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13 A holistic approach to the evaluation of socio-economic and environmental impacts of technological change in agriculture: an application in Bangladesh[1]

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13.1 Introduction

Technological change is an important factor in economic growth and development. The major technological breakthrough in agriculture in the twentieth century is the development of high-yielding modern grain varieties of wheat and rice which are highly responsive to inorganic fertilisers, insecticides, effective soil management and water control (Hayami and Ruttan, 1985). The overwhelming belief in the pursuit of this 'high-input payoff' model of agricultural development, popularly coined as the 'Green Revolution', is due to its potential in increasing foodgrain productivity, employment as well as income (seen in many countries during 1960 – 1970s), thereby, alleviating poverty and hunger. Bangladesh, being a predominantly agricultural economy with an extremely unfavourable land-man ratio owing to high population density, also sought to pursue the policy of transforming agriculture through rapid technological progress to alleviate poverty and widespread hunger. Consequently, over the past four decades, the major thrust of national policies has been directed towards diffusing the 'Green Revolution' technology (modern varieties of rice and wheat) with corresponding support in the provision of modern inputs, such as chemical fertilisers, pesticides, irrigation equipment, institutional credit, product procurement, storage and marketing facilities.

However, the impacts of this 'Green Revolution' technology among the adopting nations have been mixed and are accompanied by controversies largely due to the approach utilised in the evaluation process and the extent of the issues covered in the analyses. Freebairn (1995), analysing the results of 307 studies undertaken during the period 1970-89, observed that about 80% of these studies had conclusions that the new technology widened both inter-farm and inter-regional income inequality. The interesting point in this study is that nature of the conclusions drawn from these evaluation studies was found to be influenced by the 'regional origin of the authors', 'location of the study area', 'methodology followed', and 'the geographic extension of the study area'.

Most of the early evaluations of modern technology and/or 'Green Revolution' centred on the concerns of growth, productivity, efficiency and equity (Sidhu, 1974; Parthasarathy, 1974; Griffin, 1974; Sen, 1974; Lal, 1979; Harris, 1977; Mellor, 1978; Bisaliah, 1982; Prahladachar, 1983; and Dantwala, 1985). The anticipation that the modern technology can affect other spheres of life remained ignored. In particular, knowledge on the delayed consequences of this technological change on other spheres of the economy is nascent and has not been considered until more recently spurred by studies such as, Shiva (1991), Redclift (1989), Brown (1988), Wolf (1986), Clapham (1980), and Bowonder (1979 and 1981). However, concern over sustainability in food production, owing to technological change, is gaining momentum (Alauddin and Tisdell, 1991; Redclift, 1989; Marten, 1988; and Conway 1986). As a result there has been a growing interest in evaluating the merits of traditional agriculture as it was increasingly realised that modern technology, particularly the 'Green Revolution', though dramatically increasing food production in its initial years of inception, has been accompanied by a tapering off in production potential in later years.

Given this backdrop, the present study employed a holistic approach to evaluate the impacts of three decades of modern technology diffusion in Bangladesh agriculture, focussing on its economic, social/distributional and environmental impacts and the prospects for food production sustainability.

The chapter is organised into a number of sections. Section 13.2 presents the research design and evaluation methodology for the study. Sections 13.3-13.5 present the evaluations of the economic, social/distributional and environmental impacts of technological change in agriculture. Section 13.6 presents a synthesis of the empirical findings and the main policy implications to be drawn from the study.

13.2 Research design and evaluation methodology

The overall hypothesis of the study is that, though the diffusion of modern agricultural technology has contributed to increased production, employment and income, its distributional consequences have been mixed. Also, this technological change in agriculture has exerted adverse impacts on the environment and its diffusion has not been uniform across regions. This has resulted in regional disparities. Moreover, long run crop production levels are believed likely to reach a saturation level, thereby posing a threat to the sustainability of food production. Given this, the research is designed to provide a blend of economic (crop input-output), biophysical (soil fertility) and behavioural (farmers' perception) analyses to capture the diverse issues involved.

