Returns to Wheat Breeding in Nepal: The Case of a Small Country with Research Spillovers

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Abstract

Returns to investment in wheat research in Nepal during the Green Revolution period (1960-1990) ranged from 75-84%. Benefits of the Nepali wheat breeding program included maintenance of disease resistance and faster dissemination of exotic varieties. Attractive rates of return were due in part to Nepal's ability to capture spillover benefits from neighboring countries.

Introduction

During the late 1960s and early 1970s, improved high-yielding wheats developed in Mexico (referred to in this paper as modern varieties, or MVs) were introduced into a number of the world's most populous developing countries. The highly visible production increases associated with their introduction for many years ensured a steady flow of resources to national wheat breeding programs. But this situation changed beginning in the late 1980s, when a combination of economic and political factors reduced the availability of public-sector funding for agricultural research. As research budgets ceased expanding in real terms, policy makers found themselves forced to pay greater attention to the ways in which research resources were being used.

One country in which there is a need carefully to assess the returns to wheat research is Nepal. Even though agriculture represents the predominant sector in Nepal's economy, the overall level of public-sector support to agricultural research remains relatively low, averaging only 0.08% of agricultural GDP during the past two decades, as compared to 0.41% for a group of 92 developing countries (Pardey, Roseboom, and Anderson). Because Nepal's limited research resources are used to support a wide range of research activities, there is a need to ensure that funds invested in the National Wheat Research Program (NWRP) generate attractive returns compared to alternative investment opportunities.

Nepal makes a particularly interesting case study because of its physical proximity to India, whose national wheat program is one of the largest in the world. Staffed by approximately 450 scientists, the Indian wheat program generates a steady stream of improved varieties, many of which are well adapted to production conditions in Nepal. Because Nepali farmers are well served by Indian varieties, which contain germplasm from a wide range of sources, the question arises whether it makes sense for Nepal to support a wheat breeding program of its own. Formal analysis of the economic returns to Nepal's past investment in wheat breeding, taking into account spillover benefits from India, can help provide policy makers with the information needed to make decisions regarding the appropriate level of future support.

Analyzing returns to research: Conceptual issues

The rate of return to investment in agricultural research is frequently calculated using the economic surplus approach, which posits that an outward (downward) shift in the supply function attributable to technological change leads to an increase in the economic surplus accruing to producers and/or consumers.[1] Although early work using the economic surplus approach was based on simplistic assumptions about the supply and demand functions, over time the procedures used in evaluating the returns to research have been refined substantially.[2] Subsequent extensions of the conceptual framework have made clear that the size and distribution among producers and consumers of the increase in economic surplus depends upon the shapes of the supply and demand curves, as well as the nature of the supply curve shift (parallel, pivotal, or convergent) resulting from technological change (Voon and Edwards). Government price policies have also been shown to be important in determining the distribution of benefits (Alston, Freebairn, and Edwards).

Application to a plant breeding program

Following Brennan and Byerlee, the economic surplus approach can be adapted to a plant breeding program. First, the benefits of the breeding program are estimated as follows:

$$B_t = g\, Y_t\, A_t\, W_t$$

where:
- B = benefits from the breeding program
- g = percentage yield gain per period due to the breeding program
- Y = yield
- A = area affected by the breeding program
- W = price of the commodity
- t = period.

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1 For useful reviews of the literature on evaluating returns to investment in agricultural research, see Schuh and Tollini, Scobie, Norton and Davis.

2 Progressive refinements of the basic method appear in Griliches, Peterson, Schmitz and Seckler, Fishel, Akino and Hayami, Hayami and Herdt, Lindner and Jarrett, Rose, Wise and Fell, and Norton and Davis.

Next, the internal rate of return to the research investment is calculated as the value which drives the discounted stream of costs and benefits to 0:

$$\sum \quad [(B_t - C_t) \; / \; (1 + IRR)^t] \; = \; 0$$

where IRR = the internal rate of return, B = benefits from the breeding program, and C = cost of the breeding program.

