×
n	316		316	
R-square adjusted	0.93		0.93	
F-test	270.93		176.26	
Predict WTP per person per year in 2000 US $		8.88		12.41

Note: Model specification and estimation results are adopted from **Florax, R. J. G. M., C. M. Travisi, and P. Nijkamp. 2005.** A meta-analysis of the willingness to pay for reduction in pesticide risk exposure European Review of Agricultural Economics 32: 441-467. The t-ratios are in parenthesis.