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GENETICALLY MODIFIED CROPS: INTERNATIONAL TRADE AND TRADE POLICY EFFECTS

George Frisvold
Department of Agricultural & Resource Economics University of Arizona, Tucson, USA, frisvold@ag.arizona.edu

Jeanne Reeves
Cotton Incorporated Cary, North Carolina, USA

Abstract

Where approved, producers have adopted genetically modified (GM) crops extensively. Yet, areas not adopting GM crops account for large shares of production and consumption. GM crops differ from previous agricultural innovations because consumers may perceive them as fundamentally different from (and potentially inferior to) conventionally grown crops. Many countries maintain restrictions on production and importation of GM crops. GM crop adoption affects producers and consumers, not only through technological change, but also through trade policy responses. This article reviews open economy analyses of impacts of GM crops. To varying degrees, commodities are segmented into GM, conventionally grown, and organic product markets. Recent advances in trade modeling consider the consequences of market segmentation, along with consequences of GM crop import restrictions, product segregation requirements, and coexistence policies.

Key Words: *Genetically modified, biotechnology, trade, coexistence, non-tariff barriers*

1. Introduction

In countries where approved, genetically modified (GM) crops account for 90% of soybean, 78% of cotton, 72% of canola, and 60% of maize hectares (Frisvold & Reeves, 2010). Yet, areas *not* adopting GM crops account for large shares of production and consumption. Many countries maintain restrictions on production and importation of GM crops because of environmental or food safety concerns and to protect domestic farmers from foreign competition. GM crop adoption affects producers and consumers both through technological change and trade policy responses.

This article reviews open economy analyses of GM crop adoption, considering effects on commodity prices, world trade and economic welfare in adopter and non-adopter countries. Effects of GM crop import restrictions, product segregation requirements, and interactions with farm support policies are examined. Policies exert strong influences on the size and distribution of effects of GM crop adoption. Import bans on GM commodities may benefit domestic producers facing foreign competition, but reduce welfare of domestic consumers ban and GM crop exporting producers. While price-support payments can shelter producers technology-induced price reductions, this can come at substantial government costs. Labeling, crop segregation, and identity preservation requirements can greatly reduce the size and alter the relative benefits from biotechnology. The coexistence of conventional, GM, and organic markets will be an important area of continued research as markets for GM and organic crops mature.

Economists have long studied the effects of agricultural innovations, which often increase supply and lower output prices (Alston et al., 1995). Economists considering their trade effects often use single-commodity, two-regions models. Though simple, these models provide important insights into the distribution of gains of innovation between producers and consumers and between adopting and non-adopting regions. They have also quantified the importance of technological spillovers (Edwards & Freebairn, 1988) and interactions between innovations, farm programs, and trade policies (Alston et al., 1988, 1995).

Three factors have changed the way economists assess agricultural innovations. First, in developed countries, the private sector has surpassed the public sector in agricultural R&D investment. Private technology suppliers hold intellectual property protection, allowing them to capture higher profits from innovations. Moschini and Lapan's (1997) seminal paper modeled effects of a monopolist bringing an improved agricultural technology to market, with gains from innovation divide among producers, consumers, and the technology supplier. The monopolist can charge a higher price for the innovation that is tempered by the availability of the conventional technology. The rise of large biotechnology-seed-chemical firms raises policy questions about the share of gains of innovation captured as monopoly rents. Several studies have relied on the Moschini-Lapan framework to address these questions.

Consumer perceptions are a second factor affecting biotechnology assessments. Many consumers perceive genetically modified (GM) crops as fundamentally different from and often inferior to conventionally grown or organic crops. Consumers have separate demands for GM, conventionally grown, and organic commodities (Moschini et al., 2005). Many countries have imposed product segregation and labeling requirements as well as outright bans on GM products. While economists have long examined interactions between policies and agricultural innovations (Alston et al. 1988, 1995), innovations were assumed to affect product supply, but not demand. Research on consumer effects, coexistence of GM and conventional varieties, and product segregation represents a significant departure from previous studies (Moschini et al., 2005; Sobolevsky et al., 2005).

