Genetically Modified Crops and Labor Savings in US Crop Production

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Abstract:

In spite of widespread adoption there is mixed evidence as to whether or not adopting Genetically Modified (GM) crops increase farm welfare. One possible reason for widespread adoption is the labor savings. Using a treatment effect model we estimate the time savings associated with adopting a GM crop.

Keywords: *genetically modified crops, agricultural biotechnology***,** *endogeneity, treatment effects, survey weights*

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Introduction:

Genetically modified organisms (GMOs) have been used in crop production for a decade. Currently, the most common GMOs can be classified into two groups: herbicide tolerant (HT) and insect resistant varieties of corn, cotton and soybeans. This technology was not developed via conventional crop breeding methods. Instead, a trait that is foreign to the organism was inserted into its genome. Roundup Ready soybeans are resistant to the herbicide glyphosate, which Monsanto markets under the brand name Roundup. Glyphosate resistance has also been inserted into corn and cotton. Insect resistance is achieved by inserting a gene from the bacteria *Bacillus thuringiensis* (*Bt*), which creates a toxin that affects Lepidoptera larvae. Currently the *Bt* trait has been inserted into corn and cotton to control the European Corn Borer, the Corn Rootworm, the Cotton Bollworm, the Pink Bollworm, the Asian Bollworm and the Tobacco Budworm.

Fernandez-Cornejo *et al.* (2002) found that HT soybean adoption did not have a statistically significant effect on farmer profit. Why then do we observe high levels of HT soybean adoption if there is no profit effect? It has been hypothesized that GMOs save labor and management (Alston *et al*. 2002; Bullock and Nitsi 2001; Marra 2001). Based on ARMS data from 2001-2003 Fernandez-Cornejo and Caswell (2006) report that 17%, 23%, 26%, 6%, 15% of all HT soybean, HT cotton, Bt cotton, HT corn and Bt corn, respectively use the technology to save on management time and make other practices easier, but they do not directly estimate time savings. We estimate the time savings associated with adopting a GM input, and find that HT soybeans and *Bt* cotton save labor while GM corn does not.

Literature Review:

Marra et al. (2002) and Marra (2001) reviewed literature on GM crops and concluded that farmers who adopt GM crops are better off. The authors reached several broad conclusions regarding the current generation of GM field crops, *Bt* cotton is likely to be profitable in the cotton belt and reduces pesticide use, adopting *Bt* corn should provide a small yield increase, and in some cases adopting causes significant increases in profit. For HT soybeans they conclude that cost savings should offset any revenue loss due to yield drag. These conclusions seem plausible as there are several effects that could induce a welfare gain. Bullock and Nitsi (2001) list four advantages of HT crops. 1) HT technology leads the farmer to substitute relatively less-expensive glyphosate for other herbicides. 2) Farmers realize a change in the shadow price of labor and management. 3) Due to glyphosate's effectiveness at killing larger weeds, weather induced spraying delays do not significantly affect weed control. 4) When farmers switch to HT technology substitution effects lead to a decrease in the price of alternative herbicides. The widespread adoption of GM crops may be evidence of a welfare gain. In 2005 Herbicide tolerant crops made up 87% and 60%, of U.S. soybean and cotton acreage respectively, while 35% of the corn acreage and 60% of cotton acres were insect resistant (Fernandez-Cornejo and Caswell, 2006). Bernard, Pesek and Fan (2004) found that farms in Delaware had yield increases and decreases in weed control costs when they adopted HT soybeans. So it would seem that adopting this technology results in a welfare gain for farmers. But most claims of welfare gain are not supported by empirical evidence. The literature requires more examination before one can draw a conclusion from it.

Marra *et al.* (2002) and Marra's (2001) evidence concerning the profitability of *Bt* cotton is overwhelming. All of the 47 studies that were compiled indicated that *Bt* cotton is profitable. Only two HT cotton studies were compiled, both indicated that the technology was profitable, as did two studies where these two traits were "stacked". However, the GM corn and soybean evidence lacks the depth to be conclusive; the author(s) drew conclusions based on two studies for each GM crop. Studies using the USDA's ARMS were excluded from the analysis based on the argument that field level data, such as that collected in ARMS phase II, could not capture within-farm effects leading to biased results. Marra's (2001) evidence for this argument is based on differences in unconditional means and no tests of statistical significance were presented. ARMS collects data on a large number of variables, such as education and farm size, which could be used to estimate an unbiased conditional mean in a well designed regression framework. As such, studies that use ARMS field level data should not be excluded from a review of the literature.

