The Impact of the CIMMYT Wheat Breeding Program on Mexican Wheat Producers and Consumers: An Economic Welfare Analysis

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Abstract

The increase in wheat production in Mexico's Yaqui Valley from the breeding and development of semidwarf wheat varieties released by CIMMYT is quantified for the period 1990 to 2002, and the costs and benefits of the wheat research program are estimated and evaluated using a two-region model of the world wheat market. The economic rate of return of the wheat breeding program is calculated, and policy implications are derived. Estimates of the Internal Rate of Return of the CIMMYT breeding program were 55.5 % during the 1990-2002 period, with a benefit cost ratio of 14.99, implying that for each dollar of public funds invested in CIMMYT wheat breeding research, over 14 dollars of benefits result.

Keywords: Public wheat breeding, benefit/cost analysis, agricultural research, wheat varieties.

The Impact of the CIMMYT Wheat Breeding Program on Mexican Wheat Producers and Consumers: An Economic Welfare Analysis

CIMMYT research in wheat breeding has resulted in higher yields for global wheat producers over the past several decades.[1] The sources of this research investment include federal governments, non profit organization, and grants from organizations such as the Gates Foundation. This study addressed the question, what are the economic impacts of this research effort? Specifically, empirical evidence was used to determine whether the public investment in CIMMYT wheat breeding has resulted in a socially worthwhile use of limited public funds, and how the economic benefits of the research program are distributed across consumers and producers in Mexico and the rest of the world. The results of this study are particularly important in an era of declining public funds for public agricultural research (Fuglie et al., USDA Cooperative State Research Service, 1993). CIMMYT, a public breeder, has experienced a substantial decrease in funding from roughly 12 million (2002) USD in 1990 to approximately 6 million USD in 2002. Careful measurement of the economic rate of return of the investment in wheat breeding research provides crucial information to administrators and policy makers, whose decisions on the allocation of research funding will determine the future size and scope of publicly funded agricultural research.

The contribution of wheat research was measured by quantifying the increase in yields attributable to genetic enhancements in wheat from the CIMMYT wheat breeding research program for the period 1990 to 2002. Yield gains were measured for all semidwarf varieties

[1]The Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT) is a nonprofit maize and wheat breeding research center based in El Batan, Mexico. CIMMYT was created to establish international networks to improve wheat and maize varieties in low-income countries.

tested by CIMMYT in their main experiment station in Mexico's Yaqui Valley. This increase in yield represents an increase in the supply of wheat produced in Mexico, and is the foundation of the economic impacts of the wheat breeding program.

An economic model of the world wheat market was developed and used to measure the impact of the CIMMYT wheat breeding program on: (1) Mexican wheat producers; (2) Mexican consumers of wheat (flour millers); (3) wheat producers outside of Mexico, including significant foreign producers such as the United States (USA), European Union (EU), Canada, Argentina and Australia; and (4) all wheat consumers outside of Mexico, including major wheat importers such as China and Japan. Annual benefits to each group resulting from the increased wheat yields were measured and analyzed. Several measures of the outcome of the investment in wheat breeding were calculated and assessed.

Funding of CIMMYT Wheat Breeding Research

CIMMYT, a non-profit organization, distributes improved germplasm to national agricultural research systems (NARS) for worldwide utilization. CIMMYT, through the release of modern wheat varieties, has generated substantial increases in grain yields, improved grain quality, reduced yield variability, and reduced environmental degradation in low-income countries since the Green Revolution. On average, 65–77% of these crossed samples were sent to developing countries. CIMMYT germplasm is present in roughly 24% of all wheat types using the cross rule, 38% using the cross or parent rule, 64% using the any ancestor rule, and approximately 80% of the total spring wheat area in developing countries (Lantican et al. 2005).[2]

[2]The term "CIMMYT cross" refers to a cross made at CIMMYT and the selections to obtain fixed lines that were either made at CIMMYT or by a non-CIMMYT breeding program. The term "CIMMYT parent" refers to a cross

Private wheat breeders have little incentive to breed in most low-income countries. CIMMYT fills this gap, and as a result approximately 62% of the total wheat area in low-income countries is planted to CIMMYT-related varieties (Heisey et al. 2002).

Roughly 33% of CIMMYT's funding in 2002 was from governments and agencies including, United States (23%), The World Bank (23%), Switzerland (10%), the European Commission (9%), and the Rockefeller Foundation (8%). Japan, The UK, France, Australia, and other foundations made up the remaining 27% of the funding from governments. That being said, nearly two thirds of CIMMYT's funding is obtained from grants and targeted funding from institutions like Gates Foundation. The 2002 CIMMYT annual report disaggregated the budget into spending by individual divisions within CIMMYT. Approximately 33% of CIMMYT's budget went to germplasm improvement (breeding), 26% to sustainable production, 23% to enhancing national agricultural research systems (NARS), 14% to germplasm collection, and 4% to policy. So, while the highest proportion of the budget was going to breeding expenditures, the majority of which was going to enhance other attributes of the CIMMYT program.

