Chapter 5

Measuring Costs, Benefits, and Economic Impacts of Wheat Breeding Research

How can the success of a wheat breeding program be evaluated? Wheat scientists, economists, and research policy makers all recognize that the benefits of a wheat improvement program must be measured against the costs incurred in operating that program. They may, however, take different approaches to identifying and measuring these costs and benefits, particularly the benefits.

In principle, the costs of a wheat breeding program are relatively straightforward to define and measure. In Chapter 2, we presented some measures of costs associated with international wheat breeding targeted at developing countries. Even when measuring the costs of a single international organization such as CIMMYT, we saw that different assumptions can lead to different, though related estimates. Computing the costs of all international wheat breeding research, or assessing the expenditures of NARS wheat breeding programs is more difficult. However, the difficulty is usually due to lack of data, rather than lack of a conceptual framework.

In contrast, measuring the benefits of wheat breeding research is fraught with conceptual problems. Byerlee and Moya (1993) divide the process by which wheat breeding research generates benefits into three stages:

1. New varieties are developed, released, and adopted. This part of the process has been analyzed in Chapters 3 and 4.
2. Adopted varieties generate benefits through gains in yield, improved stability, and other desirable characteristics.
3. These benefits are transmitted via prices and distributed to society through the effects on producers' and consumers' incomes.

This chapter, along with Chapters 6 and 7, will analyze the second and third steps of this process.

A number of definitional and practical problems complicate the measurement of benefits of a wheat improvement program. For example, wheat scientists tend to concentrate on yield gains, whereas economists are generally interested in increases in output or shifts in supply. Although it is theoretically possible to relate the concept of yield gains to the concept of supply shifts, the relationship is not always easy to measure empirically. Furthermore, if quality improvements are an important goal of a wheat breeding effort, measurements of benefits may be further complicated.

In this chapter, we begin by examining the ways in which the superiority of new varieties developed by wheat breeding programs can be measured. We then look at the ways in which improvements in yield or other characteristics can be translated into shifts in wheat supply. Next, we consider the economic benefits associated with a supply shift and discuss how these benefits are distributed among different groups of consumers and producers. Following this, we review how cost and benefit estimates can be combined to derive an estimate of economic impacts. Finally, we note some special issues related to the measurement of the economic benefits of wheat breeding programs.

Gains in Yield and Other Characteristics

Over time, a successful wheat breeding program is likely to generate genetic gains in yield. One component of yield gain is a gain in yield potential. Starting at time 0, each subsequent variety released at time *t* may yield more (Y_t) compared to a variety released at time 0 (Y_0). Although the gains in yield from varieties released over time will not follow a smooth trajectory, for our purposes they can be considered to follow the pattern outlined in Figure 5.1. It is important to remember that gains in yield potential are assumed to be measured with potential stresses (such as soil fertility and disease pressure) set at non-limiting levels. In reality, it is somewhat difficult to disentangle gains in yield potential alone from gains in stress tolerance or resistance.

If we consider a single important stress affecting wheat grown in a particular target region, it is possible that wheat varieties released over time may yield more when subject to the stress ($Y_t[+S]$) or free of it ($Y_t[-S]$). In Figure 5.2a, yield gains in the presence and absence of the stress are depicted as occurring at the same rate. That assumption can be relaxed, however. Alternatively, gains may be made in yield potential in the absence of the stress, but no gains may be made in the presence of the stress (Figure 5.2b). In the first case, total gains in yield may be divided into gains in yield potential and gains in stress resistance; in the second case, all yield gains may be attributed only to increases in yield potential. Gains in expected yield at time *t*, compared with time 0, in both cases would be $(1-p)\{ Y_t[-S] - Y_0[-S] \} + p\{ Y_t[+S] - Y_0[+S]\}$, where *p* is the probability that the stress occurs.

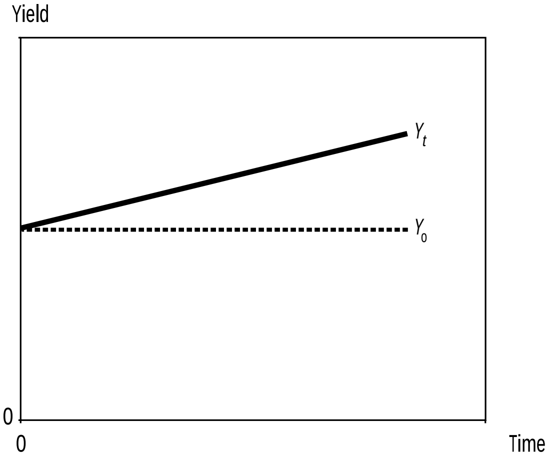

Figure 5.1. Gains in yield potential over time.

