Environmental Benefits from Reduced Pesticide Use and Returns to Research: An Application to the U.S. Cotton Industry

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Abstract

Cotton production is one of the main pesticide use industries in the U.S. This intensive use has resulted in the disruption of naturally occurring biological control factors that regulate other insect pest populations and "the pesticide treadmill". The result is resistance to insecticides, high control costs and unacceptable levels of chemical insecticides in the environment. Concerns about the environmental and human health effects from pesticide use thus need to be modeled in evaluation studies.

Keywords: Cotton, pesticide use, environmental effects, supply function.

Introduction

The economic benefits of investment in agricultural research have been evaluated for all major agricultural commodities in the United States (Araji 1980, 1989, 1990, 1998). However, the effects to the environment, natural resources and human health from such research programs have not been included in the existing returns to research studies. Traditional methods for estimating returns to research mainly focus on observed changes in market behaviour and market prices, or rather, improvements in productive efficiency (Fuglie et al. 1996). Most technological advances result in both negative and positive effects, so that some part of the society benefits while another part loses. Most negative effects tend to be associated with the environment, natural resources, health or community and family life (Fuglie et al. 1996), and they were thought to be due to excessive chemical and pesticide use.

External costs of pesticide use refer to the costs of damage imposed on society and the environment due to using pesticides in agricultural production, but that are not accounted for in the market price either through the cost of pesticides or the price of agricultural products. The lack of markets for health and environmental services means that unlike man-made products, they are not explicitly priced, so their monetary values cannot be readily observed. Several methods have been used in assigning an economic value to pesticide impacts. Such methods include: remediation cost, lost productivity, and willingness-to-pay to avoid pesticide risk. Willingness-to-pay, which is commonly used, does not measure the existence or extent of an environmental problem, rather it measures the attitude toward a problem, and whether the problem bothers a particular stakeholder enough to pay for an alternative (Levitan et al., 1995).

Inclusion of these externality effects in economic analysis is necessary to ensure appropriate, imaginative policies are devised and implemented in the global, national, sector and project levels (Lubulwa and Davis 1994). The external effects have to be valued and quantified in monetary terms before they can be included in economic evaluations. For a long time, valuing these effects was elusive, so that returns to research were always estimated without accounting for the secondary effects, resulting in higher private than social returns. With the development of non-market evaluation methods, it is now possible to bridge the gap between market and non-market studies. This study sought to address this gap by accounting for the environmental effects from pesticide use in returns to U.S. cotton.

The cotton industry is one of the major contributors to the U.S. Gross Domestic Product (GDP). The U.S. government has therefore, always attached high priority to raising productivity in the cotton industry by investing in its research. U.S. is also among the three main cotton producers in the world, alternating in second and third places between India and China and thus important in world trade. The three countries provide over half the world's cotton. Cotton is the single most important textile fiber in the world, accounting for nearly 40 percent of total world fibre production (USDA-ERS, 2008). Cotton is noted for its versatility, appearance, performance and above all, its natural comfort (Georgia Cotton Commission). The activities associated with growing, handling and ginning cotton provides a significant source of income for approximately one billion people each year. Exports of cotton lint represent a significant portion of the foreign exchange earnings for many countries (Townsend, 2002).

Cotton production has however always faced many challenges, especially related to pests. Numerous pests have been associated with cotton, so that one of the significant challenges in cotton production is to control insects with minimum use of pesticides. There have been more concerns about insecticides than other pesticides, and cotton producing countries throughout the world wish to get away from pesticide-intensive production practices (Chaudhry, 2006). Several techniques have been utilised to deal with these damaging pests (Georgia Cotton Commission). These have included;

1. utilizing the integrated pest management (IPM), a multifaceted approach that relies on natural populations of beneficial insects to suppress damaging pests.
2. genetic modification to make the cotton crop less attractive to insects eg Bt cotton. Currently, genetically engineered cotton is either resistant to specific herbicides or resistant to bollworms. The U.S. is the largest producer of GE crops and GE cotton
3. bio-technological improvements to make the plants resistant to certain worms
4. cultural practices to improve earliness

Objectives

The main goal of this study was to evaluate the impact of environmental effects from reduced pesticide use on returns to research investment in U.S. cotton. Specifically, the study sought to;

1. Estimate the value of environmental effects from reduced pesticide use due to the Boll Weevil Eradication Program (BWEP) in cotton production.
2. Incorporate the estimated environmental benefits into the cotton supply model and hence in consumer and producer surplus, and returns to investments in cotton.