CIMMYT conducts research in both wheat and maize and with the recent advancements in maize breeding and the comparatively large increases in yield, money is being shifted from the wheat to the maize sector of CIMMYT. While overall funding at CIMMYT has been decreasing, wheat has experienced the largest loss. In 1990 the wheat breeding budget at CIMMYT was approximately 12 million (2002 USD), compared to just 6 million in 2002, and down from a high of 15 million (2002 USD) in 1988 (Lantican et al. 2005). The importance of public funding, coupled with the current political climate of decreasing public sector support (Acker,1993), have

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made by a non-CIMMYT breeding program using one of the parents coming directly from CIMMYT. Lastly, the term "CIMMYT ancestor" means that there is CIMMYT pedigree somewhere in the wheat, so a CIMMYT wheat is resulted in a situation where continuation of public funding for the wheat-breeding research program is dependent on how well the program is serving the public. Empirical evidence on the economic consequences of the breeding program provides evaluation of the program, as well as assessment of the likely consequences of changes in the level of funding of public wheat breeding at CIMMYT.

Measurement of the Social Benefits of CIMMYT Wheat Breeding

The methodology used to calculate the economic consequences of the CIMMYT wheat-breeding program follows a rich literature in the welfare economics of agricultural research initiated by Schultz (1953) and further developed by Ayer and Schuh (1972) and Akino and Hayami (1975). More recently, the economic evaluation of agricultural research has been summarized by Huffman and Evenson (1993) and Alston et al. (1995).

The first step in evaluating the economic impact of the CIMMYT wheat breeding program was to measure the increase in yields from the genetic improvement of wheat, holding all other production parameters constant. Gains in wheat yield can be attributed to two factors: genetic and agronomic. Agronomic gains are attributed to improvements in fertilizer, pesticides, fungicides or other factors that are not embodied within the seed. Genetic gains are associated with improved wheat breeding, or technology that is embodied within the seed. This study will focus on the estimation of genetic gains attributed to CIMMYT. This was accomplished by applying the methodology of Traxler et al. to calculate the relative yields for each variety with data from CIMMYT wheat variety performance tests in Mexico's Yaqui Valley experiment station from 1990-2002. A total of 33 lines were analyzed with release years ranging from 1962-

not used directly in the cross, but was used in developing one of the parents.

2001, including the variety Siete Cerros, the most popular semidwarf wheat of the Green Revolution. Thus, the test period for this data set is 1990-2002 but includes lines released prior to 1990. Using relative yield performance data from nurseries implicitly assumes that actual producer yields are equivalent to test plot yields in CIMMYT experiments. Although the ***absolute*** level of producer yields may be overstated by experimental yield data, the ***relative*** yields between varieties are likely to be similar in both experimental and producer fields. Brennan (1984) reported, "The only reliable sources of relative yields are variety trials" (p. 182).

The present study follows previous evaluations of wheat breeding programs conducted by Traxler et al. (1995) who analyzed ten wheat lines released in Mexico from 1950-1985. Their goal was to analyze if CIMMYT released lines had progressively increased yield, improved yield stability, or both over time. Traxler et al. implemented a Just and Pope (1979) production function which estimates both output and output variance. The Just and Pope production function was chosen due to its ability to account for multiplicative heteroscedasticity. The multiplicative heteroscedastic correction is of importance to this data set because of the variations in both the species (durum, bread wheat, and triticale) and breeding goals across CIMMYT wheat varieties.[3] That is, since CIMMYT varieties are intended to be sown worldwide and are specifically bred for different climatic, physical, and agronomic conditions, the error terms across varieties may be heteroscedastic in nature. By accounting for this multiplicative heteroscedastic error term, comparisons across varieties are more statistically appropriate.

The Just and Pope production function can be described as such:

(1) $$Y_i = f(\mathbf{X}_i, \beta) + g(\mathbf{X}_i, \alpha)\varepsilon_i$$

[3]The goals for breeding a specific wheat variety vary and can target a specific certain climatic conditions (drought tolerance, heat stress, etc.) or target a specific physical attribute (-increased biomass, increased straw, etc.).

where Y_i is yield of the i^{th} variety , the $\mathbf{X}_i$ are explanatory variables, β and α are parameter vectors, and ε_i is a random variable with a mean of zero. The first component of the production function $f(\mathbf{X}_i, \beta)$ relates the explanatory variables to mean output. The function $g(\mathbf{X}_i, \alpha)\varepsilon_i$ relates the explanatory variables to the variance in output. Since the basis of the Just and Pope production function is that the error term on the production function depends on some or all of the explanatory variables, it can thus be viewed as a multiplicative heteroscedasticity model, which is estimated using a three-stage procedure. If variance is an exponential function of *K* explanatory variables, the general model with heteroscedastic errors can be written as:

(2) $$Y_i = X_i^{'}\beta + e_i, \quad i = 1,\ 2, \ldots , N$$

(3) $$\mathrm{E}(e_i^2) = \sigma_i^2 = \exp\left[\mathrm{X_i}'\alpha\right]$$

where $X_i^{'} = (x_{1i}, x_{2i}, \ldots, x_{ki})$ is a row vector of observations on the *K* independent variables. The vector $\alpha = (\alpha_1, \alpha_2, \ldots, \alpha_k)$ is of the dimension (K x 1) and represents the unknown coefficients. $\mathrm{E}(e_i) = 0$ and $\mathrm{E}(e_i e_s) = 0$ for $i \neq s$. Equation (3) can be rewritten as