To further complicate matters, a variety's tolerance or resistance to some stresses may deteriorate over time. This is often the case for disease resistance, because over time pathogens frequently mutate to overcome genetically based resistance in the plant. Wheat rust pathogens (stem rust, or *Puccinia graminis*; leaf rust, or *P. recondita*; and stripe or yellow rust, *P. striiformis*) continually evolve and break down genetic resistance in wheat varieties.

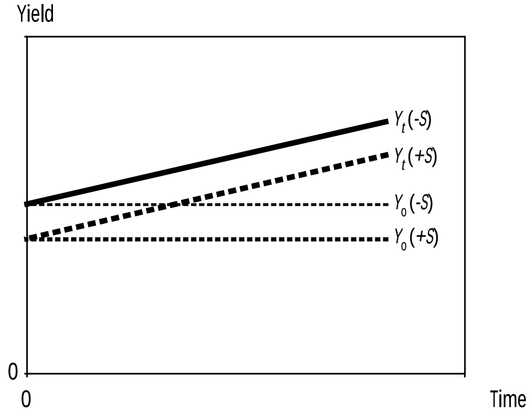

Figure 5.2a. Gains in yield with and without stress.

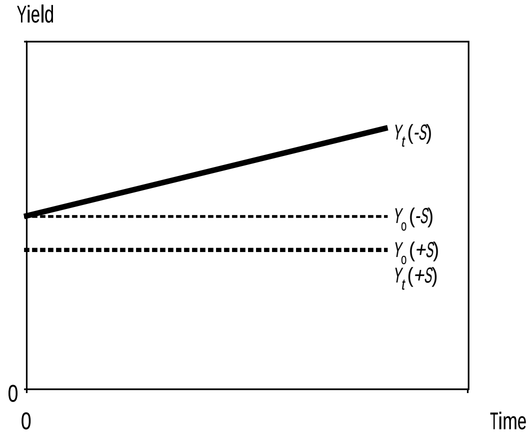

Figure 5.2b. Gains in yield only without stress.

A considerable amount of modern scientific wheat breeding has focused on securing new and more durable sources of disease resistance, particularly to rusts. Figures 5.3a and 5.3b depict two possible yield gain scenarios in which disease resistance breaks down over time. In such situations, it is conceptually possible to distinguish between gains in disease resistance resulting in an improvement in resistance, and gains in disease resistance resulting in the maintenance of resistance at the levels present in previously released varieties at the time of their release.

Byerlee and Moya (1993) argue that genetic gains in wheat yield can be classified into gains in yield potential, improvements in disease resistance, and maintenance of disease resistance. They describe the types of trials and statistical analysis necessary to measure these different types of genetic gains.

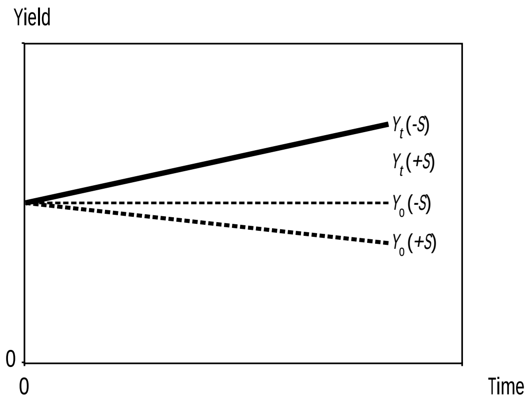

Figure 5.3a. Perfect disease resistance in new varieties and loss of resistance in old varieties.

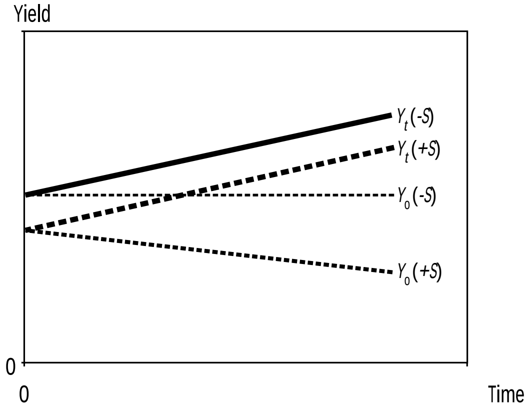

Figure 5.3b. Improvements in disease resistance in new varieties and loss of resistance in old varieties.

In practice, often gains from improving and maintaining disease resistance are not measured separately. Furthermore, gains measured in yield potential may actually be the result of gains in tolerance to other stresses, such as nutrient deficiencies and moisture stress, or heat stress. Evans and Fischer (1999) and Tollenaar and Wu (1999) present alternative approaches for conceptualizing gains in yield potential and gains in stress resistance/tolerance. At an extreme, all yield gains could be considered gains in stress resistance. At a practical level, however, breeders are often comfortable distinguishing between gains in yield potential and gains in resistance or tolerance to major stresses in their targeted environments.

