Differential Technology Adoption and Income Distribution in Pakistan: Implications for Research Resource Allocation

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A multi-market model of technological change in food production is used to simulate the long-run income distributional implications of differential diffusion of currently available wheat technologies in Pakistan. The results indicate that a research agenda emphasizing technologies suited to Pakistan's favored production environments would enhance overall production without compromising inter-group equity. It is found that when commodity prices are market determined, net consuming households are the major beneficiaries of technological change. However, in the more common situation of government intervention in markets for staple foods, net producing households are the principal beneficiaries of technological change.

Key words: income distribution, multi-market model, Pakistan, technological change.

Policy makers and research managers associated with agricultural research in developing countries are faced with the task of allocating scarce resources among alternative research agenda. One difficult problem is determining the appropriate mix of activities between developing technologies that maximize output or yield and generating technologies that promote equity. Historically, the bulk of productivity gains from biochemical technologies have occurred in well-watered or irrigated areas enjoying favorable topographic and agronomic conditions (Lipton and Longhurst). In contrast, more marginal production environments have lagged in terms of productivity increases. For this reason, interregional productivity differences have increased in many developing countries, particularly those in which technologies associated with the green revolution have had the greatest impacts on yield.

The extent to which productivity differences exacerbate income inequality is a concern (Ruttan; Binswanger and Ryan) that, while technological progress has succeeded in raising the productivity and incomes for adopting population, it may have worsened existing income inequities. At issue is the extent to which spillover effects transmitted through product and factor markets can spread the potential benefits of technological progress to populations other than adopting producers of affected commodities (e.g., to consumers and agricultural laborers).

There is a substantial literature on the welfare effects of changes in production technology of staple foods. Early work focused on macro effects, examining the relative impacts on producers and consumers (Akino and Hayami; Hayami and Herdt; Scobie and Posada). Additional work concentrated on spillover effects operating through product and factor markets as mechanisms by which the benefits of technological change were transmitted (Quizon and Binswanger; Evenson and Flores). Recently, Coxhead and Warr used a stylized general equilibrium model to measure the short-run income effects of differential regional adoption of agricultural technologies in irrigated and unirrigated areas of the Philippines. Their results indicated that the income distributional implications of new technologies are sensitive to regional

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Research for this paper was conducted while the author was a Rockefeller Foundation Research Fellow at the International Maize and Wheat Improvement Center, El Batan, Mexico.

Special thanks to Derek Byerlee for insightful suggestions at various stages of the research. The comments of John Beghin, Jeff Dorfman, Wally Thurman, Greg Traxler, and three anonymous referees on an earlier draft of this paper are gratefully acknowledged.

Review coordinated by Richard Adams.

adoption patterns, as well as to the factor biases of the technologies considered.

This paper complements the work of Coxhead and Warr by investigating the long-run income distributional implications of differential diffusion of available wheat technologies in Pakistan. The analysis compares the absolute and relative income effects of technologies targeted toward the greater yield potential of irrigated areas with the income effects of technologies aimed at improving wheat yields in (lower potential) rainfed areas. A multi-market model of technological change in food production is developed that accounts for the semisubsistence nature of Pakistani agriculture and the impact of technological innovations on factor demands. The model describes the behavior of different groups in three distinct regions—irrigated and rainfed agricultural areas and an urban sector—and allows for differential productivity impacts across regions.

The model simulates the net income effects of different regional patterns of technology diffusion. Projected impacts of technology adoption on yields and input demands are derived from experimental and on-farm data; hence the analyses account for the regional productivity differences and factor biases discussed by Coxhead and Warr. The results of the simulation analysis indicate that a research agenda emphasizing technologies suited to Pakistan's favored environments would enhance overall production without compromising inter-group equity.

The next section offers a brief review of technological progress and diffusion patterns in wheat production in Pakistan. The following section develops the multimarket model of technological change. The next two sections discuss data used in the model and present the results of simulation analyses of different regional patterns of technology diffusion. The following section presents measures of the income effects implied by the various scenarios of technological change. Concluding remarks are found in the paper's final section.

Technological Change and Wheat Production in Pakistan

Wheat is the most important agricultural commodity produced in Pakistan. It is grown by nearly all farmers in the country and is the primary staple food consumed in most areas. Enhancement of wheat farming productivity therefore is important for the well-being of both wheat producers and consumers.