(4) $$\ln \sigma_i^2 = X_{\mathrm{i}}^{'}\alpha$$

where the σ_i^2 is unknown, but using the least squared residuals from equation (2) the marginal effects of the explanatory variables on the variance of production can be estimated such that:

(5) $$\ln e_i^{*2} = X_i^{'}\alpha^* + u_i$$

where e_i^* is the predicted values of e_i and where the error term is defined as:

(6) $$u_i = \ln\left(\frac{e_i^{*2}}{\sigma_i^2}\right).$$

The predicted values from equation (5) are used as weights for generating generalized least squares (GLS) estimators for the mean output equation (2). That is, the estimates from equation (5) can be viewed as the effects of the independent variables on yield variability. The predicted values from equation (5) are then used as weights when re-estimating equation (2). The results from the re-estimation of equation (2) with the weights from equation (5), give the effects of the independent variables on yield.

In the Just and Pope production function the yield mean was specified as a function of the release year of each variety tested, which can be interpreted as the "vintage" of the wheat breeding technology (Traxler et al. 1995). The year each variety was released to the public captures the progression of wheat breeding technology across time, forming the main variable for measurement and analysis of the impact of the CIMMYT wheat breeding program on wheat yields in performance fields. That is, the coefficient on release year represents the average increase in yield due to genetic gains attributable to the CIMMYT wheat breeding program.

Release year is not a time trend variable but is modeled similar to the way that Arrow's (1962) growth model denoted embodied technology (Traxler et al. 1995). Arrow (1962) assigned "serial numbers" of ordinal magnitude to the embodied technology in capital. In the Just and Pope model the variable the release year, represents the embodied technology for a given year of release by the CIMMYT breeding program. Therefore, the coefficient on release year possesses both a cardinal and ordinal significance in defining the spacing as well as the sequencing of releases (Traxler et al. 1995).

Just and Pope regression results were taken from Nalley et al. (2007) who used the same data set to determine the annual genetic improvements attributed to CIMMYT. The shift in wheat production (J_t), which is equivalent to the coefficient on release year in the Just and Pope model, is the foundation for the analysis of the economic impacts of wheat breeding research.

An important aspect of a breeding program is its cumulative benefits over a specific period. That is, the genetic enhancement received in time period *t* are those observed in *t* plus those seen in *t*-1 as well. Therefore in this data set, the additional genetic benefits for 2002 (J_{2002}) would be the genetic gain from 2001 to 2002 plus the genetic gain from 1990 to 2001 ($J_{\sum_{2001}^{1990} J_t}$). Thus the shift in wheat production in 2002 would be a cumulative shift from 1990 to 2002.

Previous work by Echeverria et al. (1989) also used experimental yields to measure research-induced industry supply curve shifts for rice in Uruguay. Alston et al. (1995) demonstrated how to convert an annual shift in the quantity of wheat produced (J_t) into a percentage shift in cost savings (K_t): the formula is $K_t = J_t/\varepsilon$, where ε is the elasticity of supply of wheat (page 339).

A global analysis for total acres planted to CIMMYT varieties is possible since CIMMYT publishes rough estimates on regional acres planted to CIMMYT varieties. A "precise" measure of the benefits of the CIMMYT breeding program would include all global acres planted to CIMMYT lines. CIMMYT's regional acreage groupings (North Africa, West Asia, etc.) tend to be rough estimates for areas and in most instances are not disaggregated on a county level, making a precise international trade model difficult to implement. Because of this, the current study will only analyze the effects of CIMMYT varieties planted in the Yaqui Valley of Mexico rather than global acres planted to CIMMYT varieties. The reason for this is because of the precision of the data collected within the Yaqui Valley (varieties planted, hectares planted, hectares harvested, hectares planted to CIMMYT varieties, yield, etc.) and the unreliability of the data from outside the Valley.

Since CIMMYT has their principal experiment station in the Yaqui Valley it has a solid working relationship with the local farmers who are willing to exchange information regarding their yields, varieties planted, etc. for modern varieties of wheat bred by CIMMYT. CIMMYT varieties are planted outside of the Yaqui Valley in Mexico as well; however the data for other regions of Mexico is much less reliable. So, this study only includes CIMMYT varieties planted in the Yaqui Valley and excludes non-CIMMYT varieties planted within the Yaqui Valley as well as CIMMYT varieties in other regions of Mexico. In that sense, this study would represent a conservative estimate of the effects of the CIMMYT breeding program on Mexican farmers and consumers because of the exclusion of CIMMYT varieties planted in other regions of Mexico.