This simplified approach, which uses the change in the value of wheat production attributable to research as an approximation of the change in economic surplus, has two underlying restrictive assumptions. First, it is equivalent to assuming a perfectly elastic demand function for wheat, so that research-induced shifts in the supply function do not result in endogenous price changes. For a tradeable commodity in an open economy, this is a reasonable assumption. Second, it is equivalent to assuming a perfectly inelastic supply function for wheat, so that an outward (implicitly parallel) shift in the supply function is directly translated into a proportional increase in the value of production. While this second assumption is admittedly somewhat simplistic, it probably does not greatly distort the estimated benefits of wheat research in Nepal, since the supply function for wheat presumably is fairly inelastic given Nepal's intensive cropping systems (which limit farmers' ability to increase wheat production in response to price incentives).

Most previous applications of the economic surplus approach to wheat breeding have estimated research benefits as the product of the yield gains attributable to adoption of MVs times the area planted (for example, see Norton et al., Nagy, Byerlee). However, in the case of the Nepal, this conventional approach is inadequate. To understand why this is so, it is useful briefly to review the history of wheat in Nepal.

The special circumstances of wheat in Nepal

Up until the mid-1960s, wheat was a relatively minor crop in Nepal, grown primarily to provide grain for home consumption and straw for animal feed. Most of the varieties used were tall-statured Indian varieties, along with local land races. Area planted to wheat fluctuated around 100,000 ha, and yields were low. This relatively stable situation changed dramatically with the introduction of early-maturing MVs, which enabled Nepali farmers to switch from their traditional rice-fallow rotation to an intensive production system in which rice and wheat were double-cropped within the same year. As a result, wheat area began to increase rapidly, rising to nearly 600,000 ha by 1990.

Three MVs in particular are associated with the Green Revolution in wheat in Nepal. Lerma Rojo 64, the first MV grown on a large scale, was introduced from Mexico in the mid-1960s and soon spread to occupy an estimated 70% of total wheat area. Beginning in the late 1960s, Lerma Rojo 64 was replaced by another early-maturing semidwarf, RR 21, which had been selected by Indian wheat breeders from a Mexican cross. Although RR 21 initially did not outyield Lerma Rojo 64, farmers preferred RR 21 because of its superior grain quality and white color. By the late 1970s, however, RR 21 had become susceptible to foliar diseases, and farmers began to replace it with UP 262, a more resistant variety developed by the Indian breeding program.

Calculating the returns to wheat breeding in Nepal is complicated by two unusual features of the Green Revolution in Nepal. First, at the time of their release, none of the MVs associated with the Green Revolution in Nepal significantly outyielded the varieties farmers were currently growing. Lerma Rojo 64, RR 21, and UP 262 were originally adopted by farmers for reasons other than yield potential; only later, when older materials became susceptible to foliar diseases and suffered yield declines, did a yield advantage emerge. Second, the MVs which revolutionized wheat production in Nepal probably would have been adopted eventually even had there been no national wheat program. Because Nepal's principal wheat-growing area is contiguous with a climatically similar wheat-growing belt in Uttar Pradesh state of India, and because many Nepali farmers have frequent contacts with Indian farmers (often they are related), wheat seed regularly crosses the border. Thus, even if the NWRP had not been active in evaluating, releasing, and promoting Mexican and Indian materials, many of these materials probably would have entered Nepal anyway through farmer-to-farmer seed exchanges along the India-Nepal border.

Estimating key parameters

Because of these unusual features of the Green Revolution in Nepal, it was necessary to devise unconventional methods for estimating two key parameters required by the economic surplus approach: 1) yield gains attributable to wheat breeding, and 2) area affected by wheat research.

1) Yield gains attributable to wheat breeding

Because the MVs associated with the Green Revolution in Nepal did not significantly outyield farmers' current varieties at the time of their release, genetic gains due to breeding cannot be calculated using the conventional "vintage model" approach, which assumes that successive generations of MVs are characterized by ever-increasing yield potential. Instead, genetic gains realized as a result of MV adoption must be estimated as *yield losses foregone,* under the assumption that yields in farmers' fields would have declined as a result of increasing disease pressure had the older susceptible varieties not been replaced (Figure 1). This assumption is consistent with current reality in wheat breeding, as many national breeding programs now allocate the majority of their resources to maintenance breeding (i.e., breeding designed to maintain current yield levels in the face of increasing disease pressure).