For simplicity, in this report we concentrate on benefits from wheat breeding that show up in the form of yield gains. However, the process through which new varieties are developed and diffused may also bring other benefits (or losses). Earlier maturity, or the ability to plant and harvest more rapidly, may allow farmers to increase cropping intensity. This is a clear production-related benefit resulting from wheat improvement, but because it is felt at the level of the cropping system, it is less readily measured when the focus is on wheat alone. Also, wheat breeders may alter the market value of wheat by changing its quality. Measuring the effects of quality improvements requires some means of measuring quality and a way of valuing changes in quality. If byproducts such as straw are valuable, changes in the quality and quantity of byproducts will also be important determinants of the net benefits from wheat breeding (Traxler and Byerlee 1993). Environmental effects of new varieties, such as reduced chemical use for disease control when new varieties have host-plant resistance, or greater problems in the maintenance of soil quality given the management practices associated with new varieties, are particularly hard to measure. Nonetheless they, too, can be important economic impacts of wheat breeding.

Translating Yield Gains Into Economic Benefits

YIELD GAINS AT THE FARM LEVEL

Yield gains estimated from data generated through varietal evaluation trials may not be equivalent to yield gains realized in farmers' fields. Varietal evaluation trials conducted in farmers' fields are usually conducted with a package of technology that the farmer would not normally use. Furthermore, trials on experiment stations may not be carried out under environmental conditions representative of conditions in farmers' fields. Absolute yields of varieties grown in farmers' fields under farmers' conditions will usually be lower than yields in variety trials, as will the absolute size of gains in yield.

It is empirically uncertain, however, whether the relative yield gains realized in farmers' fields are lower than the relative yield gains observed in variety trials (Byerlee and Moya 1993). If yields increase in farmers' fields at the same rate that they increase in experiments, the relative rate of gain in farmers' fields would be the same as in the trials, even though the absolute gain would be less.

FARMER MANAGEMENT AND FARM-LEVEL YIELD GAINS

There are several reasons to believe that relative yield gains in farmers' fields will not be identical to experimental yield gains, even if farmers' management is equivalent to management levels in experiments. First, in farmers' fields, the supply and demand of production factors depend on economic considerations. Second, production factors may be readily substituted for one another in wheat production, or, alternatively, substitution possibilities may be limited (Alston, Norton, and Pardey 1995).

Varietal changes in farmers' fields may also induce changes in management practices as farmers choose economically optimal levels of inputs. Changes in management practices in turn imply changes in costs at the farm level. All these things must be considered if there is to be a complete accounting of economic net benefits. As we have seen, it is unlikely that yield gains measured in trials have been evaluated at a management level equal to the equilibrium level of inputs that would have prevailed in farmers' fields before the change in variety.[24] Even if they had been, the changes in net economic benefits must take into account not only changes in the value of production, but changes in costs between the old and new equilibrium levels of input use. In the language of economics, the magnitude of the supply shift is related to the yield gains resulting from research, but there may not be a simple correspondence between the measure of gains in yield resulting from breeding, the measure of yield gains in farmers' fields, and the measure of economic benefits resulting from these yield gains.

TECHNICAL AND ALLOCATIVE EFFICIENCY

The preceding discussion assumes that differences between farmers' yields and experimental yields result from conscious economic choices made by farmers. However, it is possible that farmers are also "inefficient" in their use of resources. Microeconomic theory usually distinguishes between allocative efficiency and technical efficiency. Allocative efficiency refers to the use of economically optimal combinations of inputs, given input and output prices. Technical efficiency means obtaining the greatest possible output for any given combination of inputs. Inefficiencies in input use are often associated with inadequate information (Ali and Byerlee 1991). It is sometimes

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[24] Or, for that matter, at the equilibrium level of inputs that would have been used in farmers' fields *after* the change in variety.

hypothesized that inefficiencies are greater in periods of rapid technological change, such as the Green Revolution, than in other periods such as the years following the Green Revolution (Byerlee 1992).

Most empirical studies, including those that focus on wheat production, seem to show that farmers are allocatively and technically inefficient (Rejesus, Heisey, and Smale 1999). The evidence on whether inefficiency is greater in periods of Green Revolution-like technical change is limited and mixed (Pingali and Heisey 2001). Numerous conceptual and methodological problems are associated with estimating allocative and technical efficiency. Partitioning inefficiency into these two components is sensitive to the level of input aggregation used in the modeling process (Ali and Byerlee 1991). Furthermore, it is possible to argue that apparent inefficiency is really due to unmeasured inputs, which are very likely unpriced as well. The conceptual and empirical difficulties in attributing differences between experimental and farmer yields and yield gains to farmer inefficiency are economic counterparts to agronomic difficulties in attributing experimental yield gains to gains in yield potential or gains in stress resistance.

