The IAEG Crop Germplasm Impacts Study:

A Provisional Report

September 1999

IAEG Foreword

Prof. Robert Evenson and his team of centre and NARS colleagues have managed to bring together a wealth of data and information to address some basic questions regarding the impacts of crop germplasm improvement work in the System. While individual centres have undertaken isolated case studies in the past, this is the first time that a Systemwide perspective is emerging. The IAEG study team, headed by Prof. Evenson, has been able to collect and bring together diverse sets of data to provide the basis for some answers to five fundamental and related questions:

1. What have been the overall investments of IARCs and NARS in crop germplasm improvement (CGI) activities, and what have been the impacts of the IARCs on the levels of NARS investments?
2. What are the varietal release records over time for national programmes?
3. What has been the IARC impacts on CGI and on NARS productivity, as measured by IARC content in released varieties?
4. What have been the impacts of improved crop varieties on farm production at both the farm and the aggregate levels?
5. What have been the economic impacts, given the information brought to light on the crop varietal production impacts (see question 4)?

This report provides a number of provisional answers and preliminary conclusions of Prof. Evenson and his colleagues to the five questions. These form the basis for the overall IAEG assessment activity related to CGI research in the CGIAR. The final conclusions and results of the assessment will be presented at MTM 2000.

Prof. Evenson points out that the growth of investments in the NARS has paralleled that in the Centers. While there is no evidence for direct linkages between the two, Evenson speculates that there is an indirect linkage not only in the countries where NARS programmes were non-existent or where there was little capacity in the 1960s, but also in the more developed country and crop programmes, where, presumably, there were strong interactions between the national and IARC programmes.

Evenson addresses the concern of some that varietal production is subject to diminishing returns and that varietal releases per unit of resources invested are going down. Based on an analysis of the data generated by Evenson and colleagues, the provisional conclusion emerges that the data do not support the contention that strong diminishing returns to varietal production are taking place. There is a continuing high level of NARS and IARC production of improved varieties.

With respect to question 3 above, Evenson concludes that "the direct contribution of IARC programmes (to varietal production) is impressive." Further, he reaches the provisional conclusion that in the 1980s and 1990s the proportion of total varieties produced by IARCs was well above their proportion of total resources invested in such production.

With regard to production impact, the findings are equally important in terms of IARC and NARS content of improved varieties in farmers' fields. Evenson and colleagues look at two sets of figures. First, they look at the percentage of area planted to crop that is planted to "improved" or "modern" varieties; and they find the proportion was low in 1970 (except for wheat in Asia) and grew steadily since then to a point where improved varieties are dominant in most crops.

Second, they looked at the proportion of total area planted to IARC content varieties. While the numbers still are incomplete, they show that "IARC content varieties account for roughly the same proportion of planted acreage in the 1990s that they accounted for in released varieties". Farmers place value on improved varieties that have CGIAR content as well as those that only have non-IARC content improved varieties.

When measuring the actual production impact of adopted varieties, Evenson and colleagues found that, provisionally, the annual varietal improvement total factor productivity gains ranged from 1 to 2 percent per year. The interesting question is how much lower these rates would have been if the IARC system had not been built. To address this question they specified a type of "varietal production function" that permits separation of the impacts of different inputs, in this case IARC and NARS investments. Using data collected in answering the other questions, they calculate that in the case of wheat, if IARC investment had been effectively eliminated, the varietal production would likely have been roughly half of what it was with the IARC investment. In the case of rice, the result is less severe, where the estimated reduction would have been on the order of 35 percent. Using different assumptions with regard to changes in investment, Evenson develops a perspective on the range of reductions that might have been expected.