Study Area

Cotton is grown in 17 U.S. States extending from the Southwest to the Southeast. This study was carried out at the regional level due to difficulties in obtaining State-level cost of production data. For the period 1975-1996, the regions were defined using ERS production regions which were defined following State boundaries. States were grouped according to those with similar production practices and resource characteristics. The ERS cotton production regions and their component States are respectively; Southwest (Arizona and California), Southern Plains (Oklahoma and Texas), Delta (Arkansas, Louisiana, Mississippi, Missouri, Tennessee) and, Southeast (Alabama, Georgia, North Carolina, South Carolina).

The regions were redefined in 1995 to ERS Farm Resource Regions which include; Fruitful Rim (covers most of Arizona and California, all of Florida, some small parts of Georgia and South Carolina, and southern sections of Texas), Prairie Gateway (covers all of Kansas, 50 percent of New Mexico, most of Oklahoma and Texas), Mississippi Portal (covers 25 percent of Arkansas, most of Louisiana and Mississippi, and almost 50 percent of Tennessee), Southern Seaboard (most of Alabama, Georgia, North Carolina, South Carolina and Virginia, a small portion of Arkansas, Louisiana and Texas), and Heartland that includes more than 50 percent of Missouri. For data consistency, we compared the percent area coverage of the regions using the ERS maps and we approximately merged the Southwest to Fruitful Rim, Southern Plains to Prairie Gateway, Delta to Mississippi Portal, and Southeast to Southern Seaboard.

Literature Review

Pesticide Risk Valuation

Our main focus in this study is on the environmental benefits from reduced pesticide use. It is therefore fitting to define these pesticide impacts. Impacts of pesticide use are normally defined in terms of health risks and / or environmental degradation due either to increased contamination of soil and water resources, reduction in farmland diversity, and loss of natural habitats (Florax et. al. 2005). Increased awareness about these risks has led to heightened campaigns for environmental sustainability and food safety. Such campaigns have led to advocacy for growing organic food, new policy instruments such as eco-labelling of fresh produce (Govindasamy et al. 1998; Blend and van Ravenswaay 1999), more stringent rules and regulations by the U.S. Environmental Protection Agency (EPA) governing proper use pesticides, and pesticide taxes (Swanson 1998; Mourato et al. 2000; Pearce and Seccombe-Hett 2000).

There is a rich literature on the valuation of pesticide risks. These studies have mostly focused on health risks to farmers and consumers (Misra et al., 1991; Ravenswaay and Hoehn, 1991a,b; Baker and Crosbie, 1993; Eom, 1994; Buzby et al., 1995; Roosen et al., 1998; Blend and Ravenswaay, 1999; Fu and Hammitt, 1999; Wilson, 2002). Wilson (2002) was more concerned with health risks to farmers. A handful of studies have valued both environmental and health effects from pesticide use, from an integrated pest management (IPM) standpoint (Higley and Wintersteen, 1992; Mullen et al. 1997; Foster and Mourato 2000; Brethour and Weersink 2001; Cuyno et al. 2001; Schou et al. 2002).

Brethour and Weersink (2001) and Mullen et al. (1997) analyzed the non-market benefits of a program of Integrated Pest Management (IPM) using a consumer survey in the U.S. and Ontario, Canada, respectively. Owens et al. (1998) and Cuyno et al. (2001) studied farmers' WTP for reducing the negative effects of pesticides in the U.S. and in the Philippines, respectively. These studies valued environmental effects of pesticides, considering health as one of several environmental categories. Respondents had to value their WTP in a sequence of scenarios for the different environmental and human health categories.

The cotton supply function has been modelled in various studies either as yield response, acreage response or general production. Annual production of any crop depends on the price producers expect to receive when they sell their output (expected price) and other factors that shift the supply function (such as input costs). There are various ways to model the expected price, since there is no direct measure for it. Some studies have modeled the expected price using lagged prices (Araji et al. 1995) and others have used futures price (Beach et al. 2002). Expected price is used in modeling production in order to capture the lag between planting, harvesting and selling. Usually, the higher the expected market price, the more producers are willing to supply, ceteris paribus.

