

WHO GAINS FROM GENETIC IMPROVEMENTS IN U.S. CROPS?

George Frisvold, John Sullivan & Anton Raneses¹

The distribution of gains of plant breeding and plant genetic resource exchange has been the source of heated North-South debates in meetings of the United Nations Food and Agriculture Organization (UN FAO) and the UN Convention on Biological Diversity. We report results of a study using a world agricultural trade model to estimate the size and distribution of economic gains from yield increases in major United States (U.S.) crops attributable to genetic improvements. The net global economic benefits of a one-time, permanent increase in U.S. yields are about \$8.1 billion (discounted at 10%) and \$15.4 billion (discounted at 5%). The United States captures 50-60% of these net gains. Gains to consumers in developing and transitional economies range from 6.1 billion (10% discount rate) to \$11.6 billion (5% discount rate).

Key words: genetic resources; plant breeding; returns to research; yields.

Since 1960, yield growth has accounted for 92% of the growth of world cereals production (World Bank, 1992). Genetic improvements have accounted for roughly half the yield growth of major United States (U.S.) crops (Fehr, 1984; Thirtle, 1985; Duvick, 1992; Huffman and Evenson, 1993). The contribution of genetic improvements to yield growth in other countries has been similarly impressive (Dalrymple, 1977; Silvey 1986; Byerlee & Traxler, 1995; Byerlee, 1996; Evenson & Gollin, 1997).

Yield gains are the product of public and private investments in plant breeding and the collection, exchange, and conservation of plant genetic resources (PGRs). In the latter half of this century, an extensive international system of PGR collection, exchange and research, publicly funded by multilateral donations, developed alongside national plant breeding programs. Breakthroughs in corn hybridization in the 1930s spurred the development of the private seed industry. Increased intellectual property protection for commercial seed varieties has contributed to the rapid growth of private investment in plant breeding (Fuglie *et al.*, 1996).

Despite its success, the system of PGR exchange has been controversial (Mooney, 1983; Kloppenburg, 1988; Frisvold & Condon, 1998; Knudson, 1999). Many developing countries and

¹George Frisvold is an Associate Specialist in the Department of Agricultural and Resource Economics at the University of Arizona; John Sullivan is an Economist at the Economic Research Service; and Anton Raneses is a Commodity Business Specialist at the Defense Logistics Agency. © 1999 AgBioForum.

non-governmental organizations (NGOs) have criticized the system as biased against developing countries (The Ecologist/GRAIN/RAFI, 1996). Because farmers in developing countries have spent thousands of years selecting and saving landraces, developing countries have made essential contributions to plant breeding (Mooney, 1983; Brush, 1992; Altieri & Masera, 1993). Plant breeders today still rely on genetic materials native to developing countries to instill resistance to ever-evolving plant pests and pathogens (Cox *et al.*, 1988; Goodman & Castillo-Gonzalez, 1991; UN/FAO, 1997; Knudson, 1999). Yet, while commercial seed varieties have been afforded increasing intellectual property protection, germplasm and landraces continue to be treated as public goods. Kloppenburg (1988, p.169) summarizes the basic argument, “It is no exaggeration to say that the plant genetic resources received as free goods from the Third World have been worth untold billions of dollars to the advanced capitalist nations.”

The distribution of gains of PGR exchange has been the source of heated North-South debates in meetings of the UN FAO and the UN Convention on Biological Diversity. Developing country delegates and NGOs have argued developing countries should be compensated for their historical and current contributions to developing and maintaining landraces and wild plant varieties.

Both critics and advocates of the system of PGR exchange cite dollar estimates of gains to U.S. producers and consumers from yield increases in U.S. crops attributable to the introduction of germplasm from developing countries (Kloppenburg, 1988; Mooney, 1983; Pardey *et al.*, 1996). But where do these figures come from and what do they really say about the *distribution* of benefits from U.S. yield increases?

Let us address the first question. Plant scientists and economists often estimate the benefits of yield increases using the “change in revenue method”, deriving the gross benefits of a yield increase by multiplying the percent yield increase by total crop revenues. The change in revenues is not a true measure of economic welfare change, but it can be a reasonable approximation under certain conditions (Alston, Norton, & Pardey, 1995). Now consider the question of *who* benefits from yield increases. Changes in revenue say nothing about the *distribution* of benefits between producers and consumers or between regions. Nor do they account for multimarket effects that arise because agricultural commodity markets are vertically and horizontally linked.