CHANGES IN WHEAT PRICES

Changes in wheat technology that result in increased wheat yields and increased wheat supply may result in changes in wheat output prices. The degree to which demand for wheat is sensitive to the price of wheat will influence the relationship between experimental and "industry" yields (the latter refers to yields in farmers' fields). If the country or region served by the breeding program is neither a net exporter nor a net importer of wheat, increases in wheat supply will drive down the real price of wheat. For net exporters, shifts in supply will leave the price of wheat at the export price, and for net importers, shifts in supply will leave the price of wheat at the import price. In the long run, the likely result of increased wheat supply attributable to wheat improvement research is lower real world wheat prices. This will also affect benefits generated from wheat research, although the primary effect may be on the distribution of benefits between producers and consumers, rather than on the total size of benefits.

TRANSLATING YIELD GAINS INTO SUPPLY SHIFTS

In this section, we apply the model originally proposed by Muth (1964) and further developed by Alston (1991) and Alston, Norton, and Pardey (1995) to illustrate potential changes in wheat yield in farmers' fields, as well as changes in economic benefits that may be associated with an increase in experimental wheat yields. In the simplest version of the model, it is assumed that wheat is produced using two factors, land and labor, which substitute for one another in a constant elasticity of substitution production function, with elasticity of substitution σ.[25] Land and labor are supplied with elasticities of ε_1 and ε_2, respectively. A land elasticity of 0.1, for example, would imply that a 10% increase in the price of land would increase land supply by 1%. In this model, s_1 and s_2, the cost shares of land and labor respectively, also influence the relationship between experimental yield gains on the one hand, and industry yield gains and economic benefits on the other. The cost share of land s_1 is the rental price of land times the

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[25] The elasticity of factor substitution measures the degree to which land and labor substitute for one another. A low value indicates limited substitution possibilities. A value of 1 means the CES production function simplifies to the commonly used Cobb-Douglas form, and a high value means land and labor substitute readily for one another in production.

amount of land used; in this simple model $s_1 + s_2 = 1$. In situations in which shifts in wheat supply affect the price of wheat, the final important parameter is η, the price elasticity of demand for wheat. A price elasticity of demand $\eta = -0.3$, for example, would imply that a 10% reduction in wheat price would lead to a 3% increase in the amount of wheat demanded.

For this analysis, we allowed the elasticity of land supply, ε_1, to take on the values 0, 0.2, and 0.4. A "perfectly inelastic" supply of land, $\varepsilon_1 = 0$, would characterize the case in which no more land would become available for wheat production, even if the rental rate of land rose. Although in general opportunities for land expansion are rather limited, the supply of land for a particular use, such as wheat production, might be somewhat more elastic than the overall supply of agricultural land, which is why we considered non-zero values. The elasticity of labor supply, ε_2, took several values from 0.2 to 1 in the analysis. We even considered the case where labor supply would become perfectly elastic, i.e., $\varepsilon_2 \to \infty$. In the old debate over development and growth, it was often assumed that labor was in essence infinitely elastic, particularly in densely populated countries with large, underemployed populations. In post-Green Revolution Asia, however, it has become apparent that there are significant opportunity costs for labor in agriculture and that a smaller, finite elasticity of labor supply is most realistic.

In our analysis, we let the land share, s_1, take on values of 0.25, 0.5, and 0.75, and the price elasticitity of demand, η, take on values -0.2, -0.3, and -0.4. The price elasticity of demand for wheat is often assumed to be around –0.3 in developing countries. We assumed that varietal improvement represents a biased, land-saving technological change[26] and analyzed the effects of a 1% increase in experimental yields. Not all combinations of parameters are reported here. Tables 5.1 and 5.2 report the percentage change in farm-level yields associated with a 1% increase in experimental yields in a closed economy and a small open economy. In a closed economy, the wheat price is determined by domestic wheat supply and demand. In a small open economy, the wheat price is set at the export price if the country is a net exporter, or the import price if it is a net importer.

These results illustrate the point made by Alston, Norton, and Pardey (1995) that, in general, increases in experimental yields will not lead to identical increases in farm-level yields. Over the range of parameters used in our simple model, farm-level yields appear to increase by a greater amount in a small open economy than in a closed economy. An increasing supply elasticity of land is associated with a greater increase in industry

Table 5.1. Percentage change in industry yields when experimental yields increase by 1%, land-saving technological change, closed economy.