Pakistan contains two distinct production environments—a highly productive irrigated sector and a more marginal rainfed zone. Historically, most wheat research has focused on the irrigated sector, and the rapid technology adoption and yield increases characterizing the green revolution of the late 1960s were largely confined to those areas. High-yielding varieties (HYVs) better suited to rainfed conditions were developed and released in the mid 1970s. In some rainfed areas, yield increases associated with this second generation of HYVs were substantial, but still much smaller than those in irrigated areas. Rainfed areas continue to lag behind the irrigated areas, in terms of both adoption and yield.

Azam, Bloom, and Evenson found that past investment in wheat research in Pakistan has achieved a high rate of return compared with returns on alternative public and private expenditures within Pakistan and compared to agricultural research in other developing countries. Their data indicate that wheat research accounts for about 16% of total agricultural research expenditures. The magnitude of public resources devoted to wheat research and the historically rapid adoption of new wheat technologies underscores the importance of how those research resources are spent.

A Model of Technological Change

The following model draws on the work of Quizon and Binswanger. Unlike their work, however, the model allows for regional differences in the productivity impacts of a hypothetical technological innovation. The model assumes two agricultural regions ("favored" and "marginal") and an urban sector. In each agricultural region there are three types of households: landless, small farm, and large farm. The latter two groups are semisubsistence households producing a significant proportion of the dominant staple food that they consume. The urban sector is composed of "rich" and "poor" households.

Assume that farm households in each agricultural region produce two commodities, where Q_1 is the staple food affected by an exogenous technological innovation (here modeled as a shifter variable, τ), and Q_2 is an alternate commodity. Output supplies and input demands depend on the prices of these two commodities (P_1 and P_2), the prices of variable inputs, and, except for Q_2, the technology shifter. It is assumed that labor (L) and fertilizer (F) are the only variable inputs; that land is the only fixed input; that variable inputs are not differentiated by crop; that the agricultural wage rate (W) is determined in a competitive market in which labor is mobile across agricultural regions; and that households in both agricultural regions face the same exogenously determined fertilizer price (f). The system of output supply and variable input demand functions for each household type may be written as

$$Q_{1rg} = Q_{1rg}(P_1, P_2, W, f, \tau)$$
$$Q_{2rg} = Q_{2rg}(P_1, P_2, W, f)$$
$$L^d_{rg} = L^d_{rg}(P_1, P_2, W, f, \tau)$$
$$F_{rg} = F_{rg}(P_1, P_2, W, f, \tau),$$

where the subscripts r and g—denoting region and household group—indicate variables and parameters that vary across household type. These imply the following relationships in rate-of-change notation (where "ˆ" indicates proportional rate of change):

$$(1) \quad \hat{Q}_{1rg} = \epsilon_{11rg}\hat{P}_1 + \epsilon_{12rg}\hat{P}_2 + \epsilon_{1Lrg}\hat{W} + \epsilon_{1Frg}\hat{f} + \hat{E}_{1rg}$$

$$(2) \quad \hat{Q}_{2rg} = \epsilon_{21rg}\hat{P}_1 + \epsilon_{22rg}\hat{P}_2 + \epsilon_{2Lrg}\hat{W} + \epsilon_{2Frg}\hat{f}$$

$$(3) \quad \hat{L}^d_{rg} = \beta_{L1rg}\hat{P}_1 + \beta_{L2rg}\hat{P}_2 + \beta_{LLrg}\hat{W} + \beta_{LFrg}\hat{f} + \hat{E}_{Lrg}$$

$$(4) \quad \hat{F}_{rg} = \beta_{F1rg}\hat{P}_1 + \beta_{F2rg}\hat{P}_2 + \beta_{FLrg}\hat{W} + \beta_{FFrg}\hat{f} + \hat{E}_{Frg}.$$

Here ϵ_{ikrg} and β_{jkrg} are group-specific elasticities of output i or input j with respect to price k, and $\hat{E}_{krg}$ is the proportional shift in output supply or infput demand due to the new technology holding fixed inputs constant—e.g., $\hat{E}_{1rg} = (\partial \ln Q_{1rg}/\partial\tau)\,(d\tau/dt)$.

Changes in total regional output are given by the sum of group-specific output changes weighted by each group's share of total regional output (λ_{irg}):

$$(5) \quad \hat{Q}_{1r} = \sum_g \lambda_{1rg}\hat{Q}_{1rg}; \qquad \hat{Q}_{2r} = \sum_g \lambda_{2rg}\hat{Q}_{2rg}.$$

Likewise, regional changes in input demands are given by

$$(6) \quad \hat{L}^d_r = \sum_g \delta_{rg}\hat{L}^d_{rg}; \qquad \hat{F}_r = \sum_g \phi_{rg}\hat{F}_{rg},$$

where δ_{rg} and ϕ_{rg} are the shares of total regional demands for labor and fertilizer accounted for by group g.