Here, we report some results of a study estimating the size and distribution of economic impacts of genetic improvements of several U.S. field crops – corn, soybean, wheat, cotton and coarse grains (Frisvold, Sullivan, & Raneses, 1999). These crops account for over two-thirds of U.S. cropland. We introduced yield gains as supply shocks into the United States Department of Agriculture’s (USDA) Static World Policy Simulation (SWOPSIM) model of world agricultural trade. Like the Organization of Economic Cooperation and Development’s (OECD) MTM model (Huff & Moreddu, 1989-90) and International Food Policy Research Institute’s (IFPRI’s) IFPSIM model, SWOPSIM is a multi-region, multi-commodity model with log-linear supply and demand equations and government market interventions modeled as producer and consumer price wedges. Researchers have used the model extensively to analyze trade policies (Dixit & Roningen, 1989; Krissoff, Sullivan, & Wainio, 1989; Webb Dixit, & Conley, 1989; Haley, Herlihy & Johnston, 1991; Roningen & Dixit, 1991) and effects of climate change (Tobey, Reilly & Kane, 1992; Reilly & Hohmann, 1993). Roningen (1986) and Sullivan *et al.* (1992) describe the model in detail.

The model is calibrated to 1989 data for agricultural production, consumption, trade, and prices.

Supply and demand elasticities were developed from comprehensive surveys of the literature (Roningen, 1986; Sullivan *et al.*, 1992). These elasticities are consistent with those used in other world agricultural trade models (e.g., Huff & Moreddu, 1989-1990; Parikh *et al.*, 1988). The version of the SWOPSIM model used in simulation experiments is disaggregated into 11 regions and 22 commodities. The crops in the model are: wheat, corn, coarse grains, rice, soybeans, soy meal, soy oil, other oilseeds, other meals, cotton, sugar, and tobacco. Animal products include beef, pork, mutton and lamb, poultry meat, poultry eggs, fluid milk, butter, cheese, and milk powder. Table 1 lists the regions in the model.

Modeling Genetic Improvements

In the simulations, we assumed that genetic improvements accounted for half the average annual yield gain of the crops considered. Several empirical studies have reported values around this 50% level, while others report even higher values (Duvick, 1992; Fehr, 1984; Huffman & Evenson, 1993; Thirtle, 1985). The estimated annual yield increases were 0.66% for wheat, 0.77% for corn, 0.57% for coarse grains, 0.60% for soybeans, and 1.12% for cotton. These correspond to half the actual annual average yield growth between 1975-92. To simulate the single-year impact of yield improvements, the productivity parameters in the supply functions for U.S. corn, soybeans, wheat, cotton and coarse grains were increased by the above values.

We followed a procedure similar to Rose (1980) and to Pachico, Lynam and Jones (1987), truncating the supply curve and giving it a positive intercept. For crops experiencing technological change and for U.S. livestock and animal product commodities, we assumed a positive shutdown price, set equal to the average variable costs of the lowest cost producers. Data on average variable costs came from USDA's Farm Cost and Returns Survey, which reports data on average variable cost disaggregated by commodity, region and other characteristics. So, the supply curves have a horizontal component (corresponding to the shutdown price) and an upward sloping component (determined by a constant price elasticity). This specification allows for one to model divergent, proportional and convergent supply curve shifts. Technical change is modeled as a combination of an outward shift in the upward-sloping portion of the supply schedule and a downward shift in the shutdown price. The latter shift affects producer surplus but not equilibrium quantities or prices.

A more divergent supply curve shift from technological change will yield lower producer gains, while a more convergent shift, will yield higher producer gains (Rose, 1980). We chose an intermediate specification, assuming that yield increases from genetic improvements generated a proportional reduction in the marginal cost curve throughout the entire supply schedule. Because of data limitations, shutdown prices were set at zero for the remaining commodities and regions.

Results

The change in economic welfare (dW) can be decomposed into changes in consumer surplus (dCS), producer surplus (dPS), government payments (dGP) and quota rents (dQR) such that $dW = dCS + dPS + dQR - dGP$. Government market interventions such as commodity programs or trade restrictions influence overall welfare impacts of technological change (Alston, Edwards, & Freebairn, 1988; Oehmke, 1988).