$\sigma = 0.1$ (elasticity of factor substitution—limited factor substitution)

ε_2 (elasticity of supply of labor)	ε_1 (elasticity of supply of land)	
	0	0.2
0.2	1.29%	1.67%
1	1.43%	1.72%
∞	1.50%	1.75%

$\sigma = 1$ (elasticity of factor substitution—Cobb-Douglas production function)

ε_2 (elasticity of supply of labor)	ε_1 (elasticity of supply of land)	
	0	0.2
0.2	0.84%	1.17%
1	0.63%	0.98%
∞	0.46%	0.82%

$\sigma = 9$ (elasticity of factor substitution—high degree of substitutability)

ε_2 (elasticity of supply of labor)	ε_1 (elasticity of supply of land)	
	0	0.2
0.2	0.76%	1.02%
1	0.41%	0.62%
∞	0.06%	0.14%

Note: For all estimates, $s_1 = s_2 = 0.5$, or land and labor cost shares are assumed equal; for all estimates, $\eta = -0.3$ (elasticity of demand for wheat = -0.3).

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[26] Other possibilities would be a biased, labor-saving technological change and a neutral technological change that would not be biased towards either factor.

yields. The effects of an increasingly elastic supply of labor, however, differ between a closed and small open economy. They also differ according to the degree of substitutability between land and labor. For the most part, farm-level yield gains are higher if there is little substitution between land and labor in wheat production and lower if there is a greater substitution between the two.

Tables 5.3 and 5.4 show net changes in total economic benefits (combined consumers' and producers' surplus in the closed economy, producers' surplus in the small open economy) associated with a 1% increase in experimental yields. These changes do not differ much between the closed economy and small open economy. Increasing supply elasticities for both land and labor reduces the change in total benefits. Increasing the substitutability between land and labor also reduces the change in total benefits.

Table 5.2. Percentage change in industry yields when experimental yields increase by 1%, land-saving technological change, small open economy.

$\sigma = 0.1$ (elasticity of factor substitution—limited factor substitution)		
ε_2 (elasticity of supply of labor)	ε_1 (elasticity of supply of land)	
	0	0.2
0.2	1.50%	1.67%
1	1.83%	1.86%
∞	2.00%	2.00%
$\sigma = 1$ (elasticity of factor substitution—Cobb-Douglas production function)		
ε_2 (elasticity of supply of labor)	ε_1 (elasticity of supply of land)	
	0	0.2
0.2	1.09%	1.17%
1	1.33%	1.38%
∞	2.00%	2.00%
$\sigma = 9$ (elasticity of factor substitution—high degree of substitutability)		
ε_2 (elasticity of supply of labor)	ε_1 (elasticity of supply of land)	
	0	0.2
0.2	1.01%	1.02%
1	1.05%	1.06%
∞	2.00%	2.00%

Note: For all estimates, $s_1 = s_2 = 0.5$, or land and labor cost shares are assumed equal.

Table 5.3. Percentage change in total economic benefits when experimental yields increase by 1%, land-saving technological change, closed economy.

$\sigma = 0.1$ (elasticity of factor substitution—limited factor substitution)		
ε_2 (elasticity of supply of labor)	ε_1 (elasticity of supply of land)	
	0	0.2
0.2	29.81%	4.98%
1	21.84%	4.22%
∞	19.85%	3.98%
$\sigma = 1$ (elasticity of factor substitution—Cobb-Douglas production function)		
ε_2 (elasticity of supply of labor)	ε_1 (elasticity of supply of land)	
	0	0.2
0.2	11.95%	4.98%
1	3.99%	2.49%
∞	2.00%	1.43%
$\sigma = 9$ (elasticity of factor substitution—high degree of substitutability)		
ε_2 (elasticity of supply of labor)	ε_1 (elasticity of supply of land)	
	0	0.2
0.2	10.18%	4.98%
1	3.99%	1.78%
∞	0.22%	0.21%

Note: For all estimates, $s_1 = s_2 = 0.5$, or land and labor cost shares are assumed equal; for all estimates, h = -0.3 (elasticity of demand for wheat = -0.3).

Table 5.4. Percentage change in total economic benefits when experimental yields increase by 1%, land-saving technological change, small open economy.

$\sigma = 0.1$ (elasticity of factor substitution—limited factor substitution)		
ε_2 (elasticity of supply of labor)	ε_1 (elasticity of supply of land)	
	0	0.2
0.2	30.22%	5.02%
1	22.20%	4.26%
∞	20.20%	4.04%
$\sigma = 1$ (elasticity of factor substitution—Cobb-Douglas production function)		
ε_2 (elasticity of supply of labor)	ε_1 (elasticity of supply of land)	
	0	0.2
0.2	12.07%	5.02%
1	4.03%	2.52%
∞	2.02%	1.44%
$\sigma = 9$ (elasticity of factor substitution—high degree of substitutability)		
ε_2 (elasticity of supply of labor)	ε_1 (elasticity of supply of land)	
	0	0.2
0.2	10.27%	5.02%
1	4.04%	1.80%
∞	0.22%	0.21%

Note: For all estimates, $s_1 = s_2 = 0.5$, or land and labor cost shares are assumed equal.