Individual rural household labor supply (l^s) is taken to be a function of the real wage rate w $= W/P^*_{rg}$, where P^*_{rg} is an endogenous, group-specific consumer price index)—i.e., $l^s = l^s(w)$. Denoting the population of household group g in region r as N_{rg}, group-specific labor supply is simply $L^s_{rg} = l^s_{rg} \times N_{rg}$. Letting ϵ_{Lrg} be the wage rate elasticity of household labor supply, proportional changes in regional labor supply are given by

$$(7) \quad \hat{L}^s_{rg} = \epsilon_{Lrg}\hat{w} + \hat{N}_{rg}.$$

Again, this result may be aggregated to derive changes in regional labor supply:

$$(8) \quad \hat{L}^s_r = \sum_g \psi_{rg}\hat{L}^s_{rg},$$

where ψ_{rg} is the share of labor supply in region r accounted for by group g.

It is assumed that all residual farm profits not attributable to variable inputs are accrued as returns to land. Letting Π_{rg} be farm profits of group g in region r,

$$\Pi_{rg} = P_1Q_{1rg} + P_2Q_{2rg} - W\cdot L^d_{rg} - f\cdot F_{rg}.$$

Changes in farm profits are thus given by

$$(9) \quad \hat{\Pi}_{rg} = \pi_{1rg}(\hat{P}_1 + \hat{Q}_{1rg}) + \pi_{2rg}(\hat{P}_2 + \hat{Q}_{2rg}) + \pi_{Lrg}(\hat{W} + \hat{L}^d_{rg}) + \pi_{Frg}(\hat{f} + \hat{F}_{rg})$$

where the π_{irg}'s are group-specific profit shares accounted for by outputs and variable inputs (positive for outputs and negative for inputs).

It is assumed that two commodities are consumed—the staple food affected by technological change and an alternate commodity (A). Household demand (indicated by a lower case c) is a function of the prices of these commodities and nominal income (Y_{rg}):

$$c_{krg} = c_{krg}\,(P_1, P_A, Y_{rg}) \qquad k = 1, A.$$

As in the case of labor supply, group-specific consumption (denoted by an upper case C) is simply the product of household demand and group population—i.e., $C_{krg} = c_{krg} \times N_{rg}$. Group changes in consumption are thus

$$(10) \quad \hat{C}_{1rg} = \eta_{11rg}\hat{P}_1 + \eta_{1Arg}\hat{P}_A + \eta_{1Yrg}\hat{Y}_{rg} + \hat{N}_{rg}$$

$$(11) \quad \hat{C}_{Arg} = \eta_{A1rg}\hat{P}_1 + \eta_{AArg}\hat{P}_A + \eta_{AYrg}\hat{Y}_{rg} + \hat{N}_{rg},$$

where the η_{ijrg}'s are demand elasticities ($i = Q_1, Q_2$; $j = P_1, P_2, Y$). Letting α_{krg} be the share of regional consumption of good k accounted for by group g, changes in regional consumption are

$$(12) \quad \hat{C}_{kr} = \sum_g \alpha_{krg}\hat{C}_{krg} \qquad k = 1, A$$

Nominal income for each group within a region (Y_{rg}) is the sum of the net returns to all factors rented out by that group. These include labor income, farm profits, and other exogenous sources (X) such as non-agricultural labor:

$$Y_{rg} = W \cdot L_{rg}^{s} + \Pi_{rg} + X_{rg}.$$

Let μ_{krg} denote the group-specific share of income attributable to income source k ($k = L, \Pi, X$). Again assuming no change in the distribution of land holdings, changes in real income ($y = Y/P^*$) are given by

$$(13) \quad \hat{y}_{rg} = \mu_{Lrg} (\hat{W} + \hat{L}_{rg}^{s}) + \mu_{\Pi rg} \hat{\Pi}_{rg} + \mu_{Xrg} - \hat{P}_{rg}^{*},$$

where once again P_{rg}^{*} is a group-specific consumer price index. Changes in this price index are given by

$$(14) \quad \hat{P}_{rg}^{*} = \sum_{k} \omega_{krg} \hat{P}_{krg} \qquad k = 1, A,$$

where ω_{krg} is the group-specific expenditure share for commodity k.

