Adoption and impacts at farm level in the USA

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The GM field crop revolution started in the USA in 1996 as the first GM-corn, soybean and cotton varieties became available to farmers. Soybean, corn, and cotton varieties became available with genetically engineered herbicide tolerance (HT), and cotton and corn varieties became available that were engineered for insect resistance (IR) (Fernandez-Cornejo and McBride 2000, NRC 2010). Second generation GM traits of herbicide tolerance and insect resistance became available by 2000 for cotton, and for corn shortly thereafter. Third generation GM corn varieties became available to some farmers in 2010, and Monsanto has an eight transgene variety—three genes for above ground insect resistance, three for below ground insect resistance, and two for herbicide tolerance. IR varieties provide a biological alternative to chemical insecticide applications and provide a reduced pesticide load on the environment and lower risks to human health (NRC 2010). HT soybean, corn, and cotton provide more effective weed control than with earlier herbicides. The key herbicide in this process is *Roundup*, which is environmentally and human health friendly relative to earlier chemical herbicides used for weed control (NRC 2010). In contrast, GM-wheat varieties are not available to farmers. The primary reason is the negative image that GM wheat has in the export market.

The objective of this paper is to review the adoption rates for GM field crops in the USA and examine their impacts on production decisions of farmers in US Midwestern states, which is the leading area in the USA for corn and soybean production and adoption of GM corn and soybean varieties. The impact GM corn and soybean varieties on farmers' production decisions are examined with the aid of an aggregate profit function and the associated input demand and output supply functions, which are fitted to data for eight Midwestern State over 1960-2004. This methodology uses prices of farm outputs (corn, soybean, wheat and livestock) and inputs (capital services, labor, farm energy, agricultural chemicals and other materials) and quasi-fixed factors, including technology indicators for GM seed adoption, to explain farmers' decision on the quantity of outputs to produce and inputs to use. Findings include the following technology effects: A higher GM-soybean and corn adoption rate reduces the demand for all inputs and biases input decisions toward farm chemicals. The shadow value, or increase in profit, from increasing the GM soybean and corn adoption rates is significantly larger than the marginal cost, supporting farmers' decisions to adopt these GM corn and soybean varieties and future high adoption rates of these crops.

GM Field-Crop Introduction and Adoption

In the mid-90s, the science of biotechnology was applied by private seed companies to develop new methods for controlling pests. A recent NRC report (NRC 2010) summarizes the generally favorable environmental effects of these GM crop varieties. When plants are genetically engineered to be herbicide tolerant (HT), e.g., *Roundup Ready*, they survive the application of the herbicide *Roundup* with minimal harm. When farmers plant GM-soybean varieties, this technology replaces more expensive, less effective and more toxic herbicides and hand weeding. Also, farmers have a significant window of opportunity for applying the herbicide and obtaining effective control of weeds (Fernandez-Cornejo 2008). However, when US farmers purchase GM soybeans (cotton and canola), they must sign an agreement with the seed company waving their right to save GM seed for their own use or for sale. HT corn has many of the same advantages, although corn is more competitive against weeds than soybeans, and the herbicide Atrazine can be used on non-GM corn to control broadleaf weeds. However, Atrazine use has contaminated ground water in the Midwest, and consumption of this polluted water can cause health problems.

The grand goal of plant bioengineering, however, was to create biological insect resistance (IR) in plants. For example, one major pest experienced by Midwestern farmers is the European corn borer, which damages stocks and makes the corn plant subject to lodging. *Bacillus thuringiensis* (*Bt*) is a bacteria that occurs naturally in the soil. Several advantages exist for *Bt* corn varieties. First, the level of toxin expressed can be very high, thus delivering a lethal dosage to target insects. Second, the corn plant produces the toxin throughout its life and the toxin is distributed relatively uniformly throughout all plant parts. Hence, *Bt* provides season-long protection against target insects, but has no significant effect on other insects.[1] Third, the toxin expression can be modulated by using tissue-specific promoters, and GM resistance replaces the use of synthetic pesticides in an attempt to kill target insects. Fourth, the *Bt* toxin expressed in the corn plants is not toxic to humans or animals. Although the early *Bt* corn varieties were resistant to the European corn borer, they were also somewhat protective against the corn earworm, the southwestern corn borer and to a lesser extent the cornstalk borer (Fernandez-Cornejo and McBride 2000). Later, *Bt*-corn varieties carried resistance to corn rootworms, which are a pest that reduces and weakens the root structure of corn plants. New evidence shows that farmers planting non-GM corn hybrids are major beneficiaries from other farmers planting *Bt*-corn hybrids because area-wide moth counts have been steadily declining as the *Bt*-corn adoption rate in an area increases. However, some evidence of resistance to GM rootworm control is surfacing.