Since the Yaqui Valley only accounts for approximately 15-20% of the wheat produced in Mexico and not all of the wheat varieties planted in the Valley are of CIMMYT germplasm, approximately 65-80% are of CIMMYT germplasm, the effects of the CIMMYT breeding program on increasing Mexican yield "(J_t)" needs to be adjusted (CIMMYT, 2007). Therefore, equation (7) is calculated to accurately account for the effects of the CIMMYT breeding program on the Mexican supply curve. This new (J_t') is equal to

(7) $$J_t' = J_t * \Theta_t * \psi_t$$

where (J_t) is the shift in wheat production associated with the use of CIMMYT varieties in percent increase in yield annually.[4] Θ_t is the percentage of Mexico's wheat production that takes place in the Yaqui Valley, and ψ_t is the percentage of the wheat in the Yaqui Valley that is

[4]The Nalley et al. (2007) Just and Pope production results indicated that CIMMYT contributed approximately a

planted to CIMMYT varieties. This new J_t' represents the Mexican shift in wheat supply based solely on increased yields in the Yaqui Valley attributed to CIMMYT's breeding program. From here forward when the model refers to Mexican producers, losses will be experienced by all producers in Mexico, gains however will only be experienced by those farmers who adopted CIMMYT varieties within the Yaqui Valley.

An Economic Model of the Impacts of CIMMYT Wheat-Breeding Research

Edwards and Freebairn (1984) pioneered an economic model to measure the impact of productivity gains from research into a tradable commodity such as wheat. The model was applied to Australian wool research by Alston and Mullen (1992). This simple two-country model of supply and demand is adopted here to estimate the impact of the research-induced supply shift on producer and consumer surpluses in (A) Mexico, and (B) the rest of the world (ROW, defined as all areas outside of Mexico). Alston et al. (1995) reported explicit formulas for the calculation of changes in economic surplus to producers and consumers in two countries, and their model is modified below to the case of CIMMYT wheat research. The supply (Q^s) and demand (Q^d) of wheat in Mexico (denoted by subscript M) and the ROW (denoted by subscript R) are assumed to be linear functions of the world price of wheat (P), as modeled in equations (8) through (12), where k is the percentage downward shift in supply (k = KP, where K is the percent shift in cost savings, J_t/ε, where ε is the elasticity of supply of wheat). Time subscripts have been omitted for notational simplicity.

(8) $$Q^s_M = \alpha_M + \beta_M(P + k)$$

(9) $$Q^d_M = \gamma_M + \delta_M P$$

0.18% increase in yield annually from 1990-2002 to the Yaqui Valley (J_t = 0.0018).

(10) $$Q^s_R = \alpha_R + \beta_R P$$

(11) $$Q^d_R = \gamma_R + \delta_R P$$

(12) $$Q^s_M + Q^s_R = Q^d_M + Q^d_R \text{ (market-clearing).}$$

To simplify, we assume no transportation costs, resulting in a constant price in both regions, and a system of five equations (8 through 12) to solve for five unknowns: P, Q^s_M, Q^s_R, Q^d_M, and Q^d_R. The solution to this system of equations results in the changes in price and quantities of wheat produced and consumed as a result of the supply shift, as in equations (13) and (14):

(13) $$\Delta P = -k\beta_M/(\beta_M + \beta_R - \delta_M - \delta_R) < 0$$

(14) $$\Delta Q^s_M = \beta_M(\Delta P + k); \quad \Delta Q^d_M = \delta_M \Delta P; \quad \Delta Q^s_R = \beta_R \Delta P; \quad \Delta Q^d_R = \delta_R \Delta P.$$

The welfare changes for producers and consumers in Mexico and ROW are given in equations (15) through (19), where PS is producer surplus, CS is consumer surplus, and TS is total surplus:

(15) $$\Delta PS_M = (k + \Delta P)(Q^s_M + 0.5\Delta Q^s_M)$$

(16) $$\Delta CS_M = -\Delta P(Q^d_M + 0.5\Delta Q^d_M)$$

(17) $$\Delta PS_R = \Delta P(Q^s_R + 0.5\Delta Q^s_R)$$

(18) $$\Delta CS_R = -\Delta P(Q^d_R + 0.5\Delta Q^d_r)$$

(19) $$\Delta TS = \Delta PS_M + \Delta CS_M + \Delta PS_R + \Delta CS_R$$

To solve this model, price and quantity data, together with elasticity estimates of supply and demand and a measure of research-induced productivity change (k), are necessary. Using supply and demand estimates from the 2020 IMPACT model (Rosegrant et al., 1995) a supply elasticity of wheat in Mexico (ε_M) of 0.17 was used along with a demand elasticity (η_M) of -0.54. Using individual country estimates from the 2020 IMPACT report a weighted (by production and consumption, respectively) global supply and demand estimate for wheat could be calculated (ε_R =0.13 and η_R = -0.53).[5] The price of wheat (P) is the season average price received by farmers (USDA *Agricultural Outlook*), deflated by the PCE (US Department of Commerce). The quantity of wheat supplied in Mexico (Q^s_M) was taken from FAOSTAT, and the Mexican quantity demanded (Q^d_M) is the number of metric tons for food, feed, and seed (FAOSTATa,b 2007). Wheat production in ROW (Q^s_R) was found by subtracting Mexican production from the world wheat production reported by FAOSTAT (FAOSTATa,b 2007). The market-clearing equation (12) was then used to calculate ROW demand (Q^d_R).