One study that was excluded in Marra's analysis was that by Fernandez-Cornejo *et al.* (2002), which used ARMS data and concluded that HT soybean adoption did not have a statistically significant effect on farmer profit. The Fernandez-Cornejo *et al.* study made use of a flexible functional form to estimate a profit function and corrected for endogeneity using the Heckman 2-step procedure. As cited earlier, the authors did not find a statistically significant profit effect. Bullock and Nitisi's (2001) study, which used a cost-minimizing simulation, found that GM soybean farmers are less profitable than their conventional counterparts. However, they did not take into account the labor and management savings that arise from convenience and timing factors, as these were not observable variables. This leads to a puzzling conclusion; it is uncertain whether or not HT soybeans are more profitable than conventional soybeans, but almost every farmer uses the technology. Perhaps the research community has been unable to measure an important component of farmers' welfare.

There are several possible factors that may not have been measured. Most notably are the potential time and management savings associated with these crops. Carpenter and Gianessi (1999) cite that the primary reason for adopting HT soybeans is simplicity of weed control and that glyphosate can control a wide range of weeds without harming the HT crop. Additionally, the authors point out that "Roundup Ready weed control programs fit into on-going trends towards postemergence weed control, adoption of conservation tillage practices and narrow row spacing" (p 67). Glyphosate can also kill larger weeds than other postemergence herbicides, and it has no residual activity thus it does not limit crop rotation programs. Fulton and Kyowski (1999) discussed the importance of management and cropping practices in their analysis of HT canola in Australia. "The argument that producers benefit if the relative price of growing [HT] canola falls depends critically on the belief that all farmers are identical in the agronomic factors they face, the management skills they possess, and the technology they have adopted" (p. 86). In their theoretical model the authors showed how farmers who use a reduced tillage cropping practice may find it profitable to adopt HT canola while those who use conventional tillage may not. Fernandez-Cornejo *et al.* (2005) made an important advancement by explaining high adoption rates for roundup ready soybeans in spite of the technology's inability to increase farm profits. Using a household production framework they found a positive relationship between HT soybean adoption and off farm income. Their result suggests that adopting HT soybeans can free up resources for alternative uses without decreasing on-farm income.

One of the more recently developed GMOs is a *Bt* variety that is resistant to Corn Rootworm (CRW). Until recently, crop rotation was an adequate control for CRW, but the pest has evolved, diminishing the effectiveness of crop rotation. Alston *et al.* (2002) provided an *ex-ante* analysis of CRW-resistant GM corn. The analysis assumed that the GM control method will cost the same as the conventional control method, but the GM control should provide higher yields, "because its effectiveness does not depend on timing, weather, calibration of application equipment or soil condition" (p.74). By varying location, pest pressure and crop rotation practice the authors were able to generate adoption benefits ranging from \$0.00 to \$31.87 per acre. They reported that producers would be willing to pay an average of \$4.18 per acre for the time savings and risk reduction associated with CRW-resistant corn.

Methods:

If, as is the case for HT soybeans, there is no clear profit effect then labor and management savings may be the key reason farmers adopt the technology. Farmers can then reallocate household labor to off-farm work or leisure thus increasing household welfare and maintaining the same on-farm profit. Due to data limitations it is difficult to measure the quantity or quality of management used on a farm; however we can test the hypothesis that GM crops save household labor. We assume that a farm is managed by a single household, which supplies all of the unpaid on-farm labor. There is a well developed literature on how agricultural households allocate labor between on and off-farm work (see Benjamin 1992; Skoufias 1994; Fernandez-Cornejo *et al*, 2005). Under the assumption of separability a household will first determine the quantity of on-farm labor needed to maximize profit. Then the household will use farm profits, wages and prices to maximize utility. "[U]nder separability the market wage provides an exogenous measure of the value of time of family labor, irrespective of whether they work on or off of the farm, while production decisions of the household influence family labor supply only through the income effects of changes in farm profits" (Skoufias, 1994 p. 215). The necessary conditions to ensure labor separability are rather steep, they require that 1) off-farm employment constraints be non-binding, 2) family and hired labor must be perfect substitutes, and 3) farmers have no preferences for on or off farm work. Fall and Magnac (2004) concluded that farmers exhibited preferences for on-farm work in Europe, thus it is reasonable to expect that separability may not hold in U.S. agriculture. If the household exhibits a preference for on-farm work there will be important implications in how the household allocates labor. If the preference is strong enough then all available labor will be allocated to on-farm work, constrained by the number of hours in the day or off-farm obligations.

