DIFFUSION OF BT COTTON AND INSECTICIDE USE

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Abstract

This study used state-level and sub-state, region-level data to econometrically estimate factors explaining regional differences in the speed an extent of the diffusion of Bt cotton varieties from 1996 to 1999. Differences in diffusion patterns could largely be explained by supply-side factors (availability of Bt varieties adapted to local production conditions) and demand-side factors (such as expected pest control cost savings, expected yield gains, market prices and program payment rates). The study next estimated the effect of Bt cotton adoption on the change in regional insecticide use from the pre-Bt 1991-5 average, controlling for other factors affecting insecticide use. Bt adoption had a large and statistically significant negative impact on insecticide use. Bt cotton adoption contributed to a drop in insecticide use of 0.71 applications per total U.S. cotton acres in 1996 and a drop of 1.68 applications in 1999.

Introduction

Many studies report significant reductions in conventional insecticide use targeted at budworm, bollworm and pink bollworm (PBW) as a result of Bt cotton adoption. Carpenter and Gianessi and Edge et al. provide good surveys of these studies. Yet, many of these studies are based on small-scale farm field or experimental plot experiments. In many cases the sample sizes are quite small, so that differences in insecticide use on Bt versus conventional plots are not statistically significant. A few studies using larger data sets have found significant differences in selected regions (Carlson and Marra; Fernandez-Cornejo and MacBride).

This study has two objectives. The first is to estimate factors explaining regional differences in the rate and extent of adoption of Bt cotton from 1996 to 1999. Griliches was the first economist to attempt to estimate the role of supply-side factors (availability of seed varieties adapted to local production conditions) and demand-side factors (expected economic gains from adoption) in explaining the rate of diffusion of new seed varieties (Griliches, 1957, 1960, 1980). We expand on the early approach of Griliches and Mansfield by estimating a generalized logistic diffusion model, where the parameters of the diffusion model are themselves functions of agronomic, economic and policy variables.

Our second objective is to estimate the impact of Bt adoption on use of insecticides targeted at budworm, bollworm and PBW. Evidence indicates that targeted insecticide use has indeed fallen *since* Bt cotton became available (Carpenter and Gianessi; Williams). Yet, it is a more controversial matter to what extent this reduction has been caused by Bt cotton adoption. Other factors, such as falling returns to cotton production over this period, or boll weevil eradication activities might also contribute to this drop. We thus estimate an econometric model of the reduction of targeted insecticide use, controlling for such factors. We also correct for possible simultaneity bias arising from the fact that Bt adoption may be an endogenous regressor in the insecticide use equation.

Diffusion Model Specification

The proportion of acres planted to Bt cotton in region i in time t, P_{it} is represented as a logistic function:

(1) $$P_{it} = K_i / [1 + \exp(-a_i - b_{it}\, t - u_{it})].$$

The term a_i characterizes the initial rate of Bt cotton adoption in region i in the first year it is available. The term K_i is an adoption ceiling defining the maximum proportion of acreage that will ultimately be planted to Bt cotton. The term b_{it} captures the rate of Bt cotton adoption. It determines how quickly the rate of adoption moves from the initial adoption level to the adoption ceiling. Finally, u_{it} is an error term.

We specify K_i, a_i, and b_{it} as functions of economic, agronomic, and policy variables. The maximum potential adoption rate, K, will be less than 100 percent in all regions because of EPA refuge requirements. Maximum potential adoption may also vary significantly across regions. Within a region there will be areas where bollworm / budworm pressure neither exceeds insecticide treatment thresholds, nor leads to appreciable yield losses. For example, in 1995, 15% of U.S. cotton acreage were reported to be without bollworm / budworm infestation, while 37% of cotton acreage were not treated for these pests (Williams, 1996). The adoption ceiling is specified as:

(2) $$K_{it} = k_0\, 0.96 + k_1\, hilat + \;+ k_2\, midlat + k_3\, strip$$

where the k_i terms are parameters to be estimated, 0.96 represents the impact of the 4-percent minimum refuge requirement, *hilat* is a dummy variable for high latitude regions, *midlat* is for mid-latitude regions, and *strip* is a dummy variable for stripper cotton regions. Stripper varieties of Bt cotton were not available in 1996-9, so we hypothesize that stripper cotton regions would have a lower adoption ceiling.