Closing the model requires specification of the conditions under which the markets for commodity 1 and labor clear.[1] As the interest here is to examine long-run effects of technological change, it is assumed that labor is sufficiently mobile over the long-run that wage rates are determined in a national labor market. The market clearing condition is thus

$$L_d = \sum_{r} L_r^d = \sum_{r} L_r^s = L^s = L$$

or, in rate-of-change notation,

$$(15) \qquad \sum_{r} \frac{L_r^d}{L} \hat{L}_r^d = \sum_{r} \frac{L_r^s}{L} \hat{L}_r^s.$$

Note that this formulation ignores wage differentials between regions arising from the transactions costs of moving from one area to another, thus implicitly assuming a constant proportional regional difference in wages. Note also the absence of dynamics in this formulation; rather, it provides for a comparison of two static equilibria occurring at different points in time.

Market clearing in the market for commodity 1 is based on the identity $C_1 = Q_1 + G$, where C_1 is total national consumption, Q_1 is total national production, and G is the quantity of commodity 1 accounted for by government-controlled imports. In rate-of change notation, this calculation becomes

$$(16) \quad \sum_{r} \frac{C_{1r}}{C_1} \hat{C}_{1r} = (1 - \Gamma) \sum_{r} \frac{Q_{1r}}{Q_1} \hat{Q}_{1r} + \Gamma \cdot \hat{G},$$

where $\Gamma = G/C_1$ is the share of national consumption accounted for by imports.

Two variant solutions based on equation (16) are considered. Variant I assumes a closed economy in which P_1 is determined by the intersection of aggregate supply and demand curves for commodity 1. Here, P_1 is endogenously determined and G is exogenous. In contrast, variant II assumes that P_1 is exogenously determined by government price policy. In this case, G becomes endogenous; that is, imports are determined such that they make up for the excess demand or excess supply of commodity 1 implied by the exogenously determined price (P_1).

Data

Implementation of the multi-market model required a large set of parameters capturing the salient features of the Pakistani economy. Parallel information on the parameters of interest for both irrigated and rainfed production environments were drawn from secondary sources. Income, profit, and input demand shares were computed from farm survey data collected in 1987 in the Punjab—Pakistan's most important wheat producing province (Khan and Haque).[2] All other share parameters applied to Pakistan as a whole. Regional production and labor supply shares were computed from Agricultural Census data. Household expenditure shares and regional consumption shares for wheat and other commodities were computed from the 1984 Household Income and Expenditure Survey. Documentation of how the share parameters were assembled is available from the author.

Output supply and input demand elasticities were taken from estimates published by Pinckney and by Ali. These are generally inelastic. Own-price demand elasticities for wheat and other commodities were taken from Ahmad and Ludlow, and income demand elasticities of wheat were taken from Alderman. Cross-price and

[1] All other prices are assumed to be exogenously determined.

[2] This was dictated by a lack of comparable on-farm data for other provinces. However, given the dominance of the Punjab in agricultural production in Pakistan, it was felt that the generality of the results was not compromised.

nonwheat income demand elasticities were then derived such that Cournot and Engel's aggregation conditions were satisfied. Wheat price and income elasticities are fairly low in Pakistan (ranging from −0.10 to −0.22, and 0.20 to 0.45, respectively). Demand for nonwheat is considerably more price elastic, although still less than one in absolute value.

Most of the qualitative results of the simulation analyses are explained by key features of Pakistan's economy reflected in the model's parameters. First, large farm households in rainfed areas and both small and large farm households in irrigated areas are net wheat producers, while small farm households in rainfed areas are net wheat consumers (appendix, table 1). Thus, an innovation that depresses the price of wheat (say, through a shifting out of wheat supply) will tend to have a more positive impact on the incomes of landless, urban, and rainfed small farm households—i.e., net consumers.

Second, approximately 90% of Pakistan's wheat is produced in irrigated areas. Increasing the productivity in those areas will have a proportionately greater impact on such key aggregates as output and labor demand than increased productivity in rainfed areas.

Third, profits from farming are a much more important component of total income for farm households in the irrigated areas than those in the rainfed areas (appendix, table 2). Moreover, the share of farm profits in total household income is larger for large farm households than for small farm households. Consequently, any profit-enhancing technological innovation will tend to affect more strongly the incomes of large farm households and households located in irrigated areas.

Fourth, input use across farm-size classes, while similar on a per hectare basis, vary considerably on a per farm basis between small and large farms (appendix, table 2). Overall input use is thus more strongly affected by the responses of large farms than of small farms, particularly nonlabor inputs. At the same time, most agricultural labor is supplied by small farm households. Thus, a change in real wages brought about by a new technology will affect the incomes of small farm households to a greater extent than other household types.