A third factor affecting analysis of biotechnologies is an innovation in economic modeling itself – the Global Trade Analysis Project (GTAP) a consortium of scholars and policy analysts. The GTAP model is a global multi-sector, computable general equilibrium (CGE) model calibrated to replicate production, prices, employment, taxes, subsidies, trade policies, and bilateral trade flows between countries (Hertel, 1997). While researchers tailor commodity and regional aggregations to suit their purposes, the GTAP model provides a common data source and framework. GTAP studies have measured how technological competition from other countries and trade restrictions imposed on GM products affect the size and distribution of gains of biotechnology adoption. They also estimate effects on vertically linked markets (e.g. cotton and textile markets or feed and livestock markets).

2. Partial equilibrium studies

Partial equilibrium studies report large differences in the distribution of net benefits across crops, biotechnologies, and regions. Much of the difference stems from different modeling choices researchers make. Readers may be alarmed that results vary across studies based on modeling choices. However, model results differ in ways predicted by economic theory, given their assumptions. Price et al., (2003), Scatasta et al. (2006), and Smale et al. (2006), provide excellent discussion of alternative methods and their consequences.

Bt cotton

Falck-Zepeda et al. (2000a) conducted the first major study of the distribution of gains to Bt cotton. They used a single commodity, two-region model where the US is a cotton net exporter to the rest of the world (ROW). Returns to technology suppliers were derived from price premiums paid for Bt seed. They relied on farm surveys and experimental plot studies to estimate cost reductions and yield increases for US adopters. State-level adoption rates were used to derive a downward, vertical shift of the US cotton supply curve. While adopters pay more for Bt seeds, they can gain from insecticide cost savings, yield gains, or both. Yet, increased output lowers prices they receive. Non-adopters only feel the negative effect of falling prices. With the model calibrated to 1996, US producers received 59% of the surplus gains from Bt cotton, while technology suppliers captured 26%. By increasing output, Bt cotton reduced the world cotton price, allowing US consumers captured 9% of the gains. The ROW captured the remaining 6% in net gains, as ROW consumer gains outweighed ROW cotton producer losses.

Falck-Zepeda et al. (2000b) updated this Bt cotton analysis to 1997, including effects of adoption by ROW producers. ROW adoption effects were small, however, because ROW Bt cotton acreage accounted for only 0.2% of global cotton acreage. US consumers captured 7% of total surplus gains with the share to net ROW (consumer gains minus producer losses) 6%, similar to 1996. The technology supplier share rose from 26% to 44%, while US producers' share fell from 59% to 42%. Differences in pest pressure accounted for much of the difference between years. In 1996, underlying pest pressure was a severe problem in the US south (Falck-Zepeda et al., 2000a). In 1997, with less pest pressure, Bt cotton provided smaller yield advantages.

Frisvold and Tronstad (2002) used a two-region (US, ROW) model to consider Bt cotton effects from 1996-98, ROW and US demand curves and ROW supply curves were assumed linear. US supply was modeled in a multi-state mathematical programming model. This specification was general enough to represent either divergent or convergent supply curve shifts. Convergent shifts steer relative benefits to producers, divergent shifts to consumers (Alston et al., 1995). They also included effects of loan deficiency payments (LDPs): per-pound output subsidies based on the difference between the world cotton price and a government-set loan rate. LDPs shelter US producers from lower market prices. World prices were high 1996 and 1997, so LDPs were insignificant. In 1998, with cotton prices lower, LDPs served as a price floor for US growers.

From 1996-98, under a moderate impact scenario, technology suppliers captured 45%-47% of gains, US consumers captured 29%-35%, and net ROW 14%-21%, with ROW consumer gains outweighing producer losses. US non-adopting producers had *losses* ranging from 5% of *net* surplus gains in 1998 to losses as high as 45% of net surplus gains in 1996. LDPs (absent in 1996) protected non-adopters from the effects of falling cotton prices in 1998. US adopter gains rose from 44% of net gains in 1996 and 1997 to 59% in 1998. Government payments to US producers rose from 0% of net surplus in 1996 to 8% in 1997 and to 47% in 1998.

Frisvold et al. (2006) et al. updated this model to 2001, separating China from ROW. They compared effects of adoption by the US alone, China alone, and by both countries. In 2001, the US and China accounted for 40% and 95% of global cotton production and Bt cotton acreage. In 1999, Chinese Bt seed suppliers just covered their costs, while multinational suppliers earned less than $2 million in *gross* revenue (Pray et al., 2001). Monopoly rents in China were suppressed by competition between supply sources and because Chinese farmers saved Bt cottonseed. Frisvold et al. (2006) assumed technology suppliers captured no rents in China.