The final question addressed relates to how the results derived in answering question 4 on impacts on varietal production translate into economic terms. The results of this part of the study are still provisional. However, using a global equilibrium market model available from IFPRI, and dealing first with the 1990-95 South Asian base case for rice, Evenson concludes that 1.24 percent of productivity growth can be attributed to public research, of which approximately 1 percent is due to varietal improvement. Similar calculations were carried out for other areas and crops. Evenson then carries out a "counterfactual" analysis by comparing cases where this varietal component is reduced by 30 and 50 percent to simulate the counterfactual cases where IARC investments had not been made. The results of these simulations for a variety of crops are summarized in the study. The results are interesting. For example, wheat prices would have been 26 and 34 percent higher than under the two sets of counterfactual assumptions mentioned above.

The trade implications of the counterfactual cases are that food imports into developing countries would have been considerably higher. In addition, and supporting the conclusions of the IAEG Panel report on environmental impacts of CGIAR research, there would have been significant implications in terms of negative environmental impacts due to the increased amount of land that would have been cleared.

Evenson concludes that "clearly, the greatest harm is done to consumers in the counterfactuals from price rises. Furthermore, this harm is greatest among the poorer groups because the poor spend a higher proportion of their income on food." While Evenson and colleagues recognize that these simulations require further refinement and calibration, the provisional conclusion is that the IARC investments have made important economic contributions to both poor farmers and to poor consumers. For example, Evenson estimates that "between 1.5 and 2 percent fewer children in developing countries are malnourished than would have been the case without IARC investment."

It is concluded that the impact of CGIAR investment in germplasm improvement has been large, partly because of high "leverage" through IARC-NARS joint production.

The IAEG congratulates Prof. Evenson and his colleagues for the important results and insights that they are bringing forth on the impacts of crop germplasm improvement work in the CGIAR. The IAEG also thanks the CGIAR Centres participating in this study for their efforts and commitment. The final results of this broad set of assessment activities will provide significant information for use by the Group, by TAC and by others who are interested in the value and impacts of agricultural research.

Hans Gregersen
Chair
CGIAR Impact Assessment and Evaluation Group (IAEG)

September 1999

The IAEG Crop Germplasm Impacts Study:
A Provisional Report

R.E. Evenson
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The Impact Assessment and Evaluation Group (IAEG) of the Consultative Group for International Agricultural Research (CGIAR) is undertaking a study of crop germplasm impacts. This study covers ten crops for which both International Agricultural Research Center (IARC) and National Agricultural Research System (NARS) germplasm improvement programs have been in place in recent decades. Germplasm improvement is defined to include plant breeding activities including selection and field testing and pre-breeding activities including the collection, management and distribution of genetic resources, and the evaluation of genetic resources for potential plant breeding value. This evaluation thus encompasses genetic resource collection activities of both IARCs and NARS and the international nursery programs of IARCs as well as plant breeding programs.

This report is a provisional draft of the Centers-Wide report of the project. The final report will be presented in May 2000.

Coverage-Collaborators

The crops covered by the study and the associated IARC collaborators are:

Rice-Asia - IRRI (M. Hossain, D. Gollin)
Rice-Latin America - CIAT (N. Johnson, D. Pachico)
Rice-Africa - WARDA (T. Dalton)
Wheat - CIMMYT (P. Heisey, P. Pingali)
Maize-Latin America - CIMMYT (M. Morris)
Maize-South and West Africa - IITA (V. Manyong)
Sorghum - ICRISAT (C. Bantilan, U. Deb)
Pearl Millet - ICRISAT (C. Bantilan, U. Deb)
Barley – ICARDA (A. Aw-Hassan)
Beans - CIAT (N. Johnson, D. Pachicho)
Lentils - ICARDA (A. Aw-Hassan)
Potato - CIP (T. Walker)

In addition three country studies have been commissioned:

India (J. McKinsey, Bryant College, P. Kumar, IARI)
Brazil (A. F. Avila - EMBRAPA)

China (J. Huang, R. Hu – CAAS, S. Rozelle - UC Davis)

Each IARC collaborator has undertaken basic data collection and analysis, and study reports will be forthcoming from each. The country studies are intended to complement study objective 5 (see below) the estimation of production impacts. Country study reports will also be included in the final study report.