Results

The model developed above will be used to simulate the impacts of various scenarios of technological change in Pakistan. Two sets of analyses are conducted, both of which assess the long-run impacts of different regional patterns of technology adoption relative to a baseline case in which no technological change occurs. The first assumes that government controls both producer and consumer prices of wheat and wheat flour; the second assumes that wheat prices freely adjust to changes in domestic supply and demand conditions.

Model Implementation

The simulation analyses focus on technologies that are currently "on the shelf" in Pakistan. These include (*i*) wheat varieties possessing greater yield potential resulting from genetic improvement; (*ii*) zero-tillage in irrigated areas where double-cropping has led to delays in wheat planting; (*iii*) chemical herbicide application in irrigated areas infested with weeds; and (*iv*) deep tillage in rainfed areas. Various scenarios of diffusion of these technologies are compared with a baseline scenario that assumes no technology adoption and exogenous growth of population and nonagricultural income at historically observed rates of 3.1% and 2.6% annually (World Bank).[3] The time-frame for the analysis is ten years.

Exogenous shifts in wheat output and input use implied by technology adoption were calculated from experimental data. It was assumed that yield increases resulting from breeding research amount to 0.75% per year in irrigated areas and 0.3% per year in rainfed areas. The figure for irrigated areas was computed by Byerlee and Heisey, based on an estimated 1% annual rate of yield increase and adjusted downward to reflect differences between experiment station yields and those on farmers' fields. The figure for rainfed areas is half the rate of yield gain from breeding research in dryland areas of Australia (CIMMYT 1989) and is probably optimistic, given that the current prospects for wheat breeding in Pakistan's dryer rainfed areas are bleak.

[3] Because of space limitations, the output of the baseline scenarios is not reported here. These scenarios portend a rather bleak future for Pakistan in the absence of future technological improvements, largely because the very high population growth will outstrip the growth of both agricultural and non-agricultural sectors of the economy. This population growth gives rise to a situation of falling wage rates and widening gaps between wheat demand and domestic supply, leading to large increases in wheat imports and/or steep increases in wheat prices.

For the three crop management practices, it is assumed that at the end of ten years adoption levels will reach 50% in areas where the practice is applicable.[4] For zero-tillage, this figure includes irrigated areas in which wheat is grown after cotton or rice (accounting for roughly 60% of irrigated wheat area nationally). For herbicide use, 20% of fields in irrigated areas are assumed to be infested. This level corresponds to levels of serious weed infestation observed in farm management surveys in Pakistan's major wheat-producing areas. Finally, it is assumed that the use of deep-tillage expands from its current level of adoption on 3.2% of rainfed land to encompass 50% of all rainfed area.

Yield improvements over ten years implied by the assumed rates of genetic improvement and adoption of crop management practices are 13.8% and 16.4% in the irrigated and rainfed areas, respectively. Taken as a whole, adoption of the crop management technologies entails a net increase in labor use and a net decline in the use of other inputs in the areas for which they are suited. Both zero-tillage and deep-tillage significantly reduce input use for planting operations (land preparation and sowing), but require greater input use for harvesting operations (including threshing). Increased yields from genetic improvement boost input use for harvesting, particularly in irrigated areas. Likewise, chemical weed control increases input use, particularly in harvesting operations.

Technological Change under Controlled Wheat Prices

In Pakistan, as in many developing countries, the government is active in the markets for wheat. For producers, the government sets a support price prior to planting time, and typically procures about 50% of marketed wheat. On the consumption side, the government enforces prices to be paid by various entities in the marketing chain (including transporters, millers, and distributors). When the price of wheat is an outcome of government price policy, wheat imports are endogenously determined such that they make up for the excess demand or excess supply resulting from the exogenously-determined prices. Throughout the 1980s, Pakistan imported slightly over 750,000 metric tons per year on average.

Table 1 presents the simulated impacts of various scenarios of technological change under government-controlled prices. The three scenarios considered include one in which diffusion of currently available technologies occurs only in rainfed areas; one in which diffusion is confined to irrigated areas; and one in which diffusion occurs in both areas.[5]

The results indicate distinctly different impacts on real agricultural wages and farm profits, depending on the regional pattern of technology diffusion. In all cases, agricultural wages increase because of a shift in labor demand accompanying technology adoption. However, wages are more profoundly affected where technologies are adopted in irrigated areas, because of the dominance of irrigated areas in total wheat acreage (and hence labor demand). Likewise, diffusion of improved technologies in irrigated areas has a stronger effect on total wheat production than if diffusion were confined to rainfed areas. As such, enhanced productivity of irrigated wheat farms holds greater potential for reducing import demand.