The first successful GM field-crop varieties were planted in 1996, accounting for 7 percent of the soybean acreage, 4 percent of the corn acreage and for 17 percent of the cotton acreage. Although *Bt*-cotton adoption got off to a fast start in 1996, the HT-cotton adoption rate surpassed the *Bt*-cotton adoption rate by 1998, reflecting the fact that weeds are a persistent problem in cotton, and HT-cotton has experienced higher adoption rates than Bt-cotton through 2010. Although the US adoption rate for HT-soybean varieties was initially lower than for *Bt*-cotton, HT-soybean varieties have experienced very rapid adoption rates over 1997-2007, except for a brief setback over 1999-2000, when new uncertainties about the future market for GM crops in Europe surfaced. However, in 2004, GM soybeans accounted for 85 percent of planted acres in 2004 and 93 percent acres in 2010. The adoption of HT- and IR-corn varieties started more slowly. The GM adoption rate for HT corn declined a little over 1998-2000, and the *Bt* corn adoption rate declined significantly over 1999-2000, deviating from trend by more than 10 percentage points. After 2000, the IR- and HT-corn adoption rates increased slowly until the mid-2000s when the pace peaked up. In 2004, 47 percent of US corn acreage were planted to varieties with one or more input traits. By 2010, this adoption rate had reached 86 percent. In the eight Midwestern US states that are the focus of the empirical analysis of production effects of GM field crops, the adoption rates mirrored those at the US level.

1 Bt produces spores that form the crystal protein insecticide δ-endotoxins. The protein toxin is active against species of the order Lepidoptera, Diptera, Coleoptera, Hymenoptra and nematodes. When these insects ingest toxin laden crystals, chemicals in their digestive track activate the toxin. It inserts into the insect's gut cell-membrane and dissolves it and eventually causes death of the insect.

Production Decisions and Impacts of GM Field Crops

The responsiveness of farms to (expected) prices of outputs and inputs is an important dimension of the structure of Midwestern farm production (see Schuring et al. 2011 for more details). All own-price elasticities are negative for inputs and positive for outputs, except for livestock. The negative own-price effect for livestock may arise as farmers respond to an increase in livestock prices by marketing animals at lighter weights or building breeding-stock inventories. Among the outputs, the own-price elasticity of supply for wheat is largest, 0.79, for corn is moderate, 0.33, and for soybeans is smallest, 0.12. Hence, the elasticity of supply of major crops produced in Midwestern production is substantial. Among inputs, the own-price elasticity of demand for farm chemicals is largest, -0.71, and followed by farm energy, -0.38 and "other materials, -0.27. The other (variable) inputs have somewhat smaller own-price elasticities; -0.09 for farm capital services and -0.04 for farm labor.

Farmers' adoption of GM corn and soybean varieties affects other production decisions. An increase in the adoption rate for GM soybean and corn varieties reduces the demand for all variable inputs. However, a weak tendency for GM soybean adoption to increase the supply of soybeans and wheat occurs but it reduces the supply of corn and livestock. A higher GM-corn adoption rate tends to reduce all outputs, but its largest impact is on the supply of wheat and livestock.

Farmers' adoption of GM soybean and corn varieties has been profitable. An increase in the adoption rate for GM-soybean varieties by one percentage point has a shadow-value payoff of about $2.7 million per year in the average Midwestern state (in 1996 prices). This compares with an estimated technology fee for switching one percentage point of the soybean acres over 1996 to 2004 from non-GM to GM soybeans of $757,000. Ignoring any short term discounting, this translates into a benefit-cost ratio of about 3.6. An increase in the adoption rate for GM-corn varieties by one percentage point has a shadow-value payoff of $26.8 million (1996 prices) per year in an average Midwestern state (in 1996 prices). This compares with an estimated technology fee cost for switching one percentage point of corn acres over 1996 to 2004 from non-GM to GM corn varieties of $515,000. This translates into a benefit-cost ratio of about 52. These benefit-cost comparisons are quite large and support continued higher use of GM corn and soybean varieties in the US Midwest.

Farmers in the US have experienced a high payoff to adopting GM corn and soybean varieties, and the new crops have been environmentally friendly but a small amount of resistance by target pests has surfaced. This is expected because of the evolving nature of target pest.

Selected References

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