With both the US and China adopting, technology suppliers only captured 17% of net world surplus and net ROW captured 8%, while China captured 71% (51% to producers and 20% to consumers). US consumers captured 6%. Without LDPs, US producers would have lost surplus from joint US-Chinese adoption. With joint adoption, technology supplier rents accounted for 83% of US welfare gains. Technological competition from another region (i.e. two countries adopting) had only modest impacts on the total welfare of an adopting country, although it shifts relative gains to domestic consumers. Both countries, however, forego large surplus gains if they do not adopt while the other country does.

Price et al. (2003) followed Falck-Zepeda et al.'s (2000a, b) approach, but updated production and trade data and assumed less elastic US cotton supply, more elastic US demand, and less elastic US export demand. They assumed higher rates of ROW adoption than Falck-Zepeda et al. (2000b). Price et al. first assumed ROW productivity increases from adoption were 50% of US increases. They conducted sensitivity analysis lowering this rate to 10% and raising it 100%. Increasing the ROW rate reduced US producer returns, while increasing US consumer returns.

Falck-Zepeda et al. (2008) considered the potential impacts of Bt cotton adoption among five West Africa cotton exporters (Benin, Burkina Faso, Mali, Senegal, and Togo) and the ROW. In their Scenario 1, the ROW adopts Bt cotton, while the five countries do not. The five countries suffer producer losses from lower world cotton prices. In Scenario 2, adoption starts first in Burkina Faso, with the other countries following later. West African producers capture 39% of the surplus (14% Burkina Faso, 25% others) and technology suppliers 61%. In Scenario 3, adoption is only permitted for West Africa developed cotton varieties. Bred for local conditions, these varieties may perform better, but may take longer to develop. There are trade-offs between the Bt insect-protecting trait, other traits, and product availability. Results suggest gains from developing local varieties may outweigh the costs of delay in their development. In Scenario 4, the five countries collectively negotiate a lower technology fee, increasing their share of gains to 53%. Scenario 5 assumes adoption, dis-adoption then re-adoption in Benin and Mali to simulate effects of policy instability on adoption. Here, the producer share of returns falls to 35%.

Herbicide-tolerant soybeans

Falck-Zepeda (2000b) used a two-region model (US, ROW), to examine herbicide tolerant (HT) soybean in 1997. They assumed ROW HT soybean adoption had the same impacts on yield and costs as in the US. They also report results using two different values of the US soybean elasticity of supply. Assuming a supply elasticity of 0.22, US producers capture 76% of net world surplus, technology providers only 10%, net ROW 9%, and US consumers 4%. With more elastic supply (0.92), US producers capture 17% of net world surplus, technology providers 25%, net ROW 28%, and US consumers 17%. This occurs because the method converting yield increases into vertical shifts in the supply curve is highly sensitive to the supply elasticity parameter (Aston et al., 1994, Oehmke and Crawford, 2002). As supply grows less elastic, a yield increase translates into a larger cost reduction.

Moschini et al. (2000) examine HT soybean adoption in a model with three regions: the US, South American adopters (Argentina and Brazil), and the ROW. HT soybean varieties provide better weed control, lowering per hectare production costs even though HT soybean seed costs more. HT soybeans do not affect yields in the baseline simulation. Yields are assumed to increase with the soybean price. Total soybean acreage is increasing in average profits per acre. They assume HT soybeans have the same impacts on costs and yields in the US and South America, but that technology fees are lower in the latter because of weaker IPRs. They specify separate demand curves for soybeans, soybean oil, and soybean meal.

In the base simulation, technology suppliers capture 45% of net global surplus, US producers 19%, US consumers 10%, South American producers 3%, South American consumers 4%, and net ROW 18%. ROW is a net importer of soybean products with consumer gains outweighing producer losses. Moschini et al. (2000) compared a case of 100% adoption in the US only with 100% adoption in the US and South American and 100% adoption in all three regions. As adoption increases, both global and US welfare increases absolutely, with relative gains shifting from US producers to US technology suppliers and consumers. South American welfare declines with increased adoption in ROW. Broader adoption shifts relative gains from producers to consumers. As stronger IPRs (modeled as greater seed price mark-ups) are extended to more regions, technology supplier profits increase while consumer benefits fall. Strengthening IPRs in developing countries increases US producer gains while reducing South American and ROW producer gains.