Study Objectives

Study objectives were developed reflecting past policies of emphasis on crop germplasm improvement (measured by crop varietal improvement) as the "core" of the research effort in both IARCs and NARS over recent decades. The study seeks to evaluate both IARC and NARS program impacts, recognizing that many improved crop varieties are the joint product of IARC and NARS programs. Study objectives also reflect the mechanisms by which IARC programs contribute to NARS programs.

IARC programs can contribute to crop production <u>directly</u> by developing improved crop varieties (that are then tested and released by NARS programs) or <u>indirectly</u> by providing genetic resources (often via international nurseries) and associated testing and evaluation to NARS programs. Thus IARCs can stimulate more (or less) NARS investments in crop germplasm improvement and they can also affect the production and productivity of NARS researchers through the provision of genetic resources and associated testing and evaluation services.

<u>Study Objective 1</u>

To document IARC and NARS crop germplasm investments and to assess the impacts of IARC activities on NARS investments.

<u>Study Objective 2</u>

To document the record of crop germplasm improvement in the form of crop varieties released in national programs.

<u>Study Objective 3</u>

To evaluate the direct and indirect IARC impacts on crop genetic improvement and on NARS productivity. This will entail developing indexes of IARC content in released varieties.

<u>Study Objective 4</u>

To estimate the impacts of improved crop varieties on farm production, at both the farm and aggregate level. A secondary objective is to determine whether IARC content affects varietal impact.

<u>Study Objective 5</u>

To develop economic impact estimates based on the crop varietal production impacts (objective 4). Economic impacts are impacts on consumer income and welfare and impacts on farm producer income and welfare. Because crop markets are international, these economic impacts are international. This objective thus requires international “general equilibrium” model “counterfactual” simulations.

Provisional Findings: Study Objective 1, Investments in Crop Genetic Improvement (CGI)

Study collaborators collected data on IARC investments in crop genetic improvement activities over the period of IARC existence. In addition a survey of NARS investments in the late 1990s was made. Some data for NARS investments in earlier years were available and further data collection is underway.

Partial data available at this time are summarized in Table 1. These data will be useful to inform study objective 3 where indirect IARC impacts on NARS are estimated.

Table 1 makes the following points.

1. IARC programs were initiated in different periods. They also differed in the time required to reach full strength.
2. Most IARC programs reached full strength by the early 1980s from an investment perspective. Full strength from a productivity perspective was generally reached later. IARC programs have not been further strengthened from an investment perspective in the 1990s.
3. NARS programs varied greatly in strength in the 1960s. For many countries, particularly in Sub-Saharan Africa, little real investment had been made. For some crops in all developing countries little research capacity existed in the 1960s.
4. NARS programs have been strengthened in most countries and for most crops since the 1960s. For countries where research capacity existed in the 1960s, the major period of strengthening occurred in the 1970s. By the end of the 1980s, a number of these countries had ceased expansion and strengthening and many were undertaking reform programs.
5. NARS programs for crops where 1960s’ programs were in existence were also strengthened, again with major strengthening in the 1970s.
6. NARS programs for crops with little capacity in the 1960s were effectively initiated in the 1970s and 1980s. The initiation and strengthening of these programs continues into the 1990s.
7. For maize, sorghum and pearl millet, private sector research based on hybrid seed programs have grown rapidly in the 1990s.

Later work (also see Objective 3) will attempt to statistically confirm the following provisional conjectures regarding indirect IARC impacts on NARS investments.

a) For the more developed country and crop programs with capacity in the 1960s, virtually all were strengthened in the 1970s and 1980s after, and presumably to some degree in response to, the establishment and strengthening of IARC programs.
b) NARS country programs with little capacity in the 1960s initiated strengthened programs (with international support) and further strengthened them in the 1980s and 1990s. This is

also likely to have been in response to IARC program development. IARC programs effectively supplied much of the genetic raw material on which these programs were based.