Model Results: Research-Induced Changes in Economic Surplus

The results of the model appear in table 1: Mexican wheat producers gained an average of $1.88 million 2002 dollars per year from 1990 to 2002 by growing wheat varieties developed and released by CIMMYT. Not all producers benefited: only those producers who adopted the high-yielding varieties from CIMMYT earned these higher levels of economic surplus. Consumers of wheat in Mexico on average benefited by $0.004 million per year thorough the breeding efforts at CIMMYT from 1990 to 2002. This relatively small benefit resulted from the relatively small research-induced shift in the world supply of wheat, because Mexico produced only approximately 0.64% of the world's wheat over this time period (FAO 2007a). An even smaller

[5]Given the importance of the magnitude of the wheat supply elasticity in the model, sensitivity analyses were conducted (reported in tables 4 and 5 below) for elasticity estimates ranging from $\varepsilon = 0.075$ to $\varepsilon = 1.0$.

portion, 0.10%, of the worlds wheat is of CIMMYT germplasm and grown in the Yaqui Valley. This fact allows for large gains for producers who adopted CIMMYT varieties in the Yaqui Valley, with only a limited decrease in the world price of wheat.

Wheat producers who resided outside of the Yaqui Valley were made worse off by the decrease in the price of wheat, with an average annual loss of $0.478 million (table 1). Non-Mexican consumers benefited from the research-induced shift in the supply of wheat by an annual average of $0.477 million. The ROW producer losses were approximately equal to the ROW consumer gains. This outcome, together with the relatively large gains to Mexican wheat producers and small Mexican consumer gains, resulted in an annual average change in total economic surplus (ΔTS) of $1.89 million 2002 USD (table 1). These annual benefits were large relative to the annual average costs of the research program of approximately $10.1 million when you account for the ratio of acres of wheat planted to CIMMYT varieties in the Yaqui Valley to the global CIMMYT acres planted. Since CIMMYT does not disaggregate their breeding budget into regions a simple ratio of average CIMMYT acres in the Yaqui to global acres planted to CIMMYT crosses is calculated. From 1990 through 2002 there was an average of 56.56 million acres planted to CIMMYT crosses worldwide compared to an average of just 0.216 million acres of CIMMYT germplasm planted in the Yaqui Valley (Lantican et al. 2005). Thus if it is assumed that the breeding costs are constant globally then the Yaqui Valley only accounts for 0.38% of the total global CIMMYT breeding cost.

The final step in the evaluation of the impacts of the CIMMYT wheat breeding program was to calculate the rate of return to the public investment in the genetic improvement of wheat varieties. Proper measurement of the rate of return requires careful consideration of the timing of varietal development and the discounting procedure. Input from CIMMYT agronomists led to the assumption that 10 years are required to develop a variety from the initial variety cross to the release date (Ammar 2006).[6] Because the nature of the data set, the economic benefits of CIMMYT semidwarf varieties began in 1990, to capture the lag between initially crossing a variety and releasing it costs from the period of 1981 to 2002 were included in the analysis (table 2).

CIMMYT breeds for 12 specific "mega-environments" throughout the world, but does not disaggregate their breeding budget between environments.[7] Mega-environment 1, of which the Yaqui Valley is a part, is the largest mega-environment, accounting for 18.2% of the total world's wheat production (Lantican et al. 2005). Since CIMMYT does not disaggregate breeding costs into specific mega-environments, the following calculations will attribute all breeding costs to mega-environment 1. Thus, the following cost-benefit ratios will be conservative since the costs have been overstated.

The economic benefits (ΔTS) reported in table 1 were used for the period 1990 to 2002. After 2002, the 5-year average benefit level from 1998 to 2002 ($2.215 million) was assumed to decrease at 10% per year, until all research program benefits are depleted in year 2011. Cost and benefit data are reported in table 2.

[6] Interviewed CIMMYT breeders stated that on average there is a 5-year breeding and testing period at CIMMYT followed by a 3 to 4 year testing period at experiment stations within Mexico, such as the Yaqui Valley station. The last step is a 2 year seed production stage before its release. Therefore, from initial breeding to release is estimated at approximately 10 years.

[7] Mega-environment 1 is classified as low latitude (35^o N-35^{o}S), irrigated land, temperate climate, with the major constraints being rust and lodging. It consists of 35% of the wheat production in South and East Asia, 33% in West Asia and North Africa, 28% in South and East Asia, and 7% in Latin America. It accounts for 42.9% of the worlds total durum wheat acres and 16.5% of its total bread wheat acres (Lantican et al. 2005)

The benefit-cost ratio (BCR) is calculated as a measure of gross research benefits:

(20) $$BCR_t = \frac{\sum_t \frac{B_t}{(1+r)^t}}{\sum_t \frac{C_t}{(1+r)^t}}$$

where B_t is the total economic surplus in year t (ΔTS from table 1), C_t are annual program costs, and r is the assumed rate of discount. The BCR_t for CIMMYT wheat varieties, assuming a 10% rate of discount, equals 14.99 (table 4): for each dollar of public funds invested in wheat breeding research, over 14 dollars of benefits result, with over 99% (1.88/1.89) of the benefit received by Mexican wheat producers.