Moschini et al. (2000) also consider what happens if HT soybeans increase yields as well as reduce costs. Yield and per-acre cost shocks are specified separately, generating a divergent supply curve shift. Divergent shifts can reduce producer returns because, with inelastic demand, total revenues can fall more than total costs. With a 5% yield increase, adopter producer returns fall in all scenarios, except when the US is the only country to adopt.

In Price et al.'s (2003) two-region (US, ROW) HT soybean adoption model, US producers captured 20% of surplus gains, with technology suppliers capturing 68%, US consumers 5% and net ROW 6%. They assumed cost and yield changes from HT soybeans adopted in the ROW were 50% of US impacts. Lowering this value to 10% or raising it to 100% had no effect on total US gains. Increasing the value from 10% to 100% did shift gains from US producers to US consumers. Despite considering the same crop, year and technology, Price et al. (2003) found technology suppliers captured 68% of global gains compared to 45% in Moschini et al. (2000). When they altered their modeling assumptions to be similar to those of Moschini et al. (2000), results of the two models converged.

Qaim and Traxler developed a three region model (Argentina, US, ROW) for HT soybeans adopted in the US and Argentina. The US and Argentina are net soybean exporters, while ROW is a net importer. This study highlights differences in IPR protection in the US and Argentina. HT soybeans benefited from patent protection in the US, but were not patented in Argentina. Further, Argentine farmers were allowed to use saved seed, which reduced seed sales. Use of saved HT seed was extensive in Argentina. Seed suppliers captured smaller rents in Argentina.

In 1996, with adoption only in the US, US producers captured 40% of the surplus, global consumers 47%, and technology suppliers 37%. Non-adopting ROW and Argentine producers had losses equal to -25% of net surplus gains. In 1997, however, Argentine growers began adopting HT soybeans. By 2001, US producers captured 12% of world surplus, Argentine producers 25%, global consumers 53%, and technology suppliers 34%. Non-adopting ROW producers had losses equal to -24% of net global welfare gain. Argentine farmers gains grew to more than double US producer gains because adoption rates were higher in Argentina. Losses to non-adopting ROW producers rose from -$5 million in 1996 to more than -$290 million in 2001.

Sobolevsky et al. (2005) assume consumers would treat GM soybeans as inferior to conventional soybean varieties. Although GM soybeans are cheaper to produce, consumers are willing to pay less for them. As long as product segregation costs are not too high, producers have an incentive to segregate conventional and GM soybeans. Next, they include effects of US loan deficiency payments (LDPs). The model has four regions: the US, Brazil, Argentina, and ROW, which may all adopt HT soybeans.

Sobolevsky et al. (2005) report many results under varying parameters. In their central case, they assume US LDPs are in place, medium segregation costs, and all regions adopt. Only Brazil produces conventional soybeans and segregates crops. Technology suppliers capture 54% of global welfare gains. US LDP expenditures (a welfare loss) equal -51% of global gains, however. US producer gains are 27% of this total. Consumers gain in all regions. While US and ROW producers gain, Brazilian and Argentine producer surplus falls. Without price supports (but medium segregation costs), the US becomes the only region not to fully adopt HT soybeans, although adoption is 90% of acreage. Removing LDPs reduces welfare to all regions, except ROW, and to all consumer groups. It lowers returns to US producers, but raises returns to producers in all other regions. Without LDPs, US producer returns decline. Interestingly, removing LDPs lowers global welfare. Sobolevsky et al. (2005) explain this as a second-best effect. Monopoly pricing of HT soybeans creates over-pricing and under-consumption of HT seed varieties. The LDPs counteract this negative effect.

If costs of growing two separate crops and segregating them increases sufficiently, global adoption of HT soybeans *increases*. If segregation costs become prohibitive, growers grow only HT soybeans, and technology supplier profits increase. Without LDPs, increasing segregation costs have increasingly negative effects on US producers. With LDPs, US producers are unaffected by segregation cost changes. A production and import ban by the ROW benefits ROW producers, but reduces welfare for ROW consumers. By lowering world soybean prices, the ban benefits consumers and hurts producers in other regions, while lowering technology supplier returns 42%.