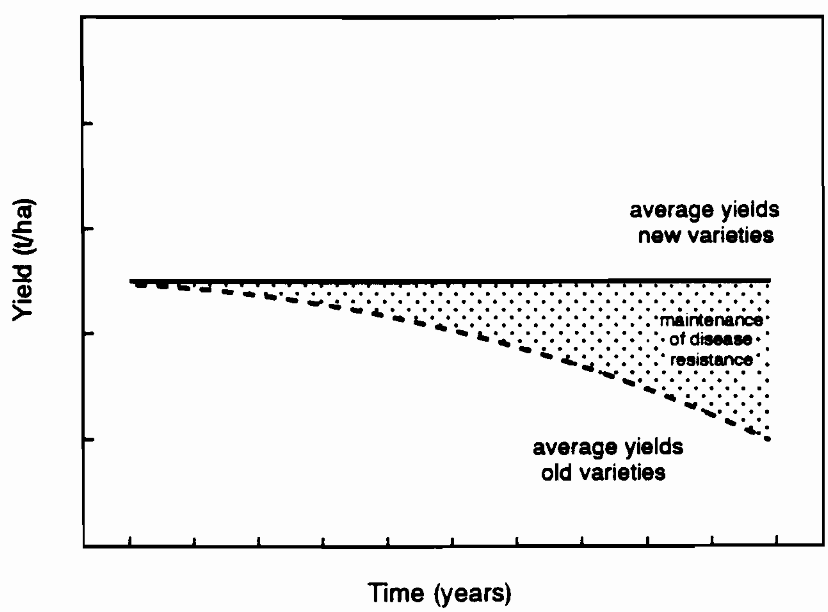

Figure 1. Genetic gains (yield losses foregone) in Nepali wheat varieties attributable to improved disease resistance.

The yield losses foregone in Nepal because of varietal replacement (specifically, replacement of RR 21 by UP 262; Lerma Rojo 64 was dropped from NWRP varietal trials in the late 1960s because it had largely disappeared from farmers' fields) were estimated using 15 years of trial data from six agricultural research stations. The following function was estimated using OLS regression techniques:

$$\ln Y_{ijt} = \alpha + \beta T_t + \delta D_i + \gamma D_i T_t + \sum \mu_j S_j + \upsilon$$

where Y = yield of variety i (RR 21 or UP 262), T = time trend, D = intercept-shifting dummy variable on variety UP 262, D T = slope-shifting dummy variable on variety UP 262, S = dummy variables for sites j, and υ = error term.

The following results were obtained (standard errors in parentheses):

$$\ln (Y_{it}) = \underset{(0.094)^a}{8.48} - \underset{(0.008)^a}{0.068\, T_t} - \underset{(0.116)}{0.169\, D_i} + \underset{(0.011)^b}{0.025\, D_i T_t}$$

$$- \underset{(0.080)^c}{0.02\, S_1} - \underset{(0.087)^c}{0.16\, S_2} - \underset{(0.080)^c}{0.01\, S_3} + \underset{(0.081)^c}{0.05\, S_4} + \underset{(0.080)^c}{0.11\, S_5}$$

$n = 444$ $R^2 = 0.48$ $F = 16.92^a$

a = significant at level 0.01
b = significant at level 0.05
c = F ratio for group of S_j dummy variables significant at level 0.01

These results are noteworthy in several respects. First, the coefficient on the time trend (T) is negative and highly significant, indicating that over the past 15 years, yields of RR 21 declined at an average annual rate of 6.8%. This striking rate of decline appears to be due to increasing leaf rust and *Helminthosporium* leaf blight susceptibility, as well as crop and resource management problems on the research farms where the trials were conducted. Second, the coefficient on the intercept-shifting dummy variable (D) is not significantly different from zero. This confirms that at the time of its introduction, UP 262 offered no significant yield advantage compared to RR 21. Third, the coefficient on the slope-shifting multiplicative dummy variable (D T) is positive and significant, indicating that over the past 15 years yields of UP 262 have declined approximately 2.5% per year more slowly than yields of RR 21. Since the two varieties received identical management in the experiment-station trials from which the yield data were drawn, the only explanation for the faster rate of yield decline of RR 21 is its higher level of susceptibility to foliar pathogens.