Changes in the farm profits of different farm types depend on whether or not they adopt the new technologies. In all cases, farm profits increase for farms located in adopting areas while profits fall for farms in nonadopting regions. Declines in the profits of nonadopting farms is the predictable outcome of higher wages in the face of constant production technologies. Increases in farm profits are potentially large in rainfed areas, although the base level of profitability of those farms is considerably less than that of irrigated farms.

The net impact on real household incomes of new technologies depends on changes in wages and profits engendered by adoption of those technologies and the relative importance of those two components of household income. The results in table 1 indicate that effects on farm profits generally dominate wage effects in the overall distribution of benefits and losses. Net producing households—i.e., large farm households in rainfed areas and both small and large

[4] This assumption was based on the fact that adoption of crop management technologies in Pakistan has historically been much slower (and less complete) than varietal adoption. A detailed appendix analyzing the sensitivity of the empirical results to assumed adoption rates, yield impacts, and selected parameters is available from the author upon request.

[5] Each scenario considered two alternative wheat pricing regimes, one in which both consumer and producer prices remained at current levels and one in which both were assumed to rise by 20%. For a given variable, however, differences between the results for the baseline scenario and technological change scenarios were identical for both regimes.

farm households in irrigated areas—achieve the greatest benefits or losses, depending on whether or not they adopt. Where technological change occurs in both rainfed and irrigated areas, income increases for net producing households are considerably larger than for net consuming households. Where technological change is confined to one production environment, net producing households in the nonladopting region realize either negligible gains or small declines in real income. Moreover, the income effects in nonladopting regions are inversely related to the size of land holdings.

Technological Change under Endogenous Wheat Prices

Table 2 presents simulated impacts of technology diffusion under endogenously determined wheat prices. In the absence of government intervention, diffusion of current technologies would depress real wheat prices and increase real agricultural wages relative to a situation of zero technological progress. The magnitudes of these effects are relatively greater in scenarios in which technological change takes place in irrigated areas—again because of the dominance of irrigated areas in total wheat production. Interestingly, technological change in irrigated areas has a negative impact on irrigated farm profits because wheat demand in Pakistan is considerably less elastic than output supply.

With regard to income effects, net consumers of wheat—urban households, landless households, and small farm households in rainfed areas—are now the major beneficiaries of technological change. This finding contrasts sharply with the results of the controlled price simulations, where it was found that adopting net producers achieved the greatest real income gains. This difference arises because consumers capture the bulk of the rents created by technological change when wheat prices are free to adjust to shifting supply. Increases in agricultural wages also contribute to the income gains for some net consuming households (particularly landless households).

Income Distributional Implications

Assessing the income distributional implications of different regional diffusion patterns requires

Table 1. Net Effect of Various Scenarios of Technological Change Under Government-Controlled Wheat Prices[a]

	Technological change occurring in		
	Rainfed areas only	Irrigated areas only	Both areas
	Percentage changes		
Farm profits			
Rainfed small farm[b]	29.4	−6.4	23.0
Rainfed large farm[c]	20.3	−2.7	17.6
Irrigated small farm[c]	−1.1	8.9	7.8
Irrigated large farm[c]	−1.0	8.3	7.3
Wages and imports			
Real agricultural wage	1.2	3.9	5.1
Wheat imports	−7.7	−45.1	−52.8
Real income			
Rainfed landless[b]	0.2	0.6	0.8
Rainfed small farm[b]	0.7	0.3	1.1
Rainfed large farm[c]	4.0	0.1	4.1
Irrigated landless[b]	0.4	1.2	1.5
Irrigated small farm[c]	−0.2	5.3	5.0
Irrigated large farm[c]	−0.4	5.9	5.4
Urban poor[b]	0.0	0.0	0.0
Urban nonpoor[b]	0.0	0.0	0.0

[a] All values are changes relative to a baseline scenario that assumes 3.1% annual population growth, 2.6% exogenous income growth, and no technological change.
[b] Net consuming households.
[c] Net producing households.