3. Other crops

In Phillips' (2003) analysis, Canadian HT canola adoption lowers herbicide costs and because the crop is cleaner, elevator dockage costs. Because of pollen drift and outcrossing, HT canola can contaminate organic canola. Organic producers would suffer losses because they could not claim price premiums. Adopting canola producers gain through lower costs and increased production, but lose through lower market prices and reduced organic premiums. Net producer gains are positive, however. From 1997-200, the producer share of current returns rise from 6% to 29%, processor / consumer returns rise from 0% to 14%, and technology supplier returns fall from 94% to 57%. Consumer returns are divided among processors, which have market power, and domestic and foreign canola purchasers. Phillips (2003) notes market power allows processors to capture much of the downstream consumer benefits and that canola importer requirements for identity preservation and crop segregation could substantially reduce gains. Phillips (2003) also traced technology supplier seed development costs back to 1985, demonstrating innovator net gains can be substantially lower than gross returns. From 1985 to 1996, development costs outweighed returns from seed sales. Annual net returns turned positive in 1997, but the net present value of HT canola did not turn positive until 2000.

Price et al. (2003) estimated the distribution of gains from HT cotton in a US-ROW model for 1997, when the US was the only adopter. US producers captured only 4% of world surplus gains, technology suppliers 6%, US consumers 57%, and net ROW, 33%. They report HT cotton caused more of a price reduction in the world price of cotton than Bt cotton, leading to consumers capturing a large share of the gains.

Dillen et al. (2009) conducted an *ex ante* analysis of potential HT sugar beet adoption in the EU and ROW, focusing on effects of the European Common Market Organization (CMO) policy. Under the current CMO, some EU countries face binding sugar-production quotas and fixed institutional prices, while others face the world sugar price. Because the CMO fixes EU consumer prices, yield increases from HT sugar beet provide no gains to EU consumers. Technology suppliers capture 39% of global welfare gains, EU producers 29%, and net ROW 31%. ROW consumer gains outweigh ROW producer losses. Among ROW producers, those who adopt HT sugar beet gain, while sugar cane producers lose. In EU areas facing binding quotas, increased yields from HT sugar beets reduces technology supplier returns. Because of binding quotas, higher yields reduce acreage planted to sugar beets and consequently seed sales.

4. General equilibrium studies

The studies discussed here use variants of the GTAP database or CGE model where all prices are endogenous, while trade, tax, and price support policies are explicitly modeled.

Biotechnology adoption effects are modeled as Hicks neutral or factor-augmenting technical change (Frisvold, 1997). All markets are assumed perfectly competitive and technology supplier monopoly rents are not measured. These studies focus on changes in national economic welfare and trade flows from biotechnology adoption as well as interactions between technology adoption and trade policies. Separate producer and consumer welfare measures are not reported, but researchers provide indirect measures of effects on producers (e.g., changes in output prices, land rents, and revenues).

Anderson and Yao (2003) compare cases where China either does or does not join GM crop adopters. If China does not adopt GM rice along with others, their domestic rice production, price, and trade change little, while welfare increases slightly from falling world rice prices. When China also adopts GM rice, its welfare gains increase to $1.1 billion, 55% of global gains. All adopting regions still gain when China also adopts. If China joins other Bt cotton adopters, China produces more cotton, imports less cotton, and exports more textiles and apparel. When joining adopters, China’s welfare gains rise from $15 million to $340 million. Welfare gains in other adopting regions total $642 million if China does not adopt and $650 if China does. In contrast, losses to non-adopting cotton exporters increase when China adopts too. For maize and soybeans, all adopting regions gain modestly when China also adopts.

Anderson and Yao (2003) also estimated that gains to China from adopting all the GM crops (along with other regions) were $2.3 billion and that these gains would fall by <7% if Western Europe banned imports of Chinese agricultural products. If Japan and South Korea joined this import ban, China’s gains from GM adoption would fall by two thirds. This occurs because China’s agricultural exports to Japan and South Korea are much greater.

Huang et al. (2004) evaluated effects of adoption of Bt cotton and Bt rice in China. Chinese trade balances in rice, cotton and textiles all increase, but decrease in other regions. Chinese Welfare gains in 2010 would be $1 billion from Bt cotton adoption, $4.1 billion from GM rice adoption, $5.2 billion if both were adopted. They estimated that Chinese public biotechnology R&D from 1986 to 2000 totaled less than $0.5 billion (2000 constant prices), arguing that gains of deployment of Bt cotton and GM rice would far outweigh R&D expenditures. A GM crop import ban would impose only small losses on China, with large losses felt by consumers in import-banning regions.