2) Area affected by wheat research

Under the economic surplus approach, the area affected by a plant breeding program can be measured either indirectly (in the form of a shift in the supply curve, which implicitly reflects changes in area planted) or directly (by estimating the rate of adoption of MVs and applying this rate of adoption to the area planted to the crop). A direct approach was used in this study. However, use of the conventional method would have understated the impact of the Green Revolution in Nepal, because the introduction of early-maturing MVs in and of itself spurred a significant expansion in wheat area which would not otherwise have occurred. Therefore, Nepal's wheat area was disaggregated into two components: 1) a "base area" which probably would have been planted to wheat even if early-maturing MVs had not been introduced (estimated by applying a 3% annual long-term growth rate to the area planted to wheat prior to 1968, the year in which wheat area began to expand rapidly), and 2) an "incremental area" which was planted to wheat only because of the appearance of MVs (Figure 2).

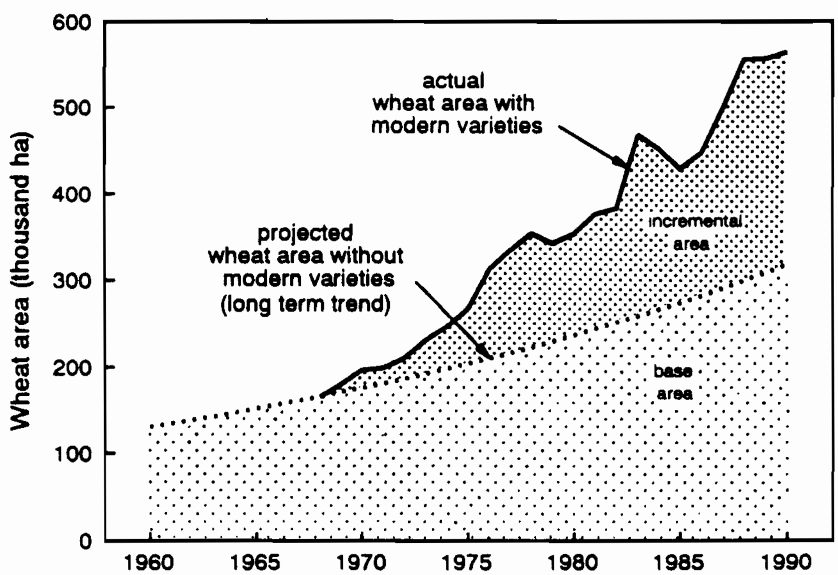

Figure 2. Incremental growth in area planted to wheat in Nepal attributable to the introduction of modern varieties.

Different methods were used to estimate the benefits of breeding research in each of the two areas. Since the incremental area by definition was not planted to wheat prior to the appearance of MVs, the benefits to wheat breeding over the incremental area were estimated based on net income per hectare of wheat production, defined as gross income minus fixed and variable costs.

Estimation of benefits over the base area was based on the conventional method of multiplying the genetic gains attributable to MVs (in this case, the yield losses foregone) times the area planted to MVs. However, as pointed out earlier, in Nepal MV adoption would probably have occurred through farmer-to-farmer seed exchanges along the India-Nepal border even had there been no national wheat program. Thus, the impact of the NWRP was considered to be simply an acceleration in the rate of adoption. This was modelled as the difference between the actual historical MV adoption pattern and the hypothetical adoption pattern which likely would have prevailed in the absence of a Nepali wheat program (Figure 3). Parameters of the actual historical adoption pattern (modelled as a logistic, or S-shaped curve) were estimated based on information provided by knowledgable Nepali wheat scientists about the spread of MVs, supplemented by data from producer surveys carried out during the past two decades. Parameters of the hypothetical "without research" adoption pattern were estimated based on the rate of adoption of Indian varieties which were never released in Nepal but which have come in over the border.