Research introduces new technology as an additional variable in the supply model, modeled as lagged research expenditures. Research expenditures are lagged because effects from research are not realized immediately after the initial investment. Generally, research effects will start to be realized 6 to 8 years after the initial investment (Evenson 1968); rise gradually to a maximum before declining to almost zero when the technology becomes outdated. For this reason, current production is a function of past research. Since governments tend to determine subsequent investments based on past investment levels, past research expenditures tend to be highly correlated (Araji et al. 1995).

Data and Sources

The data used to estimate the supply equations covered the period 1975 – 2008. Cotton production, acreage, yield and production by state are reported by the USDA-ERS *cotton and wool yearbook*. Similar statistics for other crops grown in the cotton study areas and marketing year average price for cotton are reported by USDA-NASS *Quick Stats State or County-crops data* (Ag Statistics database). The lagged marketing year average prices were used to represent expected prices in the supply equation.

Research expenditures were obtained from the U.S. CSREES Current Research Information System (CRIS). Average cost per acre for fertilizer, machinery and pesticides were also obtained from USDA-NASS, reported under *Farm production expenditures* Annual Summary, by region. Precipitation data for each state are published by the National Climatic Data Center (NCDC) of the U.S. Department of Commerce's National Oceanic and Atmospheric Administration's (NOAA) National Environmental Satellite, Data and Information Service (NESDIS). This provides monthly data that was averaged to annual data.

Data needed to estimate environmental benefits from reduced pesticide use were obtained as follows. Population data for each state in the study are maintained by the U.S. census bureau. Pesticide use data; providing acreage treated, rate of application and amount applied for each active ingredient were obtained from the National Center for Food and Agricultural Policy (NCFAP) and, from USDA-NASS Agricultural Chemical Use Database. NCFAP has the most comprehensive pesticide use data for 1992, 1997 and 2002. Willingness-to-pay to prevent pesticide risks were adopted from Mullen (1995). Pesticide risk levels were obtained from various sources (EXTOXNET, EPA and IUPAC). . The estimation was done in logarithmic form by least squares estimation method.

Theoretical Framework

Accurately determining the actual damages of pesticide use is always difficult due to the high cost of monitoring and measuring the extent of such damages. Despite these difficulties, an extensive empirical economic literature now exists on pesticide risk valuation. Previously, environmental impacts of pesticide use were commonly proxied through variables such as pounds of active ingredient (a.i.) applied or dollars spent on pesticides. Both these measures assume that environmental damage is directly correlated with the quantity of pesticide used, regardless of the specific chemical and formulation (Brethour and Weersink, 2001). However, it has been widely acknowledged that weight and volume measures are not adequate proxies for assessing this risk, and this is partly due to the increased availability of low-dosage alternatives (Stenrød et al. 2008).

Some previous studies have attempted to value pesticide use damages through changes in the relative risks to a series of environmental and human health categories.

Such criteria has been employed by Kovach et al. (1992) who derived Environmental Impact Quotients (EIQ's), although they did not assign an economic value to the differences in EIQ's. The economic literature offers two alternative approaches to environmental risk valuation: the human capital (HC) approach and the willingness-to-pay (WTP) approach. The former is more suited to valuing health effects, while the later can be used for both health and environmental risks.

The monetary value of a decrease in pesticide usage and the associated risks can be expressed as the aggregate individuals' willingness-to-pay for a pesticide risk reduction or, alternatively, the willingness-to-accept (WTA) a compensation for exposure to increased risk levels (Travis et al. 2006). This is based on the premise that the valuation in changes in pesticide risk will reflect the preferences of the economic actors exposed to the risk. The actors in this context are farmers, farm workers and consumers.

WTP values are normally obtained using Contingent Valuation survey method (CV), a method that has been suggested and applied as one means for valuing health and environmental benefits (Higley and Wintersteen, 1992; Mullen et al, 1997; Cuyno et al., 2001; Brethour and Weersink, 2001). This method has however received criticism, due to several potential biases including vehicle, strategic, hypothetical, starting point, and information biases. This notwithstanding, WTP can provide information on the level of environmental protection that is socially desirable, the level of human health risk that is socially acceptable and within a cost-benefit framework, the expected level of potentially excessive costs in terms of both private and public expenditure (Travisi et al., 2006).