The study is based on time-series crop input-output data for 47 years (1948 – 1994) and farm-level cross-section data for crop year 1996 collected from three agro-ecological regions. It also includes soil samples from representative locations and information on infrastructural facilities. The research is conducted at two levels: macro-level and micro-level, respectively. The macro-level analysis comprises all of the agricultural regions of the country. The following method was adopted for the selection of areas for in-depth micro-level analysis. First, relatively homogenous agricultural regions with respect to a set of technological, demographic, infrastructure and crop production efficiency parameters were identified at the macro-level, which were then classified into five levels of development[2]. Then, one region each from 'high', 'medium', and 'low' level was selected[3]. The specific selected regions are the Comilla, Jamalpur, and Jessore regions. Once the regions had been selected, a multi-stage random sampling technique was employed to locate the districts, then the thana (sub-districts), then the villages in each of the three sub-districts and finally the sample households. A total of 406 households from 21 villages (175 households from 8 villages of Jamalpur Sadar thana, 105 households from 6 villages of Manirampur thana and 126 households from 7 villages of Matlab thana) forms the sample of the study. In terms of varieties of crops[4] produced, the total number of observations were 1,448: 117 local rice, 829 modern rice, 103 modern wheat, 92 jute, 71 oilseeds, 59 potato, 70 pulses, 47 spices, 44 vegetables and 16 cotton, respectively.

A comprehensive assessment of the multifaceted impacts of technological change is a huge task. The present study attempts to provide an analysis of economic, social/distributional, and environmental impacts of technological change in Bangladesh agriculture using a 'holistic' approach.

The term ‘holistic’ is used to signify the coverage of multiple issues (employment, income, poverty and environment) from multiple components (social, economic, biophysical and environmental) that are analysed at multi-levels (macro- and micro-level) by applying multi-techniques (spatial, quantitative and behavioural) using multi-period information (time-series and cross-section).

13.3 Economic impacts of technological change

One of the major arguments in favour of promoting the ‘Green Revolution’ is its potential in increasing aggregate crop production by increasing crop productivity as well as cropping intensity. Also, as the ‘Green Revolution’ technology is input intensive, its widespread adoption is expected to influence the demand for inputs as well as increase their prices. Finally, a positive influence on household income from increased agricultural production is expected.

Impact on aggregate crop production

The impact of technological change on production is analysed by estimating an aggregate crop production function with regionwise disaggregated data for 29 years (1960/61 – 1991/92). Data are taken from the *Statistical Yearbook of Bangladesh* (BBS, 1980, 1989, 1991, and 1995), *Yearbook of Agricultural Statistics* (BBS, 1978, 1986, 1992, 1994), Hamid, (1991 and 1993) and Deb (1995).

The Cobb-Douglas aggregate production function model is used for the estimation:

$$CROP = f\,(LAND,\ LABORFORCE,\ LIVESTOCK,\ FERTILISER,\ HCAP,\ ROAD,\ PMVAR,\ PIRRIG) \quad (1)$$

Note: The explanatory notes for these variables, and for the variables in subsequent equations, are presented in Appendix Table 13.1.

Three alternative models were estimated using different variables to represent technology. Model 1 uses the irrigation index (PIRRIG) as the proxy for the technology variable. Model 2 uses the proportion of area under modern varieties of rice and wheat (PMVAR) as the technology variable. Since both the irrigation index and area under modern varieties are complements, the multiplication of irrigation index and area under modern varieties (PIRRIG*PMVAR) is used in Model 3 to remove any potential multicollinearity problems. The OLS (Ordinary Least Squares) estimation procedure, corrected for first-degree autocorrelated disturbances using the Prais-Winsten method, is used. All three models provided similar results.

Impact on prices

As the increased diffusion of modern agricultural technology increases the supply of foodgrains, the price of foodgrain is likely to remain low relative to other crops. This will lead to a rise in real wages for agricultural labourers for both adopting as well as non-adopting regions. Apart from the indirect favourable impact of modern agricultural technology on the labour and output market, similar adjustment of income transfer can occur through the operation of the land market, particularly through changes in tenurial arrangements and rental income from land. Fertiliser is an integral component of the modern agricultural technology. Hence, a positive association between fertiliser demand and area cultivated under modern varieties of rice and wheat is expected. The increased demand for fertiliser may put an upward pressure on fertiliser prices.

In order to identify factors affecting labour wages, fertiliser prices, land rent and output prices, the following equations are fitted separately to the plot level data:

$$WAGE = f\,(LABOR, OWNLND, MVAR, INFRA, SOIL) \quad (2)$$

$$FP = f\,(FERT, OWNLND, MVAR, INFRA, SOIL) \quad (3)$$

$$LANDRENT = f\,(LANDPC, MVAR, IRRIG, TNC, CAPL, INFRA, SOIL) \quad (4)$$

$$OUTP = f\,(QTY, OWNLND, PMVAR, INFRA, SOIL) \quad (5)$$

OLS estimation procedures were applied to estimate these price functions.