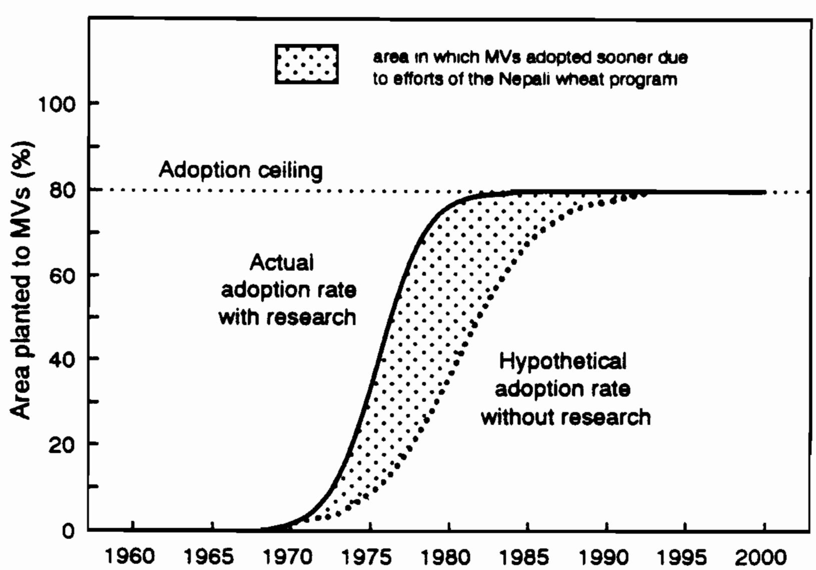

Figure 3. Accelerated rate of adoption of MVs attributable to research.

Average annual wheat prices, adjusted for inflation, were used in valuing the research benefits (i.e., the extra production attributable to accelerated adoption of MVs and the production from the incremental area).

Returns to wheat research in Nepal

Three categories of research expenditures were included on the cost side: 1) the NWRP budget, 2) the budgets of the 11 research farms where wheat research takes place, and 3) wheat research costs of scientists working in the disciplinary divisions in the Ministry of Agriculture. The three categories were disaggregated into breeding and breeding support costs, seed production costs, and other research and extension costs. Based on estimates made by NWRP breeders, a research lag of eight years was assumed, meaning that eight years of research costs were incurred prior to the release of the first MV.

Table 1. Parameters used in the rate of return calculations

Parameter	Mid Hills	Terai
Yield losses foregone due to research (% per year)	2.5	2.5
Pattern of adoption of modern varieties		
(a) with wheat research:		
* time to full adoption (years)	15	10
* adoption ceiling (% of wheat area)	80	80
(b) without wheat research:		
* time to full adoption (years)	25	20
* adoption ceiling (% of wheat area)	80	80
Wheat area growth without research (% per year)	3.0	3.0
Research lag (years)	8	8

Using the parameters summarized in Table 1, the IRR to wheat research in Nepal during 1960-1990 was estimated as 75%. This figure includes returns to wheat breeding and breeding support activities, crop management research, and seed production activities carried out at the various agricultural research farms. If the benefits accounted for in the analysis (yield losses foregone due to adoption of MVs and expansion in wheat area) are attributed exclusively to wheat breeding and breeding support activities, the IRR rises to 84% due to the exclusion of non-breeding research costs. These estimated IRRs, while high by conventional investment criteria, fall within the range of IRRs reported in other recent studies (Table 2).

Table 2. Summary of returns to investment in wheat research, selected studies

Study	Year	Country	Period	Rate of return (%)
Ardito-Barletta	1971	Mexico	1943-63	90
Eddleman	1977	USA	1978-85	46
Hertford et al.	1977	Colombia	1927-76	11-12
Kislev and Hoffman	1978	Israel	1954-73	125-150
Pray	1980	Bangladesh	1961-77	30-35
Sundquist et al.	1981	USA	1977	97
Yrarrazaval et al.	1982	Chile	1949-77	21-28
Zentner	1982	Canada	1946-79	30-39
Nagy	1983	Pakistan	1967-81	58
Ambrosi and Cruz	1984	Brazil	1974-90	59-74
Furtan and Ulrich	1985	Canada	1950-83	29
Norton et al.	1987	Peru	1981-2000	18-36
Evenson and da Cruz	1989	Brazil	1979-88	110
Byerlee	1990	Pakistan	1978-87	16-27

Source: Echeverria.