To value environmental benefits due to BWEP we followed criteria similar to Cuyno et al., 2001 and Mullen et al., 1995, that have evaluated the benefits from IPM. Thus:

1. Categorized the environmental impacts from pesticide use into impacts on, acute and chronic human health, mammals, birds, non-target insects, aquatic species, groundwater and surface water.
2. Identified pesticides used to control the weevil in cotton production before and after the BWEP, and to control pests in other crops in the cotton study area.
3. Established the risk level of each pesticide active ingredient to each environmental category in (1).
4. Estimated the monetary value of the environmental benefits / savings to society from the BWEP.

The cotton production sector includes farms with diversified crop production, thus in estimating environmental benefits / costs from pesticide use on cotton, we also have to consider pesticides used on other crops grown in the study area. The total active ingredient used in the study area for all states was given by the general formula in equation (1) below.

$$Use_{ij} = \sum_{k=1}^{S}\left(\sum_{m=1}^{n-1} Use_{ijm} + Use_{ijc}\right)_k \qquad (1)$$

where $n =$ number of all crops in a given State's study area

$k =$ number of cotton growing States in our study

Use_{ijm} = amount of class ij active ingredient used on other crops in cotton study area

Use_{ijc} = amount of class *ij* active ingredient used on cotton in the study area

Use_{ijm} and Use_{ijc} are given by the formulas below

$$Use_{ijm} = \sum_{p=1}^{g} (Acres_m * Treat_{mp} * Rate_{mp}) \qquad (1.1)$$

$$Use_{ijc} = \sum_{a=1}^{y} (Acres_c * Treat_{ca} * Rate_{ca}) \qquad (1.2)$$

where g = number of active ingredients (*a.i.*) of class ij applied to crop m

y = number of active ingredients of class ij applied to cotton

$Acres_m$ = acres of crop m harvested in study area

$Acres_c$ = acres of cotton harvested in study area

$Treat_{mp}$ = proportion of crop m acres treated with *a.i.* p in study area

$Treat_{ca}$ = proportion of cotton acres treated with *a.i.* a in study area

$Rate_{ca}$ = application rate of active ingredient a on cotton

$Rate_{mp}$ = application rate of active ingredient p on crop m

The amount of active ingredient applied to the cotton study area before and after the BWEP were estimated using slight modifications of the second term in equation (1). Thus

$$Use_{ij,w/BWEP} = \sum_{k=1}^{17} \left(\sum_{b=1}^{w-1} (Use_{ij})_b + Use_{ijc,w/BWEP} \right)_k \qquad (1.3)$$

$$Use_{ij,w/oBWEP} = \sum_{k=1}^{17} \left(\sum_{b=1}^{w-1} (Use_{ij})_b + Use_{ijc,w/oBWEP} \right)_k \qquad (1.4)$$

where $Use_{ij,w/BWEP}$ = amount of class *ij a.i.* applied on cotton after BWEP

$Use_{ij,w/oBWEP}$ = amount of class *ij a.i.* applied on cotton before the BWEP

The assumption in equations (1.3) and (1.4) is that change in pesticide use between $Use_{ij,w/BWEP}$ and $Use_{ij,w/oBWEP}$ is with regard to pesticides used on cotton, so the first term is the same in the two equations. The total *a.i.* used on all upland cotton is the sum of the *a.i.* for the *S* States. For the eradication program to be effective, it was mandatory for all cotton farmers to participate in the program, therefore we considered BWEP under high adoption rate. The reduction in pesticide use in the study area due to the BWEP in cotton for each k^{th} State was determined using equation (1.5).

$$reduction_{ijk} = 1 - \frac{E\left[Use_{ij}\text{with BWEP}\right]}{E\left[Use_{ij}\text{without BWEP}\right]} , \qquad (1.5)$$

where:

$$E\left[Use_{ij}\text{with BWEP}\right] = Use_{ijk} = \sum_{b=1}^{w-1}\left(E[Use_{ij}]\right)_b + E[Use_{ijc,k}] \qquad (1.5a)$$

$$E\left[Use_{ij}\text{without BWEP}\right] = \sum_{b=1}^{w-1}\left(E[Use_{ij}]\right)_b + E[Use_{ijck,w/oBWEP}], \qquad (1.5b)$$