Table 2. Net Effect of Various Scenarios of Technological Change Under Endogenous Wheat Prices[a]

	Technological change occurring in		
	Rainfed areas only	Irrigated areas only	Both areas
	Percentage changes		
Farm profits			
Rainfed small farm[b]	19.4	−65.0	−45.6
Rainfed large farm[c]	14.2	−38.0	−23.8
Irrigated small farm[c]	−3.9	−7.0	−11.4
Irrigated large farm[c]	−3.3	−4.9	−8.7
Wages and prices			
Real agricultural wage	1.3	4.6	5.9
Real wheat price	−3.5	−20.5	−24.0
Real income			
Rainfed landless[b]	0.6	3.1	3.7
Rainfed small farm[b]	1.0	1.7	2.7
Rainfed large farm[c]	3.1	−4.0	−0.9
Irrigated landless[b]	0.8	3.6	4.4
Irrigated small farm[c]	−1.2	−0.2	−1.4
Irrigated large farm[c]	−1.6	−0.8	−2.4
Urban poor[b]	0.4	2.2	2.5
Urban nonpoor[b]	0.2	1.3	1.6

[a] All values are changes relative to a baseline scenario that assumes 3.1% annual population growth, 2.6% exogenous income growth, and no technological change.
[b] Net consuming households.
[c] Net producing households.

measures of both the absolute and relative income effects on the various household groups to determine the overall level of income growth accompanying technological change and how that growth is distributed among household groups. Absolute income effects will be measured by the average percentage change in real income for all household groups, weighted by each group's share of total population. Relative income effects will be measured by Gini coefficients of income inequality.

Computation of the Gini coefficients for each simulation was based on rural household income data for 1987 (Khan and Haque), in combination with census data on the population shares of each group (appendix, table 1). Use of these data limited the scope of this analysis in two ways. First, because the income data were drawn exclusively from a sample of rural households, effects on rural-urban income inequality could not be measured. Data presented in Guisinger and Hicks indicates that estimates of Gini coefficients for Pakistan that include urban households are up to 25% larger than rural income inequality. Second, because these data are group means for different household types, they do not capture within-group variation (which is likely to be considerable). Thus, the computed Gini coefficients likely understate the true level of rural income inequality. However, as the Gini coefficients for each simulation were computed based on the same initial distribution, the results are suitable for comparing the distributional implications of the various scenarios of technological change. The computed baseline (1987) Gini coefficient was 0.237.

Table 3 presents the measures of absolute and relative income effects of the various scenarios of technological change under both controlled and endogenously determined wheat prices. Effects under controlled prices are presented for two pricing regimes, one in which the price of wheat remains unchanged and one in which the price of wheat rises by 20% over ten years. Effects under endogenous prices are presented for two assumed levels of imports; one in which imports remain at their current levels and one in which imports are assumed to double over ten years.

The absolute income effects are all negative, indicating that real incomes will fall on average in all scenarios. This result highlights the limits

Table 3. Absolute and Relative Income Distribution Effects of Various Scenarios of Technological Change

Scenario	Absolute Income Effect[a]	Gini Coefficient[b]
Controlled Price (ΔP = 0)[c]		
No technological change (baseline)	−10.24	0.240
Technological change in rainfed areas only	−10.06	0.242
Technological change in irrigated areas only	−8.29	0.241
Technological change in both areas	−8.05	0.241
Controlled Price (ΔP = +20%)[c]		
No technological change (baseline)	−6.07	0.253
Technological change in rainfed areas only	−5.87	0.254
Technological change in irrigated areas only	−4.08	0.253
Technological change in both areas	−3.86	0.253
Endogenous Price (ΔG = 0)[d]		
No technological change (baseline)	−9.02	0.249
Technological change in rainfed areas only	−8.92	0.249
Technological change in irrigated areas only	−7.82	0.245
Technological change in both areas	−7.71	0.244
Endogenous Price (ΔG = +100%)[d]		
No technological change (baseline)	−9.47	0.246
Technological change in rainfed areas only	−9.37	0.246
Technological change in irrigated areas only	−8.27	0.241
Technological change in both areas	−8.19	0.241

[a] Average percentage change in real income weighted by population share of each household group.
[b] Rural households only.
[c] ΔP is the change in the price of wheat.
[d] ΔG is the change in wheat imports.

of improved wheat technologies for counterbalancing other negative forces affecting welfare. Chief among these is Pakistan's high rate of population growth. Adoption of wheat technologies in irrigated areas (with or without accompanying technology diffusion in rainfed areas) leads to greater (i.e., less negative) income growth than when technological change is confined to rainfed areas. This is so, regardless of whether prices are determined by market forces or by the government. Because irrigated areas dominate the wheat sub-sector, the positive effects of technological change are much stronger when the productivity of irrigated areas is enhanced. By the same token, while technological change confined to rainfed areas has the capability of improving the incomes of some household groups (primarily those located in rainfed areas), its aggregate impact on average incomes is modest.