Discussion

During the past three decades, the wheat sector of Nepal has experienced a Green Revolution characterized by dramatic expansion in the area planted to wheat and rapid spread of MVs. Interestingly, none of the MVs associated with this Green Revolution were developed locally; all were exotic materials imported from India and Mexico. Although Nepali wheat scientists cannot be credited with developing these materials, clearly the national wheat program played an important role in evaluating them and promoting their dissemination. Nepal thus represents an example of a small country benefiting from research spillovers, since it has been able to capture significant benefits from wheat breeding carried out elsewhere.

Although the initial dramatic impacts of the Green Revolution in Nepal are beyond dispute, some policy makers now question whether the benefits currently being realized from varietal replacement justify the cost of maintaining a national wheat breeding program. By way of supporting this argument, they point out that yields of many newer varieties are not much higher than those of the original Green Revolution varieties. The question has important implications for deciding the level of future investment in wheat breeding research in Nepal.

This paper has reported results from a recent study undertaken to calculate the returns to wheat breeding in Nepal during the period 1960-90. In view of several unusual features of the Green Revolution in Nepal, it was necessary to devise unconventional methods for estimating two key parameters. Because the main benefit conferred by the MVs released in Nepal has been resistance to diseases, rather than increased yield potential, genetic gains attributable to wheat breeding were modelled as yield losses foregone. And because Indian materials would probably have spread into Nepal even in the absence of a Nepali wheat program, the impact of the NWRP was modelled as an acceleration in the rate of adoption of MVs.

Investment in wheat research in Nepal has generated an internal rate of return of 75-84% during the past three decades. These extremely attractive rates of return are explained by the relatively modest costs of the Nepali wheat program in relation to the substantial benefits it generates. On the cost side, NWRP has been able to take advantage of close links with the Indian wheat research program in capturing substantial benefits in the form of exotic germplasm which is generally well adapted to production conditions in Nepal. By screening and selecting imported materials, Nepali wheat scientists have been able to release several highly successful varieties while managing to avoid a substantial portion of the expenses involved in their development. On the benefits side, two principal factors can be identified as having contributed to the success of the Nepali wheat research effort. The first generation of MVs released in Nepal, particularly RR 21, fuelled a dramatic increase in wheat area due to its early maturity, which made possible double-cropping of wheat and rice in areas where farmers had previously been restricted to one crop per year. Subsequently, the replacement of RR 21 by UP 262 and other newer varieties protected farmers from considerable yield losses due to a breakdown in disease resistance.

These findings can be taken as a strong endorsement for continued investment in wheat research in Nepal. Although future returns to wheat research cannot be expected to attain the spectacular rates achieved in the past (since area expansion will eventually slow), they will remain attractive by conventional investment criteria. However, the desirable balance between breeding and crop management research will probably change over time. While the benefits realized during the Green Revolution period resulted mainly from the adoption of improved germplasm, evidence of declining yields both at the farm level as well as on experiment stations suggests that crop and resource management problems will assume increasing importance in the future.

More generally, the results of this study indicate that it may be advantageous for small countries to maintain modest national plant breeding programs if such programs improve these countries' ability to capture research spillovers emanating from larger, better-endowed neighbors, or from international agricultural research centers (IARCs). Although the limited area planted to a given commodity probably may not justify establishment of a fully-developed national breeding program, maintenance of a modest ability to speed the selection and dissemination of imported germplasm can be highly desireable on economic grounds (Brennan). This conclusion would appear to be particularly relevant for the smaller countries in Central America and West Africa, many of which are struggling to maintain fully developed breeding programs for important commodities in the face of declining levels of funding for agricultural research.

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