Provisional Findings: Objective 2, Varietal Production

To pursue objective 2, IARC collaborators undertook surveys of NARS programs and in the case of maize, sorghum and pearl millet, of private breeding companies as well. The evidence for private firms' varietal production is less complete than for public NARS. Table 2 summarizes data from IARC studies for the study crops by 5-year period from 1965 to 1998. In some cases data for 1995 to 1998 are incomplete. The data are in the form of annual released varieties by NARS and private firms. While some IARCs released varieties in early periods, recent practice has been for NARS releases even when the variety was crossed in an IARC. All varieties are treated as releases by NARS.

These data allow an assessment as to how the rate of varietal development has changed over time. There is a concern that varietal production is subject to diminishing returns and that varietal releases per unit of resources invested (or releases relative to the stock of varietal production capability) has declined over the past decade or so.

Table 2 indicates that varietal production rises into the late 1990s in every crop category except for rice in Asia, wheat in Latin America, cassava in Africa and potatoes, in all regions. For these crop categories a leveling off in the late 1980s and early 1990s is evident. There are no cases of significant decline in the 1990s.

It may also be noted that private sector varietal production of hybrid varieties is of growing importance in maize and this is also the case in sorghum and pearl millet.

For most crops we observe varietal production rates that vary with the timing of NARS investments. Leveling off of varietal production occurs later than leveling off of investments. These data, thus, do not support the contention (at least not strongly) that strong diminishing returns to varietal production associated with "exhaustion" or "fishing out" of the "pools" of potential varieties is taking place. There is little evidence that varietal release standards have changed over time, although it may be the case that the production impact of recently released varieties is less then that of earlier releases (see Objective 4 where it is suggested that this is probably not the case). The continued high level of NARS and IARC production of improved varieties appears to be the result of improved access to genetic resources in NARS and the cumulation of traits and landrace content in more recently released varieties. (See Objective 4 for a further discussion.)

Provisional Findings: Objective 3, IARC Content and Direct and Indirect IARC Impacts on Varietal Production

Table 3 reports data on IARC content in released varieties for the 1970s, 1980s and 1990s. These content indexes can provide some insight into both the direct contributions of IARCs to varietal production and on the indirect effects, which as suggested above may have contributed to the increasing (or at least not decreasing) rate of varietal production.

First consider the direct production of varieties by IARCs as measured by the proportion of varieties where the cross (and usually the selection) was made in an IARC program. These proportions can first be compared with expenditure and scientist proportions. As Table 1 indicated the proportion of IARC scientist years to total IARS plus NARS scientist years is generally below 5 percent and the proportion of IARC expenditures is generally below 10 percent. The direct contribution of IARC programs is impressive. In the 1980s and 1990s when these programs were at full strength they were producing proportions of varieties that were well above their scientist and investment proportions (except in Asian rice where parent contributions were high). In a number of crops IARC programs were continuing to contribute more than half of all improved released varieties into the 1990s. This was generally true in the 1970s as well, although a number of IARC (and NARS) programs were not at full strength at that time.

The direct contributions of IARCs, however, do not fully account for the non-decreasing varietal production indicated in Table 2 because direct shares while high are not necessarily increasing. NARS production has generally also been increasing or at least non-decreasing.

Table 3 also notes that indirect IARC contributions through the contribution of parents have been important. In the 1990s these joint IARC-NARS products accounted for a significant proportion of varietal production in most crops. The Asian rice pattern of declining direct proportion and rising parent proportions is a sign of healthy institutional development. With the growth of strong NARS programs IARCs became predominantly germplasm suppliers (through parents) and facilitators of germplasm exchange through nursery networks and other forms of technical assistance.

While the Asian rice pattern does not appear to have yet emerged in other crop programs it can be seen as a model of healthy IARC-NARS germplasm improvement in the future. This model is relevant to IARC-Private sector relationship's as well as indicated by the maize data where IARC parents are of great importance in private sector hybrid production (further reports will show this to be case in sorghum and pearl millet as well).

The Asian rice model also offers an explanation for the continued productivity of NARS programs.