The global welfare benefits of a one-time, single-year yield increase in the U.S. crops were \$590 million (1989 constant). The yield increases lead to modest declines in world commodity prices. This benefits consumers worldwide by \$954 million, while foreign producer surplus declined by \$509 million. In the United States, higher yields and lower prices increase commodity program payments and dampen the overall gains in U.S. welfare.

Table 1 shows some distributional impacts of U.S. yield increases. The United States captures 60% (\$352 million) of this welfare gain. Other developed countries captured 24% of the benefits, with other regions capturing 16%. We also experimented with a more divergent supply curve shift, such that equilibrium quantities and prices remained the same, but that U.S. producer surplus was zero (i.e., consumers capture all gains). Under this specification, the U.S. captures 44% of the gains, other developed countries capture 34%, and developing and transitional economies capture 22%. Results are similar to Frisvold (1997) who, using a CGE model of the world economy, estimated that Canada and the United States captured only 57% of the benefits from domestic crop productivity increases. Consumers in transitional economies, China and other developing countries are major beneficiaries of U.S. yield gains. Consumer surplus in these regions rose by \$443 million while producer surplus fell by \$356 million (table 1).

But what can we say about the distributional impacts within developing countries? The SWOP-SIM model is too aggregate to answer this question directly. Yet it does illustrate that developing countries are affected mainly through falling world agricultural prices. The urban poor of developing countries will benefit relatively more than the urban rich because they spend a higher proportion of their income on food. Matters are more complex in rural areas because agricultural producers both buy and sell commodities. However, the rural poor in developing countries tend to be net purchasers of food. So, one would expect falling world prices to benefit the rural poor net-food purchasers and hurt larger-scale (wealthier) producers who are net-sellers of agricultural commodities. Within developing countries, rising U.S. crop yields and falling world prices are likely to have generally progressive distributional consequences.

The results have interesting implications for the debate over the distribution of benefits of PGR use. Critics of the current system of PGR exchange may focus on the result that developing and transitional economies capture only 16-22% of the welfare benefits. Yet the results also suggest that the poor in those countries are major beneficiaries of U.S. yield gains. While developing countries do not receive direct monetary payments from the use of their germplasm, they do receive benefits in the form of consumer surplus¹. Also, these are measures of the *gross* benefits of yield growth. They do not include the research costs incurred in the U.S. to achieve yield gains.

Long-Term Impacts

The simulation estimated the impacts in a single year of a one-time increase in U.S. crop yields from genetic improvements. But yield increases from genetic improvements are not single-year events. Annual yield gains achieved in a given year have been maintained after that. It is appropriate to think of the benefits as an income stream (Evenson & Gollin, 1997). One may then calculate the present value of an annual permanent increase in yields from genetic improvements².

**Table 1: Welfare Effects Of Genetic Improvements In Major U.S. Crops
(Single Year Impacts Measured In 1989 \$millions).**

| Region ^a | Change in: | | | | |
|--|-----------------------------|-----------------------------|--------------------------------|------------------------|------------------------|
| | <i>Producer Surplus</i> | <i>Consumer Surplus</i> | <i>Government Payments</i> | <i>Quota Rents</i> | <i>Net Welfare</i> |
| Developed Countries | 9 | 511 | 25 | 1 | 496 |
| United States | 162 | 223 | 33 | 0 | 352 |
| Canada | -17 | 18 | -1 | 0 | 2 |
| European Union | -103 | 180 | -7 | 0 | 84 |
| Other Western Europe | -10 | 16 | 0 | 0 | 6 |
| Japan | -9 | 66 | 0 | 1 | 58 |
| Australia & New Zealand | -14 | 8 | 0 | 0 | -6 |
| Developing & Transitional Economies | -356 | 443 | 7 | 14 | 94 |
| China & Transitional Economies | -171 | 210 | 2 | 8 | 45 |
| Developing Agricultural Exporters | -61 | 62 | 2 | -17 | -18 |
| Developing Asian Importers | -5 | 14 | 0 | 11 | 20 |
| Rest of the World | -119 | 157 | 3 | 12 | 47 |
| World Total | -347 | 954 | 32 | 15 | 590 |

Note. Simulation experiment: yield increases for U.S. wheat (0.66%), corn (0.77%) Coarse grains (0.57%), soybeans (0.60%) and cotton (1.12%). From "Genetic Improvements in Major U.S. Crops: the Size and Distribution of Benefits" by G. Frisvold, J. Sullivan, and A. Ranases, August 8-11, 1999. Paper presented at the American Agricultural Economics Association Annual Meetings, Nashville, TN.