Huang et al. (2004) examine the implications of China imposing segregation and labeling requirements for GM soybean imports. To comply with World Trade Organization regulations, China would have to impose labeling requirements on its own GM products. Labeling and segregation costs for domestic GM rice are modeled as increased cost of services, while those for imported GM soybeans are modeled as an increase in transport and handling margins. Under the new requirements, Chinese soybean producers benefit from greater output and higher prices, but gains from Bt cotton and GM rice adoption fall by $1 billion.

Ehlberi and MacDonald (2004) examine costs of not adopting Bt cotton in West and Central Africa (WCA). They assume productivity gains from adoption in China, India, and South Africa of 7-10%, 5.3% gains in WCA, and lower gains elsewhere. When adoption occurs in other regions besides WCA, WCA cotton production, land rents, and real wages fall. When WCA adopts too, land rents fall less, real wages rise, and WCA textile production increases. WCA welfare falls by $88 million without adoption, but increases $150-$170 million when it adopts. All cotton importing, non-adopter regions gain, while non-adopting cotton exporters lose.

Frisvold and Reeves (2007) consider the costs of non-adoption of Bt cotton. China experiences the largest productivity gain and the largest gain in domestic welfare. The US and India follow with lower productivity and welfare gains than China. Mexico has relatively large welfare gains because of large productivity gains and high adoption rates. All regions experience welfare gains, even the non-adopting EU and ROW (who are cotton importers). Textile and apparel exports and employment expand in China and India, but decline in other regions. Textile and apparel imports rise in the EU and ROW. US and Chinese welfare gains are reduced only slightly if other regions adopt too. If the US did not join adopters, it would forego about $200 million in welfare gains.

Anderson et al. (2008) consider Bt cotton adoption as of 2001. Productivity increases in adopting regions were assumed to be 5% for the US, Australia, and South Africa, but 2.5% for China. The US captured 44% of global welfare gains and China, 22%. Other non-adopting regions gain, save Sub-Saharan Africa, a cotton exporter. Their next scenario assumes other regions – save SSA – catch up to the early adopters. South Asia captures 48% of the global welfare gain. Eastern Europe and Central Asia (a large cotton exporter) capture 16%. China, the US, and South Africa all post lower gains than the first scenario, while SSA loses. If SSA adopts, however, and obtains 15% productivity growth, its welfare increases by $187 million.

Bouët and Gruère (2011) use the MIRAGE model (based on the GTAP database) to examine effects of Bt and of herbicide tolerant cotton. They also consider how changes in cottonseed production affect oilseed markets. In 2004/5, among adopters the US captures 40% of global welfare gains, followed by Mexico 13%, China 12%, and India 6%. Non-adopting Rest of Asia and the EU together capture 22%. Compared to 2004/5, India's 2008/9 adoption rate rises from 5% to 70%. In 2008/9, India captures 37% of the >$3.5 billion welfare gain, followed by the US (25%), China (8%), and Mexico (7%). The EU and Rest of Asia capture 16%. In the final scenario, along with actual 2008/9 adopters, West and Central African (WCA) countries, Senegal, Tanzania, and Uganda also adopt at a rate of 50%. The new African adopters avoid welfare losses from adopting and achieve modest gains.

Van Meijl and van Tongeren (2004) examine the effects of the EU's Common Agricultural Policy (CAP) and GM production and import bans on returns to adoption of Bt corn and HT soybeans. In the base case, North American coarse grains and oilseeds sectors experience 5% productivity growth. In Scenario 1, other regions adopt. Scenario 2, adds to Scenario 1 by accounting for the effects of CAP. Scenario 3 assumes that while producers in South America and China adopt, producers elsewhere do not. Scenario 4 adds to Scenario 3 the assumption that the EU bans production and importation of GM crops.

Adoption in North America alone reduces EU farm income for each crop by 1%. EU overall welfare increases by $249 million, while North American welfare increases by $2.2 billion. EU production of oilseeds and coarse grains declines. With global adoption of the biotechnologies (Scenario 1), EU oilseeds production increases, but internal market prices fall more. With global adoption, EU farm income falls more, but EU welfare increases by nearly $1.3 billion. Spillovers reduce North American welfare gains by 3%. Including the effects of CAP, EU production of both crops increases. EU oilseeds farm income falls by a bit more, but course grains income (protected by CAP) falls by substantially less than under Scenario 1. Compared to the simple spillover case, adding effects of CAP has no effect on North American welfare, although EU welfare gains fall from $2.2 to <$0.7 billion. If EU (and other) producers reject the biotechnologies, EU production and farm income fall. If the EU bans consumption and importation of GM crops, EU incomes of oilseeds farms rise by >24% and of coarse grain farms rise by 3%, while the EU faces overall welfare losses of >$1.4 billion.

