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Diemuth E. Pemsl "Economics of Agricultural Biotechnology in Crop Protection in Developing Countries - The Case of Bt-Cotton in Shandong Province, China", University of Goettingen, 2005

Summary

Problem statement

The use of genetically engineered crop varieties has recently become an option for pest control, particularly for crops with high levels of pesticide use. However, a number of methodological and empirical challenges arise when assessing the impact of biotechnology solutions in crop protection, especially in developing countries. Major empirical challenges are the collection of accurate input and output data, and variability in the quality of agricultural inputs. Principal methodological challenges are due to the special damage control nature of pest control inputs, the uncertainty in most explanatory variables, and the interdependence of ecosystem variables and control inputs.

Research question

A review of available methods as well as results of impact studies of Bt-cotton, disclosed unresolved issues in the assessment of agricultural biotechnology. The following principal questions were addressed in this study: (1) what role do prevailing institutional conditions play in determining and potentially limiting technology success? (2) what are the consequences of different specifications of econometric models to assess the productivity of damage control inputs? (3) how important is uncertainty as element of the agro-ecosystem? and (4) how can interdisciplinary approaches be used to better consider the underlying biological and ecological processes in addition to farm level performance.

Objective

The objective of this thesis is to assess the contribution of the insect resistance trait in Bt-varieties[1] to the productivity and profitability of small-scale cotton cultivation in Linqing County, China. Concurrently, the research aims at advancing the methodology used to assess the costs and benefits of biotechnology in crop protection at the production level.

Methodology

This thesis provides an in-depth case study of the application of Bt-cotton in North East China. Season-long monitoring (March — October) of Bt-cotton production was conducted with a sample of 150 fanners in five villages in Linqing County in the 2002 cotton season.

[1] Bt-varieries are genetically engineered to carry a gene from the soil bacterium Bacillus thuringiensis. This gene encodes for a toxin that is lethal for certain insects (mainly Lepidoptera and Coleoptera species). The modified Bt-crops also express this toxin and hence are resistant against some pests.

Farm-level interviews conducted with 60 cotton-growing farmers in three different counties of Shandong Province at the end of the 2001 cotton season revealed that farmers had severe difficulties in recalling quantities of chemical pesticides and other production inputs. Consequently, farm households were visited biweekly and three additional interviews were conducted on household demographics, knowledge and perception of Bt-cotton, and the production of other crops during the input monitoring in 2002. Moreover, the survey in 2001 revealed the necessity for an integrated data collection framework to capture certain aspects of the ecological and policy environment, in addition to the farm-level information. A cotton growth experiment with Bt- and non-Bt-plots was carried out as part of the integrated approach in the 2002 season to adapt a biological ecosystems model to the conditions at the study site. In addition, cotton leaf samples from each monitored field were analyzed with regard to Bt-toxin concentration, and bollworm larvae were sampled in farmers' fields to assess the resistance level against Bt-toxin.

The framework for the analysis consists of three main parts, representing increasing levels of complexity in the analysis. First, a descriptive analysis of the case study on Bt-cotton production in Linqing County provides insight into the production practices and highlights some of the problems of the technology under local conditions. Second is an econometric analysis of the short-term productivity of the Bt-toxin and other damage control variables such as insecticides. Third, the farm-level performance of different pest control strategies in Bt-cotton is simulated using a partial stochastic budgeting model. The model accounts for the stochastic nature of the main variables and is extended to a bio-economic model by incorporating an ecosystems model.

Empirical basis and findings

Cotton is the major crop in the study area and the main source of cash income for farmers. The crop is produced with high intensity, especially in terms of labor use and input of agro-chemicals. Even though farmers are growing Bt-varieties, they sprayed on average 11 times and applied some 16 kg of formulated pesticides per hectare of cotton per season. Such high levels of pesticide use pose a considerable human health risk. The cotton bollworm (CBW, the pest that Bt-varieties are supposed to control) is still perceived as the second most important cotton pest and targeted by some 30% of all insecticides applied. Testing of the susceptibility of CBW caterpillars revealed that the local strains do not show an increased level of resistance against the Bt-toxin. Therefore, pest resistance was not a reason for the high insecticide use. It was common in the region to use saved cotton seed (on-farm propagation) and some 55% of the farmers continue this practice when planting Bt-varieties. Those who purchased cotton seed paid on average far less than the price for certified Bt-cotton seed. Leaf tissue was analyzed to quantify the Bt-toxin concentration, indicating the effectiveness of Bt-related pest control. Laboratory testing revealed that Bt-toxin concentrations vary significantly in the samples and some samples have very low toxin concentrations. The main reason for this quality problem in Bt-cotton is a lack of control and standards in the market for seed. The large number of pesticide products that are not registered and improperly labeled (or not labeled at all) suggests similar quality problems. The case study reveals that institutional problems and ecosystem changes (development of secondary pests) reduce the farm-level benefits of the Bt-technology.