Provisional Findings: Study Objective 4, Measuring Production Impacts of Improved Varieties

If improved crop varieties are to have a production impact they must first be adopted by farmers. If IARC content is important, IARC content varieties must be adopted by farmers. The study collected data regarding varietal adoption. These data are summarized in Table 4 (incomplete at present but further data are being collected).

The first indicator reported in Table 4 is the percentage of area planted to the crop that is planted to "improved" or "modern" crop varieties in developing regions. The second indicator (in parentheses) is the proportion of total area planted to IARC content varieties.

The proportion of area planted to improved varieties was low in 1970 (except for wheat in Asia where early "green revolution" varieties were already adopted). This proportion has grown steadily in all crops and in the 1990s improved varieties are dominant in most crops. The second indicator, while incomplete, shows that IARC content varieties account for roughly the same proportion of planted acreage in the 1990s that they accounted for in released varieties. Those data show that farmers have placed value on improved varieties because they have adopted these varieties. They have considered IARC-content varieties to be roughly as valuable as or more valuable than non-IARC-content improved varieties.

The next step in objective 4 is to actually measure the production impact of adopted varieties. This was approached in two ways. First, IARC collaborators are preparing syntheses of IARC studies addressing this issue. Second, the three country studies addressed this issue. Provisional estimates from the country studies are reported in Table 5. The country studies commissioned as part of this evaluation study addressed two important problems that have not been effectively addressed in prior studies. The first problem is the specification of varietal and non-varietal sources of productivity change. The second problem is the " endogeneity" of varietal diffusion indicators.

The first problem requires the development of variables in a statistical specification measuring varietal and non-varietal " service flows". Past studies have used a "percent modern varieties" variable based on past investments or research time data with time lag and depreciation weights and spatial spill-in weights. (See Evenson, 1999, for a review). This variable is used to represent research services. The coefficient on this variable (holding constant the varietal services variable) is then interpreted as representing non-varietal contributions. This practice is subject to the problem that varietal improvement may not be well measured by the percent modern varieties variable. It is possible that the continuous flow of new varieties produces improved productivity without changing the percent modern variety variable. Recently released modern varieties replace earlier modern varieties and this can have a significant productivity effect.

To remedy this, the country studies have attempted to develop "varietal turnover" variables. The varietal turnover measure is defined as the sum of positive varietal acreage share changes from one period to the next. In the Indian study both "percent modern varieties" and varietal turnover variables were used. The problem of endogeneity of adopted area is dealt with by treating the percent modern variety or variable turnover as an endogenous variable.

In the Indian study the endogenous variables are the four dependent variables, Area, % HYV, %IRR (Irrigation) and Yield. Exogenous variables include research studies (public and private), extension, markets, prices and climate and soil variables. The India study used district data for the 1959-94 period to estimate the model. The Brazil study estimated a similar model (without the irrigation variable). For China, it was possible to estimate a crop total factor productivity (TFP) equation, reducing the China model to 2 equations for TFP and varietal turnover (TFP data are available for India and Brazil also) and will be utilized in further estimation.

From the estimated coefficients in these models one can calculate the increased production per hectare that is associated with a change in varieties planted. Table 5 reports calculations based on statistically significant estimates for different commodities. Table 5 reports the estimated increase in production per hectare for a complete replacement of traditional varieties by modern varieties in the India study. These estimates range from 40 percent for rice to 100 percent for sorghum. Note that Table 4 shows that HYV adoption rates have not increased as yet to 100 percent.

The second set of estimates is for the varietal turnover variable for Brazil and China. The reported estimates are for a 100 percent varietal turnover. In Brazil varietal turnover for rice and maize was roughly 250 percent over the 1970-1996 period. For China it was similar. Thus the two sets of estimates are actually consistent in their implications.