Impact on input demand

Since, modern varieties of rice and wheat production are highly input intensive, the following demand functions for modern inputs are postulated:

$$FERT = f\,(FP, AMLND, MVAR, CAPL, AGCR, INFRA, SOIL) \quad (6)$$

$$LABOR = f\,(WAGE, AMLND, MVAR, AGCR, INFRA, SOIL) \quad (7)$$

$$ANIMAL = f\,(ANIMP, AMLND, MVAR, AGCR, INFRA, SOIL) \quad (8)$$

Furthermore, the adoption of modern varieties is dependent on the availability of irrigation. Therefore, the following equations are presented to explain the variation in adoption of modern varieties:

$$MVAR = f\,(IRRIG, AMLND, CAPL, AGCR, INFRA, SOIL) \quad (9)$$

$$IRRIG = f\,(AMLND, CAPL, AGCR, INFRA, SOIL) \quad (10)$$

Given the demand structure of modern inputs, it is clear that IRRIG and MVAR are endogenous variables since MVAR appear on the right hand side of eqs. (6), (7) and (8) and IRRIG appear on the right hand side of eq. (9). This is, therefore, a case of a simultaneous equation model with recursive structure, where irrigation determines modern technology adoption, and modern technology adoption determines the demand for fertiliser, labour and animal power services. Therefore, the simultaneous estimation of five equations, (6), (7), (8) and (9) or (10) is conducted using the Three Stage Least Squares (3SLS) technique that allows correlation among disturbances in individual equations.

Credit is an important factor in agricultural development as the majority of the farmers lack financial liquidity. Therefore, the identification of factors determining the availability of agricultural credit can serve as a vital instrument in solving the liquidity crisis of farmers. The following equation is fitted to the data at the crop level:

$$AGCR = f\,(OWNLND, MVAR, IRRIG, TNC, CAPL, WORK, FAMILY, EXPCE, INFRA, SOIL) \qquad (11)$$

OLS estimation procedures were applied to the data.

Though pesticides have not been considered as a complementary input to be used in conjunction with new seeds, fertilisers and irrigation while promoting modern technology diffusion, nevertheless they have become a major input in present day agriculture (Pingali, 1995). In order to test whether there is a significant association between modern variety cultivation and subsequent pesticide use, a multivariate analysis is performed at the crop level. The following equation is fitted to the data:

$$PEST = f\,(AMLND, PMVAR, PIRRIG, AGCR, INFRA, SOIL) \qquad (12)$$

The Tobit estimation procedure was applied to the data as some farmers do not apply pesticides and, therefore, have zero values for pesticide use.

Impact on income

Income of a household depends on a host of factors, such as, land ownership, choice of crops, working members in the family, level of education, etc. and whose effects cannot be predetermined. Therefore, in order to assess the impact of modern agricultural technology on annual household income, the following equation is fitted to the household level data.

$$INCM = f\,(AMLND, WORK, CAPL, AGE, TNC, PMVAR, PIRRIG, EDUCH, INFRA, SOIL) \qquad (13)$$

OLS estimation procedures were applied to the data. Separate regressions are undertaken for total family income as well as major component income: crop income, agricultural (crop, livestock, fisheries, and land leasing) income, and non-agricultural income, respectively.

13.4 Social and distributional impacts of technological change

Literature analysing the impacts of modern agricultural technology mostly emphasises the direct effects on income distribution and geographical regions, using the basic argument that technology is not scale neutral and mostly benefits areas endowed with favourable agroecological conditions (Lipton and Longhurst, 1989). However, Hossain *et al.* (1990) argued that modern agricultural technology might also have indirect effects that operate through factor markets and enable transfers of income across socio-economic groups as well as regions. This could occur from a change in the nature of the operation of land, labour and other input markets that would smooth income disparities across socio-economic groups through an adjustment process. The present section analyses the direct effects of modern technology diffusion on regional equity, employment, gender equity in employment, income distribution and poverty. The database, specification of models and procedures employed for individual impact areas are briefly discussed below.