$E[Use_{ij}] =$ expected use of a.i. ij on other crops in k^{th} state

$Use_{ijck,w/oBWEP}$ = amount of class ij *a.i.* applied to cotton before the BWEP

$Use_{ijc,k}$ = amount of class ij *a.i.* applied to cotton after start of BWEP

Savings in external costs from reduced use of active ingredient ij will then be calculated using equation (1.6).

$$Savings_{ijk} = WTP_{ij} * POP_k * reductions_{ijk} , \qquad (1.6)$$

where $WTP_{ij} =$ willingness to pay to reduce pesticide risks due to class ij *a.i.*

$POP_k =$ population in the study area in k^{th} State

Total savings from the BWEP for all states was then summed over all the risk / environmental category combinations using equation (1.7).

$$totalsavings_{BWEP} = \sum_{k=1}^{17}\left(\sum_{i=1}^{8}\sum_{j=1}^{3} savings_{ij}\right)_k \qquad (1.7)$$

Econometric Supply Model

The supply model for cotton was modeled on an annual basis because planting decisions are made annually. The study covered the four cotton producing Regions for the period 1975-2008. The basic model can be represented in double-logarithmic form as in equation (2).

$$InQ_{i,t} = \alpha_0 + \alpha_1 InX_{i,t} + \alpha_2 InP_{i,t} + \alpha_3 InRE_{i,t} + \alpha_4 InW_{i,t} + \alpha_5 InQ_{i,t-1} + ACPI + t \qquad (2)$$

where: for $t = 1,...,33$

$X_{i,t} =$ conventional inputs (as average cost per acre)

$P_{i,t} =$ expected output price

$Q_{i,t} =$ annual output

$Q_{i,t-1} =$ lagged cotton output, (1,000 pounds)

$W_{i,t} =$ annual rainfall weighted by acres devoted to cotton

$RE_{i,t} =$ research expenditure for region i, in year t

$ACPI_t =$ alternative crop price index

We used the quadratic polynomial distributed lag model, proposed by Almon and Cooper, for research expenditures. The research expenditure variable (RE_{it}), was modeled as a linear combination of seven research expenditure lags, following Evenson's

1968 study, with the lag coefficients following a quadratic polynomial structure with zero end-point restrictions. RE_{it} was calculated using equation (2.1).

$$RE_{i,t} = \sum_{r=0}^{L} (rL - r^2) R_{i,t-r} \qquad (2.1)$$

where: $R_{i,t-r} =$ research expenditures in region i at time $t-r$

$L =$ maximum lag length

$$i = 1,2,...,4$$
$$t = 1,2,...,T \qquad (2.1.1)$$
$$r = 0,1,...,7$$

Economic Surplus Approach

From a comparative static framework, and using Marshallian concepts of social welfare and costs, returns to research can be measured as changes in consumers' and producers' surplus resulting from a shift in the supply curve due to technological change.