Interestingly, over the range of parameter values examined here, only a high degree of substitutability between land and labor, along with a very high elasticity of labor supply, produces increases in total benefits that are smaller in percentage terms than the initial increase in experimental yields. In some analyses, benefits at time t, B_t, are calculated as $B_t = gY_tX_{1t}P_t$, where g is the percentage gain in yield attributable to the breeding program, Y_t is yield at time t, X_{1t} is land area affected by the breeding program, and P_t is price. This simplification assumes a perfectly elastic demand function for wheat (equivalent to the small open economy assumption) and a perfectly inelastic supply function (Morris, Dubin, and Pokhrel, 1992, 1994). In addition, it might be assumed that g (yield gains in farmers' fields) is equal to experimental yield gains.[27] This simplification ignores regional or international price effects that may arise from the research, as well as distributional effects (Alston, Norton, and Pardey 1995). However, over a plausible range of parameters, it does not appear that such a simplification systematically overstates total research benefits; in this formulation, at least, it often understates them.

Distributional Issues in Measuring Agricultural Research Benefits

In general, agricultural research institutions are supported because their work is viewed as beneficial to farmers. Indeed, one of the justifications for public-sector agricultural research is that individual farmers are unlikely to have the incentives, capital, or knowledge to perform agricultural research and development (Alston and Pardey 1996). Over much of the last century, however, agricultural research has often improved agricultural productivity and driven down commodity prices, thus benefiting consumers. For many purposes, it may be desirable to estimate the distribution of research benefits between consumers and producers. The most common method of doing this is to use the economic surplus method in a supply and demand framework (Alston, Norton, and Pardey 1995). The basic framework is subject to many possible modifications, but all may be understood in the context of supply and demand. One example of a more complex analysis is the division of benefits among different groups of consumers (e.g., rural and urban, rich and poor). Benefits to producers can also be attributed to different factors of production (e.g., land, labor, or capital) (Alston, Norton, and Pardey 1995). In many developing countries, small-scale farmers may be significant consumers as well as producers of a commodity such as wheat. In principle, this poses few problems for economic surplus analysis (Renkow 1994).

For research programs that have impacts in more than one region or country, such as CIMMYT's wheat breeding program, market models may include the impacts of research in different countries or groups of countries. As noted above, an important consideration is whether or not the research is expected to change the price of wheat in a given country. In the international trade context, it may be useful to analyze whether the impact of the research is felt in an exporting country, an importing country, or both.

Price policy instruments, such as input or output subsidies or tariffs, will also affect the distribution of benefits of agricultural research. As with other modifications of the simple economic surplus model, there is little in principle to preclude analysis of the distribution of research benefits when such policies are in effect (Alston, Norton,

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[27] In the context of the Muth model, one way that experimental yield gains would equal actual yield gains at the same time that the elasticity of supply of wheat would be 0, would be if land and labor supply elasticities, ε_1 and ε_2, were both equal to 0.

and Pardey 1995). The main difficulty is likely to be empirical. Obviously it is harder to obtain the data to estimate supply and demand functions for wheat in many countries or regions, or data to estimate the effects of policies in many countries, than in a smaller geographical area.

Putting Costs and Benefits Together

An analysis of the economic impact of a crop breeding program requires an examination of research costs and benefits within the same framework. Several issues are important in this regard: the time pattern of costs and benefits, the association of "correct" costs with "correct" benefits, and consideration of what would have happened had the research not occurred.

TIME PATTERN OF COSTS AND BENEFITS

Agricultural research is a long-term proposition. Research on any given subject takes years, and the outcome is uncertain. When the research result is obtained, there is usually an additional development lag as a product is refined for farmers' fields. Adoption is not instantaneous. Significant use of a product in farmers' fields may begin several years after the release of the technology. Further time will pass before the use of the technology reaches its peak. Eventually, the technology will be replaced by a newer technology. Studies that have specifically analyzed lag times for agricultural research have concluded that a 30-year lag may be necessary to capture all the effects (Pardey and Craig 1989; Chavas and Cox 1992). Since economic returns occurring at different points in time must be discounted to make them comparable, the issue of lags between when costs are incurred and when benefits are experienced is very important in the analysis of research impacts. Recently, some economists have claimed that the nature of knowledge itself makes research lags essentially infinite, and that considering these infinite lags in the context of an empirically tractable model will reduce estimated rates of return (Alston, Craig, and Pardey 1998). The economics profession has not as a whole embraced this viewpoint (Huffman 1999), and reported rates of return have in general been quite high (Evenson 2001). It is clear, however, that the assumed time pattern of research costs and benefits can have a major effect on the estimated economic benefits from the research.