Impact on regional equity

The impact of technological change on regional variations in the level of agricultural development is analysed using cross-section regionwise data for three periods covering a span of 20 years (1972/73 – 1992/93). A linear regression model is specified including indicators representing technological, infrastructural, agro-ecological, crop production efficiency, demographic, and human capital factors. The basic assumption of the model is that there exists a linear relationship between the explained indicator and the set of explanatory indicators (Pokhriyal and Naithani, 1996). The specification is given by:

GVFOOD = f (MVYLD, LVYLD, WHTYLD, FERTRATE, PESTRATE, PMVAR, PIRRIG, CI, SEED, RAIN, DENS, HCAP, CREDIT, ROAD, RDQLTY) *(14)*

A stepwise forward regression estimation procedure is used to identify the significant indicators. Three separate regressions, using triennium averages centred at the middle year for three periods: Period 1 (1973 – 75), Period 2 (1981 – 83) and Period 3 (1991 – 1993) is estimated. Then weighted standard scores are constructed utilising the regression results, which are then used to delineate the regions in descending orders of development levels to identify homogenous agricultural regions. The result is also used to determine sampling locations for the micro-level component in this study.

Impact on employment

It is widely established that modern varieties of rice and wheat utilise more hired labour than local varieties (Hossain, 1989; Ahmed and Hossain, 1990); and Hossain et al., 1990). In order to test this hypothesis and identify factors affecting labour demand, a multivariate analysis is performed at the household level. The following equation is fitted to the data:

LABOR = f (AMLND, MVAR, TNC, WAGE, INFRA, SOIL, SUBP, WORK, WORKW, EDUCH) *(15)*

Both OLS and Tobit (two limit probabilistic regression) estimation procedures were applied to data on hired labour demand as well as total labour demand functions as farmers may have zero values for hired labour use.

Impact on gender in employment

Rural women in Asia play a major role in the agricultural sector particularly in the post harvest processing. However, a major shift in technology has occurred in the post harvesting processing sector, through the introduction of rice mills, which dramatically displaced employment opportunities of rural women involved in the manual husking operation of rice grains. Ahmed (1982) estimated that rice mills displaced 29% of the total husking labor and almost all hired labor displaced were women who have limited alternative employment opportunities. His crude nationwide estimate suggests that, if rice mills are made adequately available throughout the country, a total of 45 million person-days of hired labor would be displaced leading to a reduction in the income of the rural poor of about Tk.450 million at its 1982 level.

In the present study, the issue of gender equity in employment is analysed by comparing the proportion of male and female family labour as well as hired labour used in connection with local and modern varieties of rice and wheat, respectively. Also, the mean difference between the labour wages paid to men and women is analysed and statistically tested.

Impact on income distribution and poverty

Analysis of the distributional impacts of modern agricultural technology is conducted by categorising the villages according to their level of modern technology adoption. Villages with more than 60 percent of land area under modern varieties of rice and wheat are designated as the 'high adopter' villages, between 40 – 60 percent of land area under modern varieties as 'medium adopter' villages, and less than 40 percent land under modern varieties as 'low adopter' villages. For purposes of analysing the distributional impacts of technological change, the concentration of income held by top 10 percent households, income inequality (gini-coefficient) and gini-decomposition analysis are computed for the different adopter categories of villages. For analysing the impact of modern agricultural technology on poverty, a number of poverty measures and indices, such as Sen's poverty index (1976), Kakwani's poverty index (1980) and FGT's (Foster, Greer, and Thorbecke, 1984) poverty measure are utilised.

13.5 Environmental impacts of technological change

The environmental dimension of technological change in agriculture is a relatively neglected area of statistical analysis, despite the fact that the ecological integrity of the agricultural production system is a pre-requisite for sustainability. The present study undertakes some initial analyses, which begin to fill this gap. First, it analyses the environmental impacts of modern agricultural technology as perceived by farmers in the sample of households and villages covered in the survey. This is supplemented by evidence derived from bio-physico-chemical tests of soil fertility and water quality, and from time series data relating to fertiliser and pesticide use and the sustainability of rice and wheat yields. These are used, as longer-term indicators believed to be impacted due to these technological changes. These are used to support (or refute) the conclusions drawn from farmers' perceptions.

Farmers' perception on environmental impacts was elicited in two steps. First, a list of 12 specific environmental impacts[5], that may be associated with technological change, was read out to the respondents who were asked to reveal their opinions on these impacts. Next, they were asked to provide scores, on a five-point scale, on the extent to which they considered that technological changes had resulted in the individually specified impacts. If a respondent considered that the specified environmental impact had not occurred, then it was scored zero. The methods used in the evaluation of environmental impacts are elaborated below and a summary of the principal findings is incorporated into the final section.

Impact on soil fertility

Concerns have been raised in recent years over declining soil fertility as reflected in the falling productivity of crops in Bangladesh (BASR, 1989 and Yano, 1986). Physical and chemical analyses of soil were conducted to evaluate the general fertility of the soil and inter-regional differences (if any) between the study areas. Fifteen composite soil samples (five from each region) of rice fields were randomly selected from within the total sample of households. The soil samples were taken from recently transplanted Boro rice fields.