When the estimates in Table 5 are combined with the varietal turnover and modern varieties adoption levels, the annual varietal improvement TFP gains noted in Table 5 are obtained. These range from 1 percent per year to 2 percent per year. Actual TFP rate gains range from over 2 percent for rice (see Table), wheat and maize to 1 1/2 percent or so for other crops. It appears then that varietal gains account for approximately 1/2 to 2/3 of real productivity gains in these crops.

The study is interested in the question: how much lower would these rates of productivity gains be if the IARC system had not been built? (Alternative questions could be based on partial support for IARCs)

To approach this question in a meaningful way it is necessary to specify a type of “varietal production function” incorporating IARC and NARS resources. This will enable a calculation of reduced varietal production due to reduced IARC contribution. This, in turn, can be associated with reduced productivity effects.

Consider a “Cobb-Douglas” type varietal production function where varietal production (V) is a function of both NARS investment (N) and IARC investments (I).

$$V = A\, N^{\alpha}\, I^{\beta}$$

Estimates of N and I can be obtained from Table 1. V is available from Table 2.Estimates of α and β are implicit in Tables 3 and 4. Note that α and β are production elasticities- i.e. they measure the percent increase in V from a given percent increase in N and I. Table 3 shows the percentage shares of IARC content in terms of IARC crosses and IARC parents. These shares can be considered to be approximations for α and β.

Consider the case for wheat. Data from Table 1 indicate that in 1990
N, NARS investments were 79 million dollars,
I, IARC investments were 10 million dollars.

Table 2 indicates that V, varietal production in the 1990s was roughly 64. Table 3 indicates that
the IARC cross share was approximately 0.5
the IARC parent share was approximately 0.2

This suggests a very high β for wheat, approximately 0.5 +1/2.2 or 0.6 . This implies that α is 0.4 . Using these shares we can calibrate to find the constant A. This gives:

$$64 = 2.8\ (79)^{0.4}\ (10)^{0.6}$$

Now suppose that the IARC investment was effectively eliminated . This would have two effects.

a) It would reduce N if there were a loss of stimulus to NARS investments. Suppose this reduced N to 70.

b) It would reduce, but not eliminate I. The absence of an IARC would mean that some of the NARS resources would be devoted to international activities. This is because it is in their interest to facilitate international spill-in. Suppose that international investment of 10 million dollars were eliminated and that 4 million of the NARS investment was directed to international activities. For N=66 and I=4 the varietal production function implies varietal production of 34 instead of 64, a reduction of roughly one half.

$$34 = 2.8\ (66)^{0.4}\ (4)^{0.6}$$

For rice the calculation is less severe. For rice in Asia, N is approximately 100, I is approximately 15 , β is approximately 0.3 and α is approximately 0.7. V is 50 so with calibration A is 0.88

$$50 = 0.88\ (100)^{0.7}\ (15)^{0.3}$$

Reducing N to 85 and I to 5 implies that V will be 34 ($34 = 0.88\ (85)^{0.7}\ (15)^{0.3}$) a reduction of 35 percent.

$$34 = 0.88\ (85)^{0.7}\ (15)^{0.3}$$

These two cases probably bound the cases for other crops. This implies that had the IARCs not been established but that international aid been sufficient to build NARS to within 10 percent of their late 1990s levels, varietal production would have been 35 to 50 percent lower.

Had the absence of IARC investment not led to reduced NARS investment, the calculations show that wheat varietal production would have been 40 percent lower and rice varietal production would have been 30 percent lower.

Provisional Findings: Objective 5, Economic Effects

How does the calculation made in the previous section translate into economic terms? Basic economic logic indicates that with lower rates of productivity growth, farm production costs will be higher and lower quantities of crops will be produced in developing countries. Note that developed country production would not be affected in a major way because of IARC investment policy. This would result in higher prices, not just in one country but in all or most countries because IARC investment affects many countries and because most crop markets are globalized with increased trade.

Thus to calculate economic impacts an international or global equilibrium market model is required. Fortunately, such a model is available from the International Food Policy Research

Institute (The IFPRI-IMPACT model). This model calculates equilibrium prices, production and consumption quantities, trade and welfare effects measured in terms of malnourished children. (See Agcoili et al, and Evenson and Rosegrant for details of the model.)