The initial adoption intensity variable $a_{i,}$ is a function of demand-side factors affecting expected initial gains to Bt cotton adoption, as well as the availability of Bt seed varieties that are adapted to local growing conditions:

(3) $$a_i = a_0 + a_1\, ln(yieldloss_i) + a_2\, ln(controlcost_i) + a_3\, parent_i.$$

The variable $yieldloss_i$ is the 1991-95 average real dollar value of yield losses per acre infested with budworms, bollworms and PBW in region *i* and $controlcost_i$ is the 1991-1995 average real pest control cost per treated acre. The variable $parent_i$ is the percentage of total acreage in a region in 1994 that was planted with a seed variety used to create the initial strains of Bt cotton seed. This variable is included because it is hypothesized that farmers already familiar with the non-Bt parent of Bt varieties will be more likely to adopt the Bt versions of those seeds.

The diffusion rate variable, b_{it}, is given by:

(4) $$b_{it} = b_0 + b_1\, ln(effprice_{it-1}) + b_2\, ln(costratio_{it}) + b_3\, bwerad_{it}$$

where $effprice_{it-1}$ is the lagged effective cotton price (market price + loan deficiency payment rate), $costratio_{it}$ is the ratio of the Bt technology fee to the per acre cost of conventional applications to control bollworms / budworms / PBW, and $bwerad_{it}$ is weighted boll weevil eradication cost per acre.

Data

The model is estimated for 1996-9 for the 27 states and sub-state regions reported in Williams. Williams is also the source of data on Bt cotton adoption, pest losses, pest control costs, technology fees, and eradication costs. Parent variety data came from USDA's Agricultural Marketing Service. Price data came from the National Agricultural Statistical Service, while cotton program payment data came from the Price Support Division of USDA's Farm Services Agency.

Diffusion Model Estimation Results

The Bt cotton diffusion model was estimated using nonlinear least squares, with results shown in Table 1. The model fit fairly well, with an adjusted R^2 of 0.78. Nearly all the variables were statistically significant and had the expected sign. High latitude and stripper cotton regions had significantly lower adoption ceilings than other regions. Initial adoption rates were higher in areas that had higher historical yield losses to Bt cotton's target pests and in areas with higher historical target pest control costs. They were also higher in regions that had high adoption rates of the parent varieties of first Bt varieties.

The speed of Bt cotton diffusion was increasing in lagged effective price, meant to capture price/program payment expectations. The technology fee / conventional application cost variable had the expected negative sign, but was not statistically significant. The speed of diffusion, however, was positively and significantly greater in regions participating in boll weevil eradication.

Insecticide Use Model Specification

The variable I_{it} represents insecticide applications targeted at bollworm, budworm and PBW in region *i* at time *t*. The variable measures applications divide by all cotton acres, not just to Bt cotton acres. We are interested in estimating Bt cotton adoption has changed targeted insecticide applications. We therefore estimated the following equation:

(5) $$I_{it} - \bar{I}_{i91\text{-}95} = \beta_0 + \beta_1 P_{it} + \beta_2\, effprice_{it-1} + \beta_3\, appcost_{it} + \beta_4\, bwerad_{it}$$
$$+ \beta_5\, d96 + \beta_6\, d97 + \beta_7\, d98 + \beta_8\, strip + \beta_9\, hilat + \beta_{10}\, midlat + v_{it}$$

where $\bar{I}_{i91\text{-}95}$ is the 1991-5 average targeted insecticide application rate. The regression estimates regional change in insecticide use from the historic pre-Bt cotton average as a function of the proportion of acres planted to cotton (P_{it}), lagged effective cotton price ($effprice_{it-1}$), the cost of conventional insecticide applications, weighted boll weevil eradication costs ($appcost_{it}$), along with year and region dummy variables. As before, the model covers 1996-9 for the cotton producing regions listed in Williams.