Whatever the outcome of the debate over the best way to model and empirically estimate research lags, the major outlines of a wheat breeding program provide several clear reference points in time. Costs of a breeding program incurred during years 1 through *n* result in the release of one or more varieties in year *n* (Morris, Dubin, and Pokhrel, 1992, 1994). Even before a cross eventually results in a variety, considerable research may be necessary to ensure the success of the plant breeding effort. This might include basic research on plant molecular biology, research on the genetics of plants and methods of plant breeding, and germplasm enhancement, such as "gene transfer via sexual and asexual means from germplasm accessions" or "increasing the frequencies of desirable genes in crop gene pools that will be used for developing parents or cultivars" (Frey 1996). These costs may be incurred by other institutions. Since they tend to be hard to measure and are associated with a given breeding program, they may often remain unanalyzed.

Only a few of the many crosses made by a breeding program in a given year result in finished varieties. After a cross is made, there may be as many as ten generations of sowing different numbers of lines and selection of the best resulting lines for planting in the next cycle (Brennan 1989).

If the breeding program plants only one cycle per year, this could mean ten years before a finished variety is available from a given cross. Many breeding programs, including the CIMMYT Wheat Program, use shuttle breeding to plant two cycles per year, thereby reducing the time between the initial cross and the release of a variety.

After a variety is released, seed must be multiplied and made available to farmers. Even for popular varieties, there may be a two- or three-year lag between increases in seed production and significant varietal adoption. On the other hand, the area under a variety may continue to expand even after seed production begins to decline as farmers multiply their own seed or as the variety is diffused through farmer-to-farmer seed transfer (Heisey 1990). Many released varieties will never be adopted; others will be somewhat successful over a wide area or important within a significant ecological or market niche; and others will be very successful over a very wide area (Byerlee and Moya 1993). Eventually, some maximum adoption level will be reached, after which the variety will be replaced by other varieties (Brennan and Cullis 1987).

Some of these lags can be illustrated by referring to the experiences of selected CIMMYT crosses. Table 5.5 and data presented by Byerlee and Moya (1993) suggests that for popular CIMMYT crosses, there is on average a 6-year lag between the year the cross is made and the first release by a NARS, usually in Mexico. The mean lag between the date of the cross and the average NARS release date is a little over 12 years. The mean lag between the date of the cross and the peak area covered by the variety ranges from 15 to 20 years, and in the case of Sonalika was probably even longer.

ASSOCIATING COSTS WITH BENEFITS

Increases in wheat yields and productivity can be attributed not only to varietal change but also to improved management. As noted earlier, disentangling the effects of changes in input use and/or changes in efficiency of input use from the effects of varietal change may require careful measurement and attribution. This is particularly important in the case of semidwarf wheat varieties, one of whose features was greater responsiveness to inputs such as fertilizer. Here, it may be necessary to analyze the extent to which research benefits are attributable to genetic improvement and the extent to which they resulted from other research, for example, crop management research.

Agricultural research in general is characterized by spillovers, in which research done in one location produces benefits in another. Furthermore, plant breeding is cumulative in nature. New releases are

Table 5.5. Time patterns for major crosses made by the CIMMYT Wheat Program.

Cross	Year cross made	Year released in Mexico (or first developing country release)	Average year of release in NARS	Area planted, 1990 (million ha)	Area planted, 1997 (million ha)
II8156 [a]	1957	1966	1972	1.14	0.29
Sonalika	1961	1967 [b]	1972	6.29	1.22
Bluebird [c]	1965	1970	1975	0.94	0.11
Veery	1974	1981	1988	3.39	3.35
Kauz	1980	1988	1994	—	1.09
Attila	1984	1995 [d]	1996	—	1.00

[a] This cross was the base for the most important Green Revolution varieties. In the early 1970s, II8156 was grown on about 13 million hectares, primarily in South Asia (Byerlee and Moya 1993).

[b] Not released in Mexico; first released in India.

[c] Planted on more than 3 million hectares in the early 1980s.

[d] Not released in Mexico; first released in India and Ethiopia.

produced using older cultivars and breeding materials developed by a number of different research programs, including the breeding program that releases the cultivar. Chapter 2 described the many actors in the international wheat breeding system. Under these circumstances, apportioning the credit of growth in wheat productivity to the different institutions involved may require careful accounting (Alston and Pardey 2000).

The general topic of agricultural research spillovers is analyzed by Byerlee and Traxler (2001), and the specific case of allocating wheat improvement research resources in the presence of spillovers is studied by Maredia and Byerlee (1999). One approach to partitioning benefits among cooperating wheat breeding institutions is to estimate the total impacts of international crop genetic improvement research and partition those impacts to IARCs and NARSs, perhaps using the methods developed by Pardey et al. (1996). This approach does not, however, consider the catalytic contribution IARC crop germplasm improvement may have made to NARSs' research, a possibility explored by Evenson (2000).