^a In the regional categories Transitional Economies include nations of the former Soviet Union and Eastern Europe. Developing Agricultural Exporters include Argentina, Brazil, Indonesia, the Philippines, and Thailand. Developing Asian Importers include Hong Kong, Macao, South Korea, and Taiwan.

The simulation estimated the gross annual benefits of yield increases in a single year. A conservative approximation of the value of a permanent increase in yields would be to assume that the single year benefits are received in each subsequent year. The benefit of an outward supply shift is the area between the old and new supply curves and underneath the demand curve. As income and population grow, this area would grow as demand shifted outward.

No matter the discount rate, the benefits of permanent yield increases are substantial (table 2). United States benefits range from \$4.8 billion ($r = 10\%$) to \$9.2 billion ($r = 5\%$) in 1997 constant dollars. Global benefits range from \$8.1 to \$15.4 billion. Net benefits to developing and transitional economies range from \$1.2 to \$2.5 billion. Benefits to consumers in developing and transitional economies range from \$6.1 to \$11.6 billion.

Plant breeding and genetic improvements have not merely generated one-time permanent increases in yields, but rather an annual stream of permanent yield improvements. Every year there has been a new incremental permanent increase in yields. The problem is equivalent to receiving a new annuity (of varying value) every year. One may properly think of the long-term benefits of genetic improvements as a “stream of income streams.” It is beyond the scope of our static model to calculate this stream of streams of benefits. This would require a comparison of dynamic paths of supply and demand with and without genetic improvements.

However, the discounted value of the long-term process of genetic improvements is much larger than benefit of a one-time permanent increase in yields. To illustrate, the present value of an annuity paying \$1,000 today and every year thereafter is \$21,000, discounted at 5%. Now, consider a stream of annuities the first paying \$1,000 today and every year thereafter, the second paying \$1,000 a year from today and every year thereafter, the third paying \$1,000 two years from today and every year thereafter, and so on. The present value of this stream of income streams, discounted at 5% is \$420,000. The \$1,000 corresponds to the single year impact, while the \$420,000 corresponds to the value of the stream of income streams.

Table 2: Impacts Of Permanent Yield Increases From Genetic Improvements In Selected U.S. Crops (Present Value In Billions Of \$1997).

| Discount Rate | Change in: | | | |
|---------------|-----------------------|-------------------|--|---|
| | <i>Global Welfare</i> | <i>US Welfare</i> | <i>Developing & Transitional Economies Welfare</i> | <i>Developing & Transitional Economies Consumer Surplus</i> |
| $r = 10\%$ | 8.1 | 4.8 | 1.2 | 6.1 |
| $r = 7\%$ | 11.2 | 6.7 | 1.7 | 8.5 |
| $r = 5\%$ | 15.4 | 9.2 | 2.5 | 11.6 |

Note. Crops include corn, wheat, soybeans, cotton and coarse grains.

Conclusions

This study used a world agricultural trade model to estimate the size and distribution of welfare impacts of genetic improvements of major U.S. field crops. Simulation results suggest that 50-60% of the gains accrue to the U.S., 24-30% to other developed countries and 16-22% to developing / transitional economies. Because of systematic biases in the model used, however, the absolute and relative gains to other countries are likely underestimated. Consumers in developing and transitional economies are major beneficiaries of U.S. yield gains. In developing

countries, the urban and rural poor are net food purchasers. Within developing countries, rising U.S. yields and falling world prices will generally have progressive distributional consequences.

Endnotes

¹Our simulations systematically *overstate* producer surplus losses in developing and transitional economies because, in the model, falling feed grain prices induce pivotal supply curve shifts in animal product markets.

²The results that follow do not change qualitatively if one assumes yield increases are less than permanent, say lasting 30 years.

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