Because Bt adoption and insecticide use are both pest control decisions, omitted variables, such as weather or unobserved measures of pest population, are likely to affect both the diffusion model error term and the insecticide use error term. Estimating equation (5) by ordinary least squares could then lead to parameter estimates suffering from simultaneity bias. To control for this potential bias, equation (5) was estimated using an instrumental variable approach. Here, the predicted values of P_{it} from estimation of the diffusion equation are used in the regression.

Insecticide Use Model Specification

Results of instrumental variable estimation of the insecticide use equation are shown in Table 2. The coefficient on P_{it}, the proportion of a region's cotton acreage planted to Bt cotton, is highly significant with a value of –5.15. The interpretation of this estimate is as follows. An increase in the Bt adoption rate by 10 percentage points leads to a reduction in a region's average targeted insecticide application rate of 0.515. The results can suggest what conventional targeted insecticide applications in a region would have been if Bt cotton were not adopted. For example, the model implies that a region with 50 percent of its acreage in Bt cotton would have made a regional average of 2.575 more applications per acre above its historic average if no acres were planted to Bt cotton (2.575 = 0.5(–5.15)).

The effective price coefficient was positive but insignificant, while the insecticide application cost coefficient had the wrong sign. Boll weevil eradication expenditures did not have a significant impact on insecticide use targeted toward bollworms, budworms, and PBWs.

Discussion

The results presented here are preliminary and should be treated with caution. Though preliminary, the econometric model results suggest the following. Regional differences in the rate and extent of Bt cotton adoption can be explained well by supply-side factors (availability of Bt seed varieties adapted to local conditions) and demand-side factors (such as expected pest control cost savings, yield gains, market prices and program payments). The insecticide use regression equation results suggest that a large share of the reduction in insecticide applications to control budworms, bollworms and pink bollworms can be attributed to Bt cotton adoption, even when controlling for other factors. Bt cotton adoption contributed to a drop in insecticide use of 0.71 applications per total U.S. cotton acres in 1996 and a drop of 1.68 applications per total cotton acres in 1999.

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Table 1. Diffusion Model Regression Estimates

Dependent Variable: Proportion of Cotton Acreage Planted to Bt Cotton			
	R^2: 0.8060	**Adjusted R^2: 0.7838**	
Parameter / Variable	**Parameter estimate**	**Standard error**	**t statistic**
k_0	0.676	0.0627	10.79
hilat	-0.404	0.0879	-4.60
midlat	0.169	0.0549	3.09
strip	-0.245	0.0873	-2.81
a_0	-15.75	3.9942	-3.94
ln(yieldloss)	2.97	0.7657	3.87
ln(controlcost)	1.47	0.6147	2.39
parent	0.043	0.0109	3.94
b_0	1.753	0.7145	2.45
ln(effprice)	2.27	1.3300	1.71
ln(costratio)	-.358	0.4558	-0.79
bwerad	0.047	0.0214	2.22

Table 2. Insecticide Use Model: IV Estimates

Dependent Variable: Change in Targeted Insecticide Applications between Current Year and 1991-5 Average			
	R^2: 0.7426	**Adjusted R^2: 0.7160**	
Parameter	**Parameter estimate**	**Standard error**	**t value**
Intercept	-3.77	1.633	-2.31
P_{it} *(Bt adoption rate)*	-5.15	0.589	-8.75
effprice	3.50	2.54	1.38
appcost	0.09	0.04	2.28
bwerad	0.0009	0.017	0.05
d96	-0.349	0.35	-1.00
d97	0.0273	0.253	0.11
d98	0.649	0.265	2.45
strip	-0.015	0.286	-0.05
hilat	0.32	0.35	0.92
midlat	0.520	0.224	2.32

Table 3. Change in targeted U.S. insecticide application rates attributable to Bt cotton adoption

	Bollworm, budworm, and pink bollworm applications per total U.S. cotton acres		
	1995	**1996**	**1999**
Without Bt	2.5	2.08	2.23
With Bt		1.37	0.55
Reduction attributable to Bt		0.71	1.68