In terms of relative income distributional effects, the diffusion of improved wheat technologies in irrigated areas leads to outcomes that are no less equitable (and in some cases more equitable) than technology diffusion that is exclusively confined to rainfed areas. For the controlled price scenarios, there is no difference between the implied Gini coefficients for any of the scenarios. In the endogenous price scenarios, Gini coefficients are generally smaller in the scenarios in which technological change occurs in irrigated areas.

The implied absolute and relative income effects of different regional patterns of technological change have important implications for the allocation of wheat research resources in Pakistan. Traditionally, most wheat research has been targeted toward irrigated areas. The results presented here indicate that this strategy is a reasonable one for research managers to pursue in the future.[6] Assuming that the government continues to play a dominant role in setting wheat prices, any dramatic reallocation of research resources aimed at improving wheat productivity in rainfed areas appears ill-advised. Technological change occurring exclusively in rainfed areas would be inferior in terms of promoting overall

[6] This assumes that future research will generate technologies having yield impacts and factor biases comparable to those of currently available technologies. One could also interpret these results as implying that extension activities promoting the adoption of technologies currently available for irrigated areas should be emphasized.

income growth, and cannot be justified in terms of its ability to improve relative income distribution.

Concluding Remarks

This paper has investigated the potential impacts on income distribution of currently available wheat technologies in Pakistan. A multi-market model of technological change was used to simulate the income effects of different regional patterns of diffusion of these technologies. The results indicated that the traditional allocation of the bulk of wheat research to improving the productivity of Pakistan's irrigated sector continues to be a reasonable strategy. A dramatic reallocation of research aimed at rainfed areas would be inferior in terms of promoting overall income growth, and at the same time cannot be justified on equity grounds. This finding is important in that it directly speaks to the question of whether or not there is a conflict between the goals of improving agricultural productivity and enhancing income distributional equity. Given the technologies currently available in Pakistan, it appears that such a conflict does not exist.

The results presented here are specific to Pakistan. The potential regional impacts of improved agricultural technologies on productivity, the factor intensities of those technologies, and the geographic distribution of human and agronomic resources vary considerably from country to country. Thus, one needs to be circumspect in assessing the generality of these findings. Nonetheless, two useful insights have emerged that may be relevant outside of Pakistan. The first is the finding that research aimed at enhancing agricultural productivity in favored areas can have positive absolute income effects without compromising interregional income inequality. Determining whether this phenomenon exists in other countries will require additional research.

Second, the results reported here indicate that the income distributional consequences of technological change depend importantly on whether the price of the commodity involved is market determined or government controlled. The evidence from Pakistan supports the commonly held belief that if the price of the affected commodity is market determined, net consuming households stand to be the major beneficiaries of productivity increases resulting from technological progress. However, for important traded staple commodities like wheat or rice, governments usually do intercede in domestic markets. The simulation analyses indicate that in a situation of controlled prices, net producing households are the major beneficiaries of technological change.

[Received October 1991; final revision received May 1992.]

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Appendix

Table 1. Production And Consumption of Wheat by Region and Household Type

Region and group	Wheat production (000,000 metric tons)	Wheat consumption (000,000 metric tons)	Population share (percent)
Rainfed			
Landless	0	1186	7
Small farm	878	3051	17
Large farm	1374	605	3
Subtotal	2252	4842	27
Irrigated			
Landless	0	1686	13
Small farm	4645	3636	24
Large farm	6968	1265	8
Subtotal	11613	6587	45
Urban			
Poor	0	1473	11
Nonpoor	0	2137	17
Subtotal	0	3609	28
Total Pakistan	13865	15038	100

Table 2. Profit, Income, Labor Supply, and Input Demand Shares by Household Group

	Rainfed areas			Irrigated areas		
	Landless	Small farms	Large farms	Landless	Small farms	Large farms
Profit Shares						
Wheat	—	2.27	1.33	—	0.75	0.65
Other crops	—	1.76	0.94	—	1.66	1.56
Labor	—	−1.75	−0.55	—	−0.48	−0.32
Other inputs	—	−1.27	−0.71	—	−0.93	−0.89
Income Shares						
Farm profits	—	0.02	0.18	—	0.48	0.63
Farm labor	0.10	0.08	0.10	0.20	0.17	0.11
Other sources	0.90	0.90	0.72	0.80	0.35	0.26
Variable Input Shares						
Labor supply	0.081	0.600	0.319	0.199	0.496	0.305
Labor demand	—	0.458	0.542	—	0.444	0.556
Other input demand	—	0.312	0.688	—	0.373	0.627