This relationship is shown in figure 1 below,

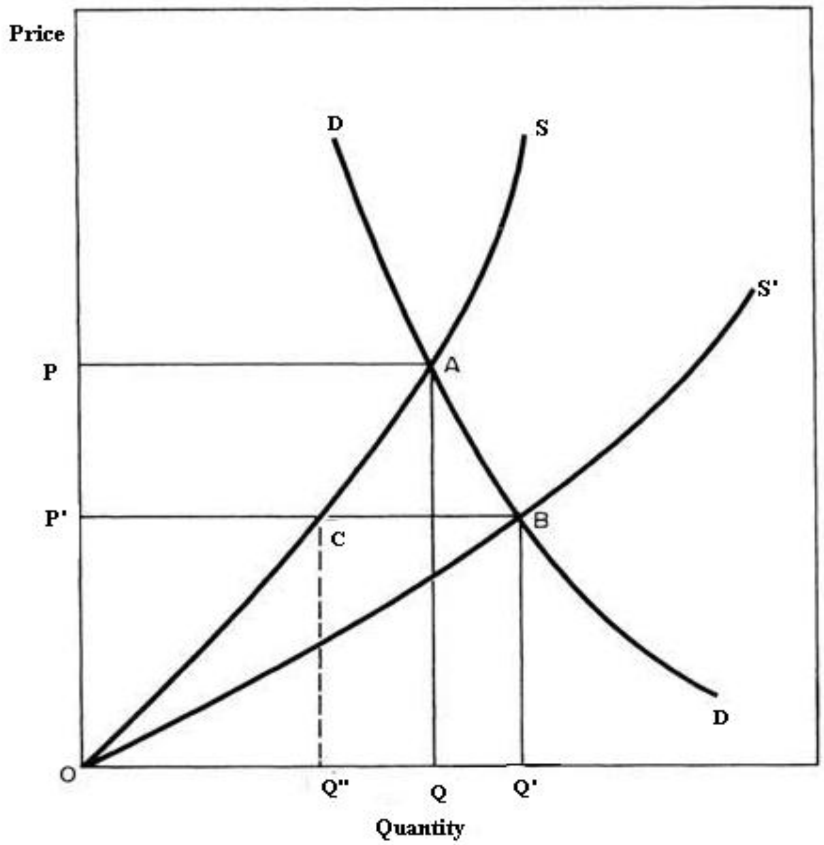

Figure 1: Shifts in Supply curve from Technological Change

where DD is the demand curve, S' and S are the supply curves with and without technological change, respectively. S'and S can be obtained by estimating equation (2) with and without the research expenditure variable (RE_{it}), respectively. The change in consumer (producer) surplus, ΔCS (ΔPS) , is the area behind the demand (supply) curve and between the two equilibrium prices, P and $P^{'}$. Consumer surplus increases by area $APP^{'}B =$ area $ABC +$ area $APP^{'}C$, while producer surplus changes by area $BCO -$ area $APP^{'}C$. Economic surplus thus equals area AOB .

Estimating consumer and producer surplus

Consumer and producer surplus were estimated using formulae below, following Akino and Hayami (1975):

$$\text{Area } ABC \approx \frac{1}{2} P'Q' \frac{[\kappa(1+\alpha)^2}{\alpha+\beta} \quad (3)$$

$$\text{Area } APP^{'}C \approx \frac{kP'Q'(1+\alpha)}{\alpha+\beta}\left[1 - \frac{\frac{1}{2}k(1+\alpha)\beta}{\alpha+\beta} - \frac{k(1+\alpha)}{2}\right] \quad (4)$$

$$\text{Area } BCO \approx kP'Q' \quad (5)$$

$$\text{Area } BCQQ' \approx (1+\alpha)kP'Q' \quad (6)$$

where:

$k =$ rate of shift in cotton, tomato production

$\alpha =$ price elasticity of cotton, tomato supply

$\beta =$ price elasticity of cotton, tomato demand

$P', Q' =$ equilibrium price and output with research

To obtain these estimates, we need to first estimate k, the rate of shift in the cotton production function as below (Akino and Hayami, 1975):

$$k \approx \frac{h_t}{1+\alpha} \quad (7)$$

where: $h_t =$ rate of shift in cotton or tomato supply curve

The rate of shift in the cotton supply curve can be obtained as the difference between output with research (from estimation of the supply equation (2) with the lagged research expenditure variable) and, output without research (from estimation of the supply equation excluding the research expenditure variable), divided by output with research. Thus;

$$h_t = \frac{Q' - Q}{Q'} \quad (8)$$

where: $Q' =$ cotton output with research expenditure variable

$Q =$ cotton output without research expenditure variable

3.4.3b Internal rate of Return

The internal rate of return, (IRR) was estimated as the rate that results in the inequality in equation (9).

$$\sum_{t=1}^{T} R_{i,t}(1+r_i)^{-t} = \sum_{t=1}^{m} C_{i,t}(1+r_i)^{-t} \tag{9}$$

where:

$R_{i,t}$ = social returns in state i, in year t

$C_{i,t}$ = costs of research in state i, in year t

r_i = internal rate of return for state

t = year of interest

T = year research ceases to produce returns

The social returns for each state in year t, will be the sum of the estimated environmental benefits, producer and consumer surplus for that state.

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