The Net Present Value (NPV_t) of the program is given in equation (21):

(21) $$NPV_t = \Sigma_t[(B_t - C_t)/(1+r)^t],$$

where r is the discount rate. The NPV_t of the program for the period 1981 to 2011, with an assumed discount rate of 10% equals \$6.13 million 2002 USD (table 4).

A third measure of economic performance is the Internal Rate of Return (IRR_t), computed as the discount rate that results in a value of zero for the NPV_t as in equation (22):

(22) $$0 = \Sigma_t[(B_t - C_t)/(1+IRR)^t].$$

The IRR_t for the wheat breeding program equaled 51.5% (table 4). The BCR_t, NPV_t, and IRR_t

provide evidence that the economic rate of return to CIMMYT wheat breeding is high, although assessing these measures further is difficult without comparable values for other public investments (the opportunity cost of funds).

Sensitivity Analysis

The results of the two-region wheat model reported here are contingent upon numerous assumptions, including the selected values for the supply and demand elasticities for Mexico and the ROW, as well as linear demand and supply curves.[8] To determine how robust the model results are to changes in elasticity parameters, a sensitivity analysis was conducted by altering the assumed values of the four elasticities: ε_M, ε_R, η_M, η_R. Table 3 reports the model results for a range of elasticity values for the average annual changes in producer, consumer, and total economic surpluses for the period 1990 to 2002. The model was estimated for both relatively inelastic supply ($\varepsilon = 0.1$) and relatively elastic supply ($\varepsilon = 0.5$) for both Mexico and the ROW.

Changes in the assumed value of the Mexican supply elasticity (ε_M) resulted in large changes in Mexican producer surplus from higher-yielding wheat varieties: inelastic Mexican wheat supply ($\varepsilon_M = 0.1$) resulted in an increase in the annual average producer surplus from 1.886 to 3.20 million 2002 USD. Conversely, when the elasticity of Mexican wheat supply was

[8] Selection of the correct functional form of supply and demand curves in welfare analyses has received a great deal of attention by previous researchers. Alston, Norton, and Pardey summarized this extensive discussion: "It turns out, empirically, that measures of total research benefits and their distribution between producers and consumers are quite insensitive to choices of functional form" (page 63). After summarizing the extensive debate over functional form and the nature of the supply shift (parallel vs. pivotal), Alston, Norton, and Pardey concluded, "Our preference -- in the absence of the information required to choose a particular type of shift -- is to follow Rose's (1980) suggestion and employ a parallel shift… Under this assumption, the functional forms of supply or demand are unimportant" (page 64). Following this line of reasoning, this study assumes a parallel supply shift and linear supply and demand curves.

relatively elastic ($\varepsilon_M = 0.5$), the average annual change in producer surplus decreased from 1.886 to 0.639 million 2002 USD. These large changes in producer surplus arose because only 0.1% of world wheat production occurred in Mexico's Yaqui Valley and were planted to CIMMYT varieties. If Mexican wheat supply is inelastic, an increase in Mexican wheat production results in large savings in costs for Mexican wheat producers, accompanied by a relatively small decrease in the world price of wheat, because the Yaqui Valley is such a small part of the world wheat market. Likewise, if Mexican wheat supply is relatively elastic, then supply increases resulting from enhanced wheat varieties require larger price decreases for the market to clear, causing lower levels of surplus for Mexican wheat producers.

Changes in the value of the ROW supply elasticity only marginally alters Mexican producer surplus, but Mexican consumers, ROW producers, and ROW consumers are affected: a larger elasticity of wheat supply outside of Mexico results in smaller losses for ROW producers and smaller gains for consumers in both Mexico and the ROW.

Demand elasticities also were altered over a broad range of values, from relatively inelastic ($\eta = -0.1$) to relatively (unitary) elastic ($\eta = -1.0$). Because Mexican wheat consumers represent only 0.93% of the world wheat market, the elasticity of Mexican wheat demand (η_M) had an insignificant impact on the model results (table 3). However, the elasticity of demand in the ROW (η_R) did affect ROW producers and all wheat consumers. A relatively elastic ROW demand decreased consumer surplus gains in both Mexico and the ROW but also decreased losses to ROW producers from technological change in Mexico. When world demand is elastic, a supply shift causes a large increase in the quantity of wheat, accompanied by a small decrease in price.

The changes in annual averages of total economic surplus (ΔTS) in table 3 reveal that the model results were affected most strongly by the Mexico's supply elasticity (ε_M). Total economic surplus was not affected by changes in the other supply and demand elasticity values. As a result, further calculations were made of the rate of return to the Mexican wheat breeding program under a range of Mexican supply elasticity (ε_M) and discount rate (r) values (table 4).