Van Meijl and van Tongeren (2004) contrast their results with a study by Nielsen and Anderson (2001) who estimated that non-adoption in the EU would lead to greater reductions in coarse grain production and farm income from non-adoption. They argue that the CAP's "price-insulating" feature shelters EU producers from the world price reductions brought on by global biotechnology adoption.

Anderson and Jackson (2003) consider why the EU has adopted less GM-friendly policies than North America. They use GTAP simulation results to make a political economy argument for differences in farm interest group incentives in the EU and North America. EU farmers are best off under the scenario where the moratorium on GM products is widest, while North American farmers are worst off under this scenario. While EU farmers gain more if they and other countries reject GM crops, North American producers gain more with wide acceptance of GM crops (even with technological competition from other regions). Anderson and Jackson (2003), however, do not explain why North American farmers would favor GM crops in the first place. In the scenario of global acceptance of GM crops with just North American and Argentina adopting (i.e. North American technological advantage and widespread consumer acceptance), North American farm income falls! North American farmers would be *best* off if the GM crop moratorium were extended to *all* countries.

5. Some conclusions and future directions

One may divide analyses of open-economy effects of GM into three types. There are partial equilibrium models where GM crop adoption shifts supply functions and provides monopoly rents to technology suppliers. Here, GM and non-GM varieties are treated as identical from a demand perspective. Second, CGE modeling exercises do not consider monopolist rents, but focus on trade policy responses. Consumer demand for domestic and imported commodities are treated as different, but there is no explicit difference in demand for GM and non-GM crops (although there are differences in demand from GM-adopting regions). GM crops are treated differently in terms of policy, but not explicitly in consumer preferences. Third, there are partial equilibrium models where consumers have different demands for GM, conventionally grown, and organic versions of crops. Further, the introduction of GM crops can impose externalities on non-GM producers, either through co-mingling or pollen drift that causes producers to lose non-GM or organic status (and price premiums), or through costly segregation and labeling requirements. These three modeling approaches provide some distinct lessons.

Many early partial equilibrium models that only consider supply shifts from GM crops reinforce earlier lessons from studies of agricultural innovations generally. Assumptions about demand and supply elasticities have relatively little effect on the total gains from GM crops but exert a strong influence on the distribution of gains between producers and consumers (Alston, et al., 1995). Wider adoption of GM crops globally increases benefits to net-importing regions and reduces benefits to net-exporting regions (Edwards and Freebairn, 1984). The reduction in benefits to net-exporting regions is often minor, however. Producers are not necessarily better off under global adoption, however. They are more likely to experience losses if (a) the new technology has less of a productivity effect at home relative to competing regions, (b) home adoption rates are lower than elsewhere, and (c) if the technology generates a divergent, rather than a parallel, supply shift. This leads to the fifth point – the nature of the supply shift affects both absolute and relative producer gains from biotechnology (Alston, et al. 1995).

Models following the Moschini-Lapan (1997) of accounting for monopoly rents add some additional insights. First, wider adoption shifts relative benefits from producers to consumers and technology suppliers. Second, imposing stricter IPRs on developing countries reduces producer surplus in developing countries and consumer surplus everywhere. Stricter IPRs increase producer surplus in developed countries and technology supplier profits. Third, there are large costs to producers who do not adopt GM crops, given that their competitors are doing so. Fourth, traditional farm income support policies in the US and EU shelter adopting producers from falling world prices that accompany the increased production from GM crop adoption. These programs affect other actors in complex ways depending on their structure. US loan deficiency payments (LDPs) increase consumer gains, while EU quota systems can prevent consumers from capturing benefits and reduce technology supplier profits. US LDPs can even improve welfare, counter under-production from monopoly seed pricing.