The productivity improvements in the IFPRI-IMPACT model include contributions from a number of sources as shown in Table 6 for the South Asian base case for rice. This table shows projections for future periods, but the model can be used to project backwards as well.

Consider the 1995-00 base case. This case attributes 1.237 percent growth to public research, of this 1.02 percent is due to varietal improvement. (This agrees with the calculations in Table 5). It is possible to compare cases where this varietal component is reduced by 30 percent and by 50 percent to simulate " counterfactual" cases where IARC investments had not been made (It is also possible to simulate future effects if IARC investments were to cease.) These simulations are summarized in Table 7. Two counterfactual simulations are reported: one based on the rice case without NARS reduction, implying a 30 percent reduction in varietal production; the second on the wheat case with NARS reduction implying 50 percent reduction in varietal production.

First consider the price effects. These are expressed relative to the base case simulation and thus compare the difference between equilibrium prices cumulated over a 25-year period under the two counterfactual cases. This shows that wheat prices would have been 26 percent or 34 percent higher under the two counterfactuals than they actually were. The price counterfactuals differ by commodity, because both supply and demand conditions vary.

The IFPRI-IMPACT model has relatively low demand elasticities because it is a global market model. These low elasticities indicate that price changes are larger in magnitude than cost changes. In the counterfactuals simulated in Table 7, the price increases for counterfactual 1 are roughly 1.5 to 2 times the implicit rises in cost of production from the reduction of varietal production. This implies that producers in developed countries would benefit from this counterfactual because their costs should not be affected very much. Producers in developing countries might also benefit from these counterfactuals because prices would rise by as much or more than costs would rise.

The trade implications of the counterfactuals are that food imports in developing countries would increase by 9 percent or so. This reflects the differential advantage that the counterfactual confers to developed countries relative to developing countries.

There are two groups that would be harmed by these counterfactual simulations. The first is the environmentalist community. The simulations show that area planted to crops would be significantly higher if IARC investments had not been made. This would create more pressure on biodiversity habitats and on fragile land problems, particularly as these would be marginal lands in many cases.

Clearly, consumers would experience the greatest harm in the counterfactuals from the price rises. This harm is done to consumers in both developed and developing countries. Furthermore, this harm is greatest among the poorer groups in each economy because the poor spend a higher fraction of their income on food. In addition, this harm is also greatest in poor economies because most food is consumed in non-processed form (often on the farm where it is produced), thus the price effect is greater than in an economy where the farm value of food is low relative to the consumer value (i.e. where high levels of processing takes place).

These simulations require further refinement and calibration. Simulations for individual crops can be made, for example.

Two points regarding these simulations should be made. The first is that the counterfactuals have a reverse side. The investments in IARC germplasm improvement have produced lower food prices and massive gains to consumers. These gains can be seen in Table 7 where effects on the percent of children who are malnourished are simulated. Because of IARC programs, between 1.5 and 2 percent fewer children in developing countries are malnourished than would have been the case without IARC investment. For India this is between 2 and 3 percent and this literally translates into millions of children.

The second point is that the finding that consumers are the largest beneficiaries of IARC program, while possibly overstated because of the low price elasticities in the IFPRI-IMPACT model (these hold globally, not locally), is nonetheless consistent with economic logic and with a large number of empirical studies. Consumers do benefit most and poor consumers benefit most of all. Farmers are consumers too and for the world's smallest farm producers the total producer and consumer gains are large. These findings are provisional. Further study is underway. More data will be available at the end of the project. Refined estimates of varietal product effect will be made. The economic contributions will be evaluated further and sensitivity experiments continued.

The provisional findings do provide support for the proposition that IARC investments have actually had impacts in all of the study crops. These impacts have been large, partly because of high "leverage" through IARC-NARS joint production. The placing of crop germplasm improvement at the core of IARC programs appears to have very strong justification.