The BCRs reported in table 4 demonstrate a range of results under differing assumptions for the Mexico's supply elasticity (ε_M) and discount rate (r). The baseline BCR is 14.99 ($r = 0.10$, $\varepsilon_M = 0.17$). Smaller supply elasticities and lower discount rates increase the total benefits to society resulting from higher-yielding CIMMYT wheat varieties. Similarly, the NPV is centered around 6.130 million 2002 USD ($r = 0.10$, $\varepsilon_M = 0.17$) but ranges from 0.533 ($r = 0.20$, $\varepsilon_M = 0.4$) to 30.728 ($r = 0.05$, $\varepsilon_M = 0.075$) million 2002 USD. The IRR ranged from 0.377 ($\varepsilon_M = 0.4$) to 0.668 ($\varepsilon_M = 0.075$), indicating high social returns to investments in wheat breeding research in CIMMYT.

The results of the sensitivity analysis reported in table 3 are wide-ranging, because the parameter values for the supply elasticities and the discount rate were selected purposefully to cover a broad range of possible values. The baseline parameter values represent the most likely scenario. Therefore, the model estimates presented in table 1 are the "best" estimates. The major conclusion from the model that the economic returns to the CIMMYT wheat-breeding program are high is verified across the entire range of parameter values selected in tables 4 and 5. However, the actual rate of return varied with the selected parameter values for the elasticity of supply and the discount rate.

Conclusions

Results of the two-region economic model of the research-induced wheat supply increase in Mexico provide empirical evidence that the wheat producers who adopt the modern CIMMYT varieties are the major beneficiaries of the technological advance. Mexican consumers are made better off, but by only a small fraction of the value of wheat purchased. A transfer of economic surplus from non-Mexican producers to ROW consumers of approximately 0.47 million (2002) USD occurs annually, because of the decrease in the world price of wheat induced by the enhanced yields of CIMMYT wheat varieties in Mexico's Yaqui Valley.

CIMMYT, a non profit organization, is competing with other non profits for limited public funds. Given the recent relative large increases in maize yields CIMMYT saw its wheat breeding budget cut in half from 1990-2002. The current political climate of decreasing public support has resulted in a situation where the continuation of public funding for wheat-breeding research is dependent on how well the program is serving the public. A common measurement of the effectiveness of a breeding program is a benefit-cost analysis. It was found that from 1990-2002, that CIMMYT had benefit-cost ratio of 14:1, implying that for each dollar of public funds invested that 14 dollars of benefits resulted. The internal rate of return for the same period was found to be 51% which provides evidence that the economic rate of return to the CIMMYT breeding program is high.

One implication for wheat breeders derived from this research is that any decrease in the long development time (10 years) of a variety would result in large economic benefits to society. An example of this is greenhouse breeding, which allows for two generations of winter wheat to be grown in 1 year. The major implication of this research is that more resources could be allocated advantageously to the wheat breeding program. An important tenet of economics is to allocate resources to the highest return. Given the large estimated economic benefits of the CIMMYT wheat-breeding program, an increase in funding is an appropriate use of scarce resources. Although the program has distributional consequences, the economic rate of return to the investment is high.

Table 1. Changes in Economic Surplus from the CIMMYT Wheat Breeding Program, 1990-2002, in 2002 U.S. Dollars.

				Mexico		ROW		
Year	Yaqui Acres Planted to CIMMYT Lines	Global Wheat Price (2002 USD/Ton)	k_t^a	ΔPS_m	ΔCS_m	ΔPS_r	ΔCS_r	ΔTS
1990	290098	220.05	0.90	3,530,220	8,100	-894,053	893,389	3,537,656
1991	199171	138.16	0.35	1,405,239	3,632	-355,865	355,395	1,408,400
1992	214967	152.32	0.45	1,610,933	3,535	-408,689	407,818	1,613,596
1993	214825	153.23	0.47	1,947,361	4,471	-493,669	492,855	1,951,018
1994	188071	138.51	0.32	1,335,836	3,371	-338,561	337,878	1,338,524
1995	191693	157.36	0.41	1,422,352	3,371	-360,897	360,009	1,424,676
1996	156347	236.77	0.61	2,062,743	4,728	-523,651	521,968	2,065,787
1997	198826	205.46	0.68	2,470,354	5,160	-626,919	625,527	2,474,122
1998	207845	156.64	0.57	1,850,327	4,245	-469,718	468,056	1,852,909
1999	217679	128.07	0.58	1,753,804	4,181	-445,228	443,354	1,756,111
2000	301399	113.46	0.59	2,077,828	5,105	-527047	525,102	2,080,988
2001	190861	118.36	0.41	1,331,477	3,336	-337,998	336,550	1,333,366
2002	211722	128.60	0.53	1,725,851	4,413	-437,993	436,074	1,728,345
Mean	214116	157.46	0.53	1,886,486	4,434	-478,484	477,229	1,889,654

[a] $k_t = K_t P_t$, where $K_t = J_t'/\varepsilon$ and P_t is the wheat price.

Table 2. Cost and Benefits of the CIMMYT Wheat Breeding Program, 1981-2011.