Ten soil-fertility parameters were tested. These are: (1) soil pH, (2) available nitrogen, (3) available potassium, (4) available phosphorus, (5) available sulfur, (6) available zinc, (7) soil texture, (8) cation exchange capacity (CEC) of soil, (9) soil organic matter content, and (10) electrical conductivity of soil. A composite weighted soil fertility index, based on the test results for the study area, was constructed and incorporated as an independent variable in all the models mentioned above. High index value refers to better soil fertility.

In addition, farmers' perceptions of 'soil fertility decline' were checked against their fertilizer application rates with an *a priori* expectation that a negative association exists between soil nutrient availability and fertilizer application rate. Also the relationship between fertilizer use and organic manure application was analyzed. Additionally, a time-trend analysis of fertilizer use per ha of gross cropped area and fertilizer productivity (aggregate output per kg of fertilizer application) at the regional level for 29 years (1961 – 1992) was carried out.

Impact on other selected components of the environment

An analysis of the effect of technological change in agriculture on human health is beyond the scope of the study. However, an inference of one aspect of the relationship may be attempted by analysing the use of pesticides by farmers, and their perception of the use of this input. The pesticides used by the farmers were assessed with reference to the World Health Organisation (WHO) prescribed chemical hazard categories.

Analysis of the effect of technological change on fish catch was attempted using time-trend analyses of fish catch in open water bodies (rivers, estuaries, and perennial depressions) at the regional level for a period of 10 years (1983 – 1994). Also, a review of the literature on the impacts of Flood Control Drainage and Irrigation (FCD/I) projects was undertaken to support the argument.

Insect/pest and disease infestation was examined by time-trend analysis of pesticide use rates at the regional level for 17 years (1976 – 1993), in addition to the analysis of categories of pesticides used by the farmers mentioned above.

Though, in the case of Bangladesh, arsenic contamination is not due to the increased use of toxic chemicals as may be observed elsewhere, it is the drive for ground water irrigation to support the diffusion of modern agricultural technology, which is primarily responsible for widespread and growing arsenic pollution in the country. This is supported by the findings from a recently conducted large-scale sample survey of arsenic pollution by BRAC (a national NGO) which also covered some of the study villages (BRAC, 1997). Also, findings from the first international conference on arsenic pollution held in Bangladesh during March 1998 support this finding (Ullah, 1998).

Impact on the sustainability of food production

In order to analyse the extent to which growth rates in food production are likely to be sustained in the future, a logistic function is applied to the data on foodgrain (rice and wheat) yield per net hectare for 47 years (1947/48 - 1993/94) and compared with the linear trend. Also, the long term compound annual growth rates of food crops (rice, wheat, and potato) were estimated for the entire period distinguishing between the pre-technological change period (1947/48 - 1967/68) and the post-technological change period (1969/70 - 1993/94). The fitted equations are as follows:

Linear trend function: $FOODYLD = \alpha + \beta T + \varepsilon$ (16)

Logistic trend function: $FOODYLD = 1/(1 + e^{-(\alpha + \beta T)})$ (17)

13.6 Synthesis of impacts and policy implications

The nature of the impacts of technological change in agriculture is complex and multidimensional (see Figure 13.1). Modern agricultural technology increases regional *crop production* but exacerbates regional disparities[6]. On one hand, an increase in aggregate crop production confirms the positive impact of technological change in raising productivity, implying that food production can be sustained in future[7]. On the other hand, the declining yield rate (-1.06% per annum during 1968/69 – 1993/94) of modern rice varieties over time is raising doubt on sustaining food production through technological change alone. Again, the observed increase in modern wheat yield (3.63% per annum during 1968/69 – 1993/94) over time will somewhat offset the effect of a depressing modern rice yield, thereby providing another source of hope for food production sustainability. Current increases in foodgrain production are largely due to switching from local to modern varieties of rice and wheat, which still provide higher yields than local varieties. Whether this can be sustained in the future remains to be determined.

Modern technology diffusion in the agricultural sector has exerted a distinct upward pressure on input and output prices as well as input demands[8]. The upward pressure on *output prices* raises the *income* of the farm producers while the upward pressure on *labour wages* may reduce income inequality through an indirect transfer of income from rich farmers to poor landless labourers, also supported by Hossain (1989). However, the increase in land rents raises equity concerns since landownership in rural Bangladesh is highly skewed with more than 