To assess the short-term productivity of Bt-toxin, a Cobb-Douglas type production function with an inbuilt damage control function (different specifications) was estimated using yield as dependent variable. Instead of a dummy variable, the continuous measures of Bt-toxin concentration were used. Results of the production function estimation are robust with only little variation in the coefficients of varying functional specifications. For all functions, the direct inputs labor and material costs increase the cotton yield while longer rotation and higher pest pressure lead to lower yield. The coefficient for farmers in village 3 is also significant, indicating differences among the villages. The coefficient for Bt-toxin is not significant and in fact shows a negative sign in some of the specifications, implying lower actual yields for higher toxin concentration. Higher use of insecticides has a significant yield-increasing effect only for the exponential damage control function. The marginal product of insecticides varies for the different functional forms, but is positive for all estimated functions. The marginal value product of insecticides calculated at different input levels shows that the economically optimal use level is only about five kilograms per hectare. This is less than one third of the amount currently applied to Bt-cotton by farmers in the study region. Thus, chemical insecticides are severely overused from a production economic view. The marginal product for the Bt-toxin is negative for all but one exponential specification.

A two stage semi-parametric approach is used as complementary method to assess the factor productivity of the Bt-trait. The pest pressure variable is implemented as a slope dummy and thus allows for varying factor productivity dependent on the level of pest infestation. Results show that the factor productivity of control inputs depends on the actual level of the damage agent such that Bt-toxin had higher productivity when pest pressure was low while insecticides had higher productivity when pest pressure was high. The results obtained differ from the outcome of the previous damage control function estimates where neither the use of insecticides (in most cases) nor the concentration of Bt-toxin led to significant coefficients in the regression. A comparison of the marginal productivities between the two approaches shows that most of the coefficients for Bt-toxin are significant in the semi-parametric approach. The level of Bt-toxin concentration in leaf tissue, the use of chemical insecticides, and pest control by manual labor explain at least part of the variation in the dependent efficiency index. The actual damage control effect of the inputs is only partly captured by the explanatory variables. This can be attributed to the variability in the quality of farming inputs caused by possible product adulteration and a lack of quality standards and control. Productivity analysis of pest control inputs using econometric methods remains a challenge because the control effect does not only depend on the amount of control agents used, but also on the timeliness and accuracy of control, the climatic conditions, and the match of damage agent and control applied. Varying yield and pest pressure due to climatic changes, market risk and uncertainty about the quality of inputs are characteristics of the local cotton production system. A stochastic budgeting model was used to assess the performance of different control strategies for the cotton bollworm. The model accounts for the stochastic nature of the main variables (cotton yield, pest pressure, and prices). The different control strategies are the use of Bt-varieties (high or low seed quality) or non-Bt-varieties with or without supplementary insecticides. The probability distributions of explaining variables were generated based on an expert survey of Chinese scientists and the findings of the case study. Cumulative distributions of net revenues for each strategy result from using Monte Carlo techniques to simulate the stochastic parameters, and running the model repeatedly with the drawn sets of variables. The results show that the use of non-Bt-cotton combined with judicious use of chemical insecticides and low quality Bt-seed dominate the high quality (and more expensive) Bt-cotton strategy. All strategies using Bt-seed result in negative net revenues if pest pressure is low because control costs are fixed and cannot be adapted to the actual pest pressure or yield level. This is also why low quality and less costly Bt-seed perform better than the high quality seed.

The presented bio-economic model consists of (i) a biological model that simulates plant growth and populations of pests and predators, including relevant interactions, and (ii) an economic budgeting part that uses the model-generated cotton yields to compute net revenues of different CBW control strategies. For the biological model, different levels of natural enemy activity are assumed as a measure of ecosystem disruption. At the study site the activity of natural enemies is reduced (disturbed situation) due to intensive use of chemical pesticides and Bt-varieties. Regressing the model-generated cotton yield on the control inputs shows that the baseline yield (without control) in an undisrupted system is only a little lower than yield outcome under intensive pest control (Bt-variety and sprays), while for a disrupted system, baseline yield is dramatically lower. A higher intensity of control results in only small yield increases. The productivity of Bt-varieties and insecticides depends crucially on the ecosystem disruption level and increases largely if natural enemy activity is disturbed. This implies that the productivity of pest control depends on prior ecosystem interventions, which often were misguided. In contrast to the results of the stochastic budgeting model, the non-Bt cotton strategy performs poorly in the analysis using the bio-economic model, because chemical insecticides can cause severe disruption of the ecosystem and calendar-based sprays rather than a need-based strategy are assumed. The low quality Bt-seed strategies perform better than the high quality options because costs are lower and ecosystem disruption is less for lower toxin concentrations. The most important result, however, is the impact of the ecosystem disruption rather than the ranking of the strategies. Pest control yields positive net revenues under the highly disrupted scenarios, while a no control strategy is the most favourable option in an undisrupted environment. The findings stress the necessity to include ecosystem variables in the assessment of damage control agents to avoid bias and overestimation of productivity effects.

The key conclusion of the study is that productivity assessment of Bt-cotton varieties benefits from a broader framework that combines ecological and economic indicators. To better understand the farm-level implications of Bt-cotton introduction in developing countries it is important to (i) capture the inherent uncertainty that exists in key variables, and (ii) integrate the ecological processes that largely determine technology performance in the analysis. Moreover, introducing the technology without enabling institutions that assure proper use of the technology can considerably limit the benefits.

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