Assuming that separability does not hold, consider now how the decision making process on the farm leads to a process that generates field-level data. A utility maximizing farm household will simultaneously decide how much labor to allocate to on- and off-farm work, input quantities, technology (i.e. GM or non-GM), production practice (i.e. no-till or conventional tillage) and total amount of land to put into production. Planting and harvesting are critical, as there is a relatively small window of opportunity to perform these tasks. If household members prefer to work on the farm then the household's labor constraint will be binding during these time periods. During the growing season the household is less likely to be faced with a binding on-farm labor constraint, and will thus have a very low opportunity cost of labor. If a random event, such as a pest infestation or adverse weather, occurs during this period the household will respond by applying labor that otherwise would have no productive value.

Upon arriving in a field it can be assumed that the household's production decisions were made at the farm level. The field-level labor allocation is based on a standard cropping practice, resulting in a structural break in the decision making process. The household, for example, has determined to use a no-till cropping practice with HT technology. Thus the worker expects to make one "burn down" herbicide application and one pass across the field with a planter. Depending on the size of the equipment used he can calculate an expected amount of time it will take to prepare and plant the field. During the growing season household labor is sitting idle, and can be called into service to respond to random adverse events. The field may, for example, develop a weed problem which can be corrected by applying glyphosate. Our objective is to compare the amount of household labor used in that field with the amount of household labor used in another field, where HT technology is not being used. This difference can be accurately identified after controlling for observable variables that may influence labor usage in the field. In addition the amount of labor used in the field could vary based on farmer ability, and the amount of capital applied to the field. From there any differences in labor could be attributed to random events such as weather and pest pressure. The structural break between the decision making process (farm level) and the unit of analysis (field level) should guard against endogeneity.

This research question can be answered by estimating a structural equation, such as a profit function or a production function, or an average treatment effect model (ATE) which we use. Heckman (2001) discussed the tradeoffs between estimating a structural equation and an (ATE) model. A structural model, derived from economic theory, is superior to a treatment effect model. Parameter estimates can be used to answer a wide range of economic questions, and provide well defined welfare comparisons. However, the theoretical restrictions needed to estimate a valid structural equation are difficult to meet, Reziti and Ozanne (1999) surveyed literature on duality and concluded that an overwhelming number of applied papers reject theoretical regularity conditions. Field-level data is generated in such a way that it will confound the estimation of a traditional production function. A pest infestation, for example, will reduce yield and require more labor. An early-season flood will result in the field being replanted at a later date. These are plausible situations that could lead to the implausible result that labor decreases yield. Rectifying this problem would require detailed data on the severity and nature of random events.

In contrast to the structural model approach an ATE model only requires the identification of a small number of parameters. Consequently, it can only be used to answer a small number of research questions. The conditions necessary to identify these parameters are weaker than those required by a structural model; all that is required is an exogenous treatment. The ATE model takes the following form (Wooldridge, 2002)

$$\ln(x_l) = \gamma_0 g + \sum_{k=1}^{K} \beta_k x_k + \sum_{k=2}^{K} \gamma_k g x_k \ . \tag{1}$$

The dependent variable, $\ln(x_l)$, is the natural logarithm of household labor used in crop production, *g* is a dummy variable indicating a GM crop. The remainder of the model is known as the control function, and x_k $(k=1,2,\ldots K)$ are control variables. The objective is to estimate the ATE, γ_0, conditional on the control function. This can be interpreted as the percentage change in labor usage. For comparison purposes consider table 1, which reports mean household labor usage by cropping practice and GM crop. The means presented in table one is of little use because they do not control for other factors that may influence the amount of labor used on a field. Any variable that could explain labor usage is a candidate for the control function. The variables used as controls will be descried below in the data section. Identification of the treatment effect requires that the treatment be exogenous, thus we test for endogeneity. *A priori* we expect that the decision to use a GM technology is exogenous, because the decision making process that could lead to endogeneity is determined at the farm level, and our data is field level. This belief has support in the literature, Bernard, Pesek and Fan (2004) did not find endogeneity when they studied HT soybean farmers in Delaware.