COUNTERFACTUAL SCENARIOS

A related question is the development of an appropriate counterfactual scenario. If a given research program had not existed, would an alternative program have come into existence? It is likely, for example, that in the absence of CIMMYT, a more limited form of international exchange of wheat germplasm would have developed, and genes for plant height, disease resistance, and other important traits would have eventually been used in wheat in the developing world. To the best of our knowledge, Evenson's recent attempt (2000) to estimate NARS varietal production in the absence of IARC crop germplasm improvement investment is the only effort to delineate the counterfactual empirically.

Special Issues in Measuring the Economic Impacts of Wheat Breeding Programs

A successful wheat breeding program does not, of course, incur costs over a fixed period of time only to release a single variety (or set of varieties) in year *n*. A successful program will release a stream of varieties over time, with later superior releases replacing earlier releases. Costs will also be spread over a longer period of time. When modelling the benefits of a wheat breeding program that releases a stream of varieties, it is important to recognize that not all varieties perform equally well. If the benefits associated with the best variety are attributed to all varieties (i.e., if the benefits associated with the best variety are assumed to have occured over the entire area planted to MVs), then the total benefits attributed to the breeding program will be overestimated (Morris, Dubin, and Pokhrel, 1992, 1994; Maredia and Byerlee 1999).

Maredia and Byerlee provide a stylized adoption model of successive releases of varieties over a period of years. Analyses of economic benefits of international wheat improvement research now usually divide benefits into Stage I gains associated with the initial adoption of semidwarf wheat and Stage II gains associated with the replacement of earlier semidwarf varieties with higher yielding cultivars (Byerlee and Moya 1993; Byerlee and Traxler 1995).

We have already discussed some questions related to attributing gains from research: for example, dividing yield gains into gains attributable to crop improvement research and gains attributable to crop management research, or dividing credit for gains attributable to breeding among different research institutions. Few authors have attempted to analyze the impacts of individual components of a breeding program (i.e. breeding sub-programs), although this kind of analysis has been more common for wheat than for other crops. In large part, this may be due to the importance that maintenance research plays in wheat.

As noted previously, maintenance research is research that is necessary to maintain current levels of productivity. In the U.S., for example, it has been estimated that anywhere from one-third to two-thirds of agricultural research expenditure is necessary simply to maintain previous research gains (Heim and Blakeslee 1986; Adusei 1988; Adusei and Norton 1990). In the context of maintenance research, delineating the appropriate counterfactual scenario becomes particularly important. What is important is not a comparison "between current and previous yields but rather between current yields and what yields otherwise would have been" in the absence of research (Alston, Norton, and Pardey 1995).

Several studies have specifically attempted to look at the expenditures and economic importance of maintenance research in wheat. Heim and Blakeslee (1986) estimated that in Washington state in the U.S., over 70% of public expenditure on production-oriented research for wheat is required for yield maintenance, and any significant prolonged reduction in real research expenditures would soon result in a decline in wheat yields. Collins (1995) studied the impact of leaf rust resistance research in Pakistan. Smale et al. (1998) analyzed the economic benefits of breeding specifically for race-nonspecific resistance to leaf rust. These studies have found a positive rate of return to maintenance research in wheat breeding.

In the disaggregation cases discussed earlier, the analytical approach was primarily to look at the overall benefits to wheat research and then distribute the benefits among component research programs. Studies of maintenance research, however, have tended to analyze the economic benefits of such research directly, rather than looking at the total benefits from wheat improvement research and partitioning them among components of the breeding program, such as yield improvement and yield maintenance. The next important step would be to compare the "top-down" and "bottom-up" approaches to evaluating maintenance research for consistency.

In summary, there are a number of key issues in evaluating the economic impact of a wheat breeding program. First, how can yield gains be characterized? Second, how can yield gains be related to shifts in wheat supply, and what are the economic benefits to consumers and producers associated with such a supply shift? Third, how can costs and benefits be combined into a measure of economic impact? In our opinion, three areas need further consideration before estimates of the economic benefits of international wheat breeding research can be made more precise. Though all these areas are noted in the literature, there is very little in the way of a standard and accepted methodology to address them. The main issue is an accurate assessment of what would have happened in the absence of the breeding program under analysis. The second and third issues are related to the first. What is the correct characterization of the time pattern of costs and benefits? And when and by how much would yields decline, particularly due to changes in disease pressure in the absence of maintenance research? The answers to all of these questions must be constructed in such a way that they are consistent with the empirically observed aggregate supply and demand for wheat, in the case of *ex post* analysis, or with plausible future aggregate supply and demand, in the case of *ex ante* analysis.