CGE model results reinforce the finding that there are high costs to producers (and countries) of not adopting GM crops when others are doing so. In general, all regions benefit as GM adoption becomes more widespread. A major exception tends to be non-adopting, small, net-exporting regions. While banning imports from GM producing countries, benefits producers in the banning regions, overall welfare in the importing regions falls overall. In some cases, losses to the importing regions are larger than losses to the GM exporting regions. The effects of bans on the GM-exporting country rise in proportion to the size of the trade relationship with the regions imposing bans. While studies have examined effects of GM crop adoption in downstream markets (textiles and apparel for cotton and livestock for feed grains and oilseeds), estimates of downstream effects of GM crop adoption have been relatively modest to date. Effects of GM feed bans on livestock markets could become more pronounced as more countries adopt GM feeds and banning regions have fewer non-GM alternatives. While important bans are straightforward to represent in CGE models, modeling labeling and segregation requirements is more challenging. Huang et al.'s (2004) modeling of such requirements as cost-increasing technological changes in services and transportation is a clever approach to this problem.

The final modeling approach we review accounts for the fact that consumers may perceive GM crops as fundamentally different from (and potentially inferior to) conventionally grown (or organic) crops. The introduction of GM crops can impose two types of costs on non-GM producers. First, through pollen drift or co-mingling, crops can lose their non-GM crops and producers can lose price premiums. Second, producers desiring to obtain price premiums from non-GM crops must incur additional segregation and / or labeling costs.

Phillips' (2003) analysis of Canadian HT canola adoption illustrates the problem. Because of pollen drift and outcrossing, HT canola can contaminate organic canola. Organic producers would suffer losses because they could not claim organic price premiums. Canola producers gain through lower costs and increased production, but lose through lower market prices and reduced organic premiums. While net producer gains are positive, this raises distributional issues. Organic and GM canola producers are not necessarily one in the same and Phillips' (2003) study does not explicitly include any form of compensation mechanisms or coexistence policies to mitigate organic producer losses.

Sobolevsky et al.'s (2005) study considered soybean markets where consumers treat GM crops and inferior to conventional ones. As long as product segregation costs are not too high, producers have an incentive to segregate conventional and GM soybeans. If costs of growing two separate crops and segregating them grow too high, however, segregation and labeling policies can have unintended consequences. Beyond a threshold, it becomes too costly to produce and market two types of soybean products (GM and non-GM). The logic is as follows: growers may be forced to choose between lower-cost, lower price GM soybeans and higher-cost, higher-price conventional soybeans. Sobolevsky et al. (2005) derive the conditions where growers opt specialize in GM soybeans. Thus, it is possible in principle for high segregation costs to drive increased adoption of (and specialization in) GM crops, drive out non-GM crops, and increase technology-supplier profits. We emphasize here that this result is a theoretical *possibility*. It remains to be seen whether such a result has or will result empirically. Yet, it serves as a cautionary tale that labeling and segregation policies with the aim of slowing adoption of GM crops and preserving non-GM crop production could possibly backfire.

It is beyond the scope of this review to consider the myriad issues associated with crop market segmentation (into GM, conventional, and organic) and GM labeling and coexistence policies. Devos et al. (2009; 2013) and Moschini (2008) provide reviews of coexistence policies and interactions between GM and non-GM markets. Gruere (2013) discusses how GM varieties can impose negative externalities on non-GM producers, but also how GM crop regulations may act as non-tariff barriers. He develops a framework to conduct market risk assessments of individual GM crop introductions. Kerr et al. (2014) discuss how the Vienna Convention on the Law of Treaties may provide guidance in resolving differences between the World Trade Organization and the Cartagena Protocol on Biosafety in resolving trade disputes over GM crops. While these studies are all certainly have trade implications, they do not formally estimate trade effects.

We close with a mention of a study by Moschini et al. (2005) that introduces a model of EU agriculture where GM, conventionally grown, and organic markets coexist and where consumers view GM crops as inferior products. Introducing GM crops may actually be welfare reducing because the costs of labeling and segregation requirements outweigh the cost-reducing gains of the GM varieties. Ironically, organic producers can benefit from introduction of GM crops, when combined with high segregation costs. This study is not a trade model *per se*, but the approach – having three segmented markets for GM, conventional, and organic crops and deriving welfare effects – is amenable to adaptation to an open-economy model. The coexistence of conventional, GM, and organic markets will be an important area of continued research, especially as markets for GM and organic crops mature. An important lesson from this review is that “policy matters” in determining the size and distribution of gains from biotechnology.

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