[Table 1. About Here]

Data:

We use data from the United States Department of Agriculture's (USDA) Agricultural Resource Management Survey (ARMS). Annual cross section field level data for corn, soybeans, and cotton were collected in 2001, 2002, and 2003 respectively. ARMS data is collected using a stratified random sampling and as such the USDA provides survey weights that can be used to correct for the survey design. These weights are required when estimating descriptive statistics, such as means or totals. However, the weights are not always needed when estimating regression parameters. Ullah and Bruening (1998), present a specification test to determine if the weights are informative. We will discuss this test in more detail below

The dependent variable, unpaid labor, is a full accounting of the time spent working on the farm throughout the growing season by individuals who were not paid for their services. It does not include any form of paid labor, such as full time, part time or seasonal workers; labor provided by custom contractors is also excluded. We assume that unpaid workers are members of the household. The "treatment variables" are dummy variables indicating the adoption of *Bt* or HT crops and the adoption of no-till cropping practices. *A priori* we expect that the coefficients on these variables to be negative. Interaction terms between treatment variables are included when appropriate.

The "control variables" are not intended to have any economic meaning, although some of them may be of economic importance. The control variables are used to condition the treatment effect on observable characterizes. Field size (aplfield and aplfield^2) is a great example of the importance of control variables. Obviously, a large field will require more time than a small field, failing to account for field size would result in an omitted variable bias. Farm size (aplfarm and aplfarm^2) is included to control for unobserved capital equipment, larger farms must invest more heavily in capital equipment. Yield can account for unobserved land quality, input usage, weather and managerial ability so it is included as a control variable. Herbicide active ingredients (herbai) can control for unobserved pest pressure. In addition to these controls we include the unpaid wage rate and the wage rate for paid full time employees. Although these last two variables – the price of the input and its substitute – are important to include for theoretical reasons they are potentially endogenous variables and hence have no meaningful interpretation in this context[1].

Results:

Prior to estimating the treatment effect we preformed two pre-tests. The first, a specification test outlined by Ullah and Bruening (1998), was used to test the hypothesis that the survey weights are not informative. The informative weights test is straightforward, after specifying the model it is augmented with weighted versions of the independent variables. If the weighted variables are jointly insignificant, based on an F-test, then one can conclude that the weights are not informative and they can be discarded. It is important to note a major drawback of this test; if the model is misspecified the test could falsely detect informative survey weights. For all three crops we find that the weights are not informative[2]. The second pre-test is the well known Hausman endogeneity test. The treatment effect, conditional on the observable control variables, can be identified if the treatment is exogenous (Greene, 2003). For soybeans and cotton we do not find endogeneity, but the treatment variables (*Bt*, HT and no-till) appear to be endogenous in the corn model[3]. It is interesting to note that, depending on the significance level chosen by the researcher, the corn model may require weights. We believe that the weights test for the corn model was biased due to endogeneity.

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[1] An early draft of this paper included interactions between the GM crop dummy variables and the control function variables, as well as state dummy variables. These variables were either insignificant or collinear and thus dropped from the model.

[2] Soybeans: F=1.27, Prob>F=0.22; Corn: F=1.49, Prob>F=0.10; Cotton: F=0.63, Prob>F=0.86. The estimated equations have been omitted for space considerations, and are available from the authors upon request.

[3] The estimated equations have been omitted for space considerations, and are available from the authors upon request.

As much of the motivation behind this research centers on HT soybeans we will begin by discussing the results from the soybean model (Table 2). Adopting HT soybeans, under conventional tillage, reduces household labor by 23 percent. This result explains how the literature on HT soybeans has not found a profit effect in spite of wide spread adoption. The result is also consistent with Fernancez-Cornjeo *et al.'s* (2005) findings. It appears that farmers are substituting HT soybeans for household labor, freeing up the resource for off-farm employment and leisure. Although not the primary focus of this study the no-till coefficient is also of interest, adopting a no-till cropping practice, conditional on using conventional soybean seeds, results in a 53 percent reduction in household labor. Although the interaction term between HT and no-till is not statistically significant we found that the three variables are jointly significant[4]. Simultaneous adoption of HT and no-till soybeans reduces household labor by 61 percent.

[Table 2. About Here]

The results from the corn model provide an interesting contrast to the soybean results[5]. The no-till coefficient is about the same size as the no-till coefficient in the soybean model; however, neither *Bt* corn nor HT corn has a statistically significant impact on household labor. This result can easily be explained, in the absence of Bt technology many corn farmers simply do not attempt to control for Corn Borers (Fernandez-Cornejo et al 2002b). Thus we should not expect to see a difference in the labor usage between *Bt* and non-*Bt* corn crops. As discussed above the literature has

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[4] F=40.44, Prob.>0=0.00

[5] The corn model was estimated using Instrumental Variables, therefore it is technically a local average treatment effect (LATE) model. A list of instruments is available from the authors upon request.

demonstrated a clear welfare gain from the adoption of *Bt* corn, thus it is not surprising to see adoption of this technology in spite of the absence of a labor savings.

Unlike *Bt* corn adopting *Bt* cotton saves household labor. This result is not surprising as cotton growers have had a long standing battle against insect pests. Conventional cotton crops require frequent spraying, *Bt* cotton requires less spraying. This difference amounts to a 29% decrease in household labor. This result is of unique importance for cotton, as discussed above *Bt* cotton increases profit due to reduced pest control cost and increased yield. If the value of unpaid labor was not counted in previous studies then our result implies that the true welfare gain is actually much higher.

To demonstrate the interpretation of these results consider Table 3, which shows the unconditional means for farm size, field size, total labor and household labor. Assume that a farmer has an average-sized soybean farm (517.4 acres) and uses the average amount of household labor per acre (1.26 hours). Complete adoption of HT soybeans will reduce the quantity of household labor applied by 23%, for a total of 148.9 hours, or about 15 10-hour days throughout the growing season. Likewise and average cotton household can save 787 hours, or an average of 30 hours a week over a 6-month growing season. It is difficult to place a value on this time as it could be used for leisure or to generate off-farm income.

[Table 3 About Here]

Conclusion:

This study is the first known estimate of the labor savings associated with GM crops. We assume that all unpaid labor is household labor, and use field-level data to estimate an ATE model. With the exception of corn, we find that GM crops save labor.

This result is consistent with current crop production practices, in the absence of *Bt* corn farmers do not rely heavily on insecticides for pest control, while cotton farmers do. Adopting HT soybeans reduces labor usage, on average, by 23 percent. This result fills in a significant gap in the literature, and explains why soybean growers have readily adopted HT technology in spite of an apparent lack of a welfare gain. Additionally, this result points us in a different direction for future research on the farm-level impacts of biotechnology. It is important to differentiate between paid and unpaid labor, and we must also consider how these technologies impact non-farming activities such as leisure and off-farm employment.

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Table 1, Household Labor by Crop

	Cotton				Corn				Soybeans			
	NT=1		NT=0		NT=1		NT=0		NT=1		NT=0	
	HT=1	HT=0	HT=1	HT=0	HT=1	HT=0	HT=1	HT=0	HT=1	HT=0	HT=1	HT=0
BT=1	1.44	***	1.92	2.04	***	***	***	3.57	-	-	-	-
BT=0	1.66	***	2.32	4.35	***	1.90	***	2.75	1.13	1.11	1.35	1.38

*** Results suppressed to prevent disclosure of personal information.

Table 2, Regression Results

Dependant Variable:	Soybeans		Corn		Cotton	
Household Labor	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
HT	-0.23***	0.06	-3.44	4.73	-0.17	0.11
NT	-0.53***	0.10	-0.60***	0.15	-0.03	0.26
BT	-	-	-0.32	1.44	-0.29**	0.14
Stacked	-	-	1.44	3.12	-0.07	0.16
HT*NT	0.15	0.10	6.97	9.85	-0.23	0.30
NT*Stacked	-	-	-1.27	3.42	0.41**	0.20
Herbai	0.00	0.02	-0.03	0.03	-0.05*	0.03
Wage	-0.30***	0.02	-0.35***	0.03	-0.34***	0.04
UWage	-0.21	0.20	0.63**	0.26	0.10	0.38
Yield	0.10**	0.04	0.05	0.05	-0.07	0.06
aplfarm	-0.07***	0.02	-0.13***	0.03	-0.17***	0.04
aplfield	0.61***	0.06	0.72***	0.13	0.86***	0.07
yield2	0.02	0.01	0.01	0.01	-0.01*	0.01
aplfarm2	-0.03**	0.01	0.01	0.01	-0.06**	0.02
aplfield2	0.01	0.02	0.03	0.03	0.00	0.03
edu	-0.04	0.05	-0.21***	0.07	0.04	0.10
_cons	1.37***	0.17	0.27	0.77	3.16**	1.13
F	138.09***		62.9***		41.74***	
Adj. R2	0.49		0.18		0.34	
N	1880		1861		1269	

* Statistically significant at the 10 percent level
** Statistically significant at the 5 percent level
*** Statistically significant at the 1 percent level

Table 3, Means - Select Variables

Variable	Cotton	Soybeans	Corn
APLFARM	1162.42	517.42	391.20
APLFIELD	34.69	41.41	36.07
Labor Per Acre	5.79	1.49	2.95
Household Labor Per Acre	2.30	1.26	2.60