Year	Estimated Costs 2002 USD (Global)[a]	Estimated Costs 2002 USD (Yaqui)[b]	Benefits (ΔTS) 2002 USD[c]	Year	Estimated Costs 2002 USD (Global)	Estimated Costs 2002 USD (Yaqui)	Benefits (ΔTS) 2002 USD
1981	13,400,000	49,911	0	1997	9,600,000	35,433	2,474,122
1982	14,200,000	62,791	0	1998	9,600,000	37,407	1,852,909
1983	14,500,000	51,482	0	1999	10,100,000	41,629	1,756,111
1984	14,900,000	45,978	0	2000	7,000,000	40,352	2,080,988
1985	14,600,000	54,333	0	2001	7,000,000	25,814	1,333,366
1986	14,400,000	67,186	0	2002	6,000,000	23,053	1,728,345
1987	13,700,000	42,377	0	2003	0	0	1,575,310
1988	15,000,000	59,226	0	2004	0	0	1,400,275
1989	13,300,000	60,690	0	2005	0	0	1,225,241
1990	13,100,000	62,264	3,537,656	2006	0	0	1,050,206
1991	13,200,000	43,451	1,408,400	2007	0	0	875,172
1992	13,500,000	48,385	1,613,596	2008	0	0	700,138
1993	13,300,000	48,060	1,951,018	2009	0	0	525,103
1994	10,900,000	34,791	1,338,524	2010	0	0	350,069
1995	9,500,000	31,186	1,424,676	2011	0	0	175,034
1996	9,900,000	26,749	2,065,787				

[a]Costs for the period 1981-2002 are the deflated annual program costs of the CIMMYT breeding program.

[b]Since CIMMYT only releases global breeding costs a ratio was used to determine the portion of the global cost associated with the Yaqui Valley. Costs attributed to the Yaqui are calculated as $\text{Global Cost} * \left(\frac{\text{CIMMYT acres in Yaqui}}{\text{Global CIMMYT acres}} \right)$ where global CIMMYT acres are the number of acres in a respective year planted to CIMMYT crosses globally.

[c]Benefits for the period 1990-2002 are the deflated total economic surplus derived from the CIMMYT wheat breeding program (ΔTS in table 1). Program benefits after 2002 are the 5-year average benefit level from 1998 to 2002 ($1.75 million) assumed to decrease at 10 % per year, until all benefits are depleted in year 2012.

Table 3. Sensitivity Analysis of Elasticity Assumptions in World Wheat Model, 1990 to 2002.

Assumed Elasticities				Economic Welfare Results (2002 USD)				
Mexico		ROW		Mexico		ROW		
ε_M	η_M	ε_R	η_R	ΔPS_m	ΔCS_m	ΔPS_R	ΔCS_R	ΔTS
0.17	-0.5	0.12	-0.53	1,886,486	4,435	-478,512	477,257	1,889,654
0.1[a]	-0.5	0.12	-0.53	3,209,244	4,438	-478,842	477,586	3,212,413
0.5[a]	-0.5	0.12	-0.53	639,324	4,420	-476,960	475,709	642,480
0.17	-0.1[a]	0.12	-0.53	1,886,467	4,462	-481,431	480,168	1,889,654
0.17	-1.0[a]	0.12	-0.53	1,886,506	4,406	-475,498	474,251	1,889,654
0.17	-0.5	0.1[a]	-0.53	1,886,341	4,637	-500,399	499,087	1,889,654
0.17	-0.5	0.5[a]	-0.53	1,887,615	2,856	-308,195	307,387	1,889,655
0.17	-0.5	0.12	-0.1[a]	1,880,617	12,642	-1,364,429	1,360,851	1,889,649
0.17	-0.5	0.12	-1.0[a]	1,887,780	2,626	-283,312	282,569	1,889,655

[a] Elasticity values designated with a superscript 'a' differ from the baseline elasticities in the first row

Table 4. Sensitivity Analysis of the Rate of Return to the CIMMYT Wheat Breeding Program.

BENEFIT-COST RATIO (BCR)[a]

Elasticity of Mexican Wheat Supply (ε_M)	Discount Rate 0.05	0.10	0.15	0.20
0.075	49.81	33.99	23.45	16.39
0.1	37.36	25.49	17.59	12.29
0.17	21.98	14.99[b]	10.35	7.23
0.2	18.68	12.75	8.80	6.15
0.4	9.34	6.37	4.40	3.07

NET PRESENT VALUE (NPV) in 2002 USD [c]

Elasticity of Mexican Wheat Supply (ε_M)	Discount Rate 0.05	0.10	0.15	0.20
0.075	30,728,509	14,450,872	7,341,578	3,958,471
0.1	22,888,994	10,728,649	5,424,443	2,904,552
0.17	13,204,886	6,130,609[b]	3,056,217	1,602,653
0.2	11,129,720	5,145,315	2,548,741	1,323,674
0.4	5,250,083	2,353,648	1,110,889	533,235

INTERNAL RATE OF RETURN (IRR) [d]

Elasticity of Mexican Wheat Supply (ε_M)	IRR
0.075	0.668
0.1	0.612
0.17	0.515[b]
0.2	0.486
0.4	0.37

[a]The calculation for the Benefit-Cost Ratio (BCR) is from equation 20.
[b]The values designated by the superscript "b" are the baseline model values.
[c]The calculation for the Net Present Value (NPV) is from equation 21.
[d]The calculation for the Internal Rate of Return (IRR) is from equation 22.

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