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ANALYSIS

The economics of biotechnology under ecosystem disruption

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ABSTRACT

Economic analysis of chemical pesticide use has shown that the interactions between plants, pests, damage control technology and state of the ecosystem are important variables to be considered. Hence, a bio-economic model was developed for the assessment of Bt variety and pesticide-based control strategies of the cotton–bollworm in China. The model simulates plant growth, the dynamics of pest populations and of natural enemies. The model predictions are used as major inputs for a stochastic micro-level profit model of alternative control strategies.

Results show that: (1) productivity effects of Bt varieties and pesticide use depend on the action of natural control agents, and (2) the profitability of damage control measures increases with the severity of ecosystem disruption. The findings highlight the importance of the choice of the counterfactual scenario in the assessment of the impact of agricultural biotechnology. Also, some doubts are raised whether the high benefits of Bt cotton varieties claimed by previous studies based on cross section comparisons are realistic.

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1. Introduction

Some fifty years ago, scientists were enthusiastic about the introduction of synthetic pesticides in agriculture to solve the world's food problem. Scientists and policy makers are currently voicing optimism about the prospects of biotechnology. While many negative effects of pesticide use have become known, intriguingly some see biotechnology in crop protection now as a solution to the very problems that pesticide use created (*e.g.* Naranjo, 2005). The experience gained with economic analysis of pesticides can provide a useful guide for issues that need to be addressed when assessing the impact of biotechnology in crop protection (Zadoks and Waibel, 2000).

There are at least three concerns that have emerged from the use of pesticides: (1) pesticides not only kill pests but they also disrupt the ecological balance by diminishing the populations of beneficial organisms (predators and parasites) that provide control of pests; (2) intensive regulation is required to reduce potentially negative effects on environment and human health and to guarantee quality standards under which effectiveness is assured. This is particularly important in developing countries where the implementation of effective regulatory frameworks is extremely difficult and often has not prevented, for example, adulteration of pesticide products. Finally, (3) promotion of pesticides as easy and single solutions to pest problems has led farmers into path dependency (Regev, 1984) and has raised the hurdles of adopting integrated pest management technologies (Cowan and Gunby, 1996).

Applying the "lessons" from the economic analysis of pesticides to the case of insect resistant Bt crops, that contain

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a gene from the soil bacterium *Bacillus thuringiensis* and thus produce an endotoxin that is lethal for certain insect pests, reveals insights for the assessment of costs and benefits of this technology. Numerous economic studies conducted in recent years concluded high benefits and good prospects for the Bt technology (mainly in cotton and maize) in the USA (Carpenter and Gianessi, 2001), Australia (Fitt, 2000), Argentina (Qaim and Traxler, 2005), China (Huang et al., 2002), South Africa (Thirtle et al., 2003) and other parts of Africa and Asia (Qaim and Zilberman, 2003; de Groote et al., 2005). In many of these studies, econometric methods were applied to cross sectional data from farm surveys or experimental data. While production economic methods can provide a good assessment of the static productivity of pest control agents (and other inputs), they are less suitable for capturing the interaction between control decisions and dynamic ecosystem reactions. Furthermore, such methods are limited in reflecting the influence of institutional settings that need to be in place if biotechnology solutions are to live up to their potential. For example, in China a large number of transgenic cotton varieties have quickly entered the seed market and maintaining quality has become a problem (Pemsl et al., 2005).

A complementary tool to the production and damage control function approach (Lichtenberg and Zilberman, 1986) is bio-economic modelling (*e.g.* Regev et al., 1976; Gutierrez et al., 1979). Such models allow the derivation of the production function from the biological processes that govern the agro-ecosystem (Wossink and Rossing, 1998). In this approach, the state of the ecosystem as well as different institutional conditions such as the market for pesticides or biotechnology products can be taken into account using scenario analysis. Thus, the relative advantage of new pest control technologies such as Bt varieties is assessed in a dynamic perspective.

In this paper, we introduce a bio-economic model that combines the dynamics of cotton–bollworm, relevant other pests and natural enemies (Gutierrez et al., 2006) with a stochastic micro-level profit model of bollworm control strategies reflecting the agro-ecosystem conditions in a major cotton growing area, in Shandong province, Northern China. The model aims to reflect the situation of cotton planting several years after the introduction of Bt cotton varieties in China. It captures a situation of multiple damaging agents and accounts for the prevailing natural resource conditions as reflected by the presence of beneficial organisms. A cotton growth experiment was used to calibrate the biological model. Farm surveys conducted by Pray et al. (2002), Pemsl (2006), and Yang et al. (2005) revealed high levels of insecticide applications by (Bt) cotton farmers in China, indicating probable ecosystem disruption, which may influence the effectiveness of pest control measures. The term ecosystem disruption in this paper refers to a reduced efficacy of natural enemies due to slower developmental rates or higher mortality of these species caused by pest control interventions such as chemical pesticides and/or Bt varieties. A specific problem with the use of Bt varieties in developing countries is the quality control of seed and hence its efficacy. Evidence of this problem has been documented in India (Morse et al., 2005) and China (Pemsl et al., 2005), countries where regulation of input markets is low and enforcement of intellectual property rights is difficult. Leave samples from 150 Bt cotton fields were collected in Shandong Province during 2002 to assess the actual concentration of Bt toxin. The data revealed that most farmers were using low price Bt cotton seeds expressing low concentrations of Bt toxin[1] (Pemsl et al., 2005). The economic component of the bio-economic model reflects these technology features as found under farm conditions and includes the product and factor prices prevailing in Shandong in 2002.

2. Theoretical background

Damage control agents such as chemical pesticides, beneficial organisms and resistant varieties depend on the stock of natural resources that govern the productivity of an open[2] agro-ecosystem. Pest control agents' may impact on two natural resources, namely: (1) the beneficial organisms that provide natural control of pests, and (2) the susceptibility of pests to the control agent, defined as the absence of resistance at the time of technology introduction. Optimal use of pest control agents thus corresponds with the economic problem of managing exhaustible resources, *i.e.* how to allocate resource stocks over time (Regev et al., 1976, 1983; Dasgupta and Heal, 1979). Extracting a unit of the resource today implies that there is less of it in the future; hence, user costs exist in addition to the direct costs of the control agent. The extraction costs are the decreasing value of the resource, while user costs are intertemporal opportunity costs or the option value of the control method available in the future. Furthermore, for common property resources producers do not perceive their actions to influence the stock of these resources and as a result operate in a myopic optimisation framework (Regev et al., 1976). This can lead to an overuse of natural resources that is reflected in a rapidly rising net price of the resources (Hotelling, 1931), so that the price of an alternative technology (choke price) is reached faster. In the case of pesticides, the net price of the natural resources is reflected in a rising marginal product (Lichtenberg and Zilberman, 1986). Therefore, current levels of pesticide use can pre-determine higher use levels in the future (Fleischer, 2000). For example, the high use of pesticides in some cropping systems such as cotton in Peru and California (*sic* worldwide), and in tropical vegetable production (with diamond back moths as a major pest), are typically triggered by prior misguided pest control interventions, thus leading to what is called the pesticide treadmill (van den Bosch, 1978). Degradation of natural resources in pest control may also “stimulate” the introduction of new pest management technologies such as transgenic varieties. For example, Bt cotton was introduced in China right after a major outbreak of the cotton–bollworm (Wu and Guo, 2005), which may partly explain its rapid diffusion.

Thus, taking account of natural resource processes has consequences for the productivity and benefits assessment of

[1] Tests were conducted by Prof. Dr. Wu Kongming, Chinese Academy of Agricultural Sciences, Beijing.

[2] This is in contrast to protected production (*e.g.* in glasshouses) where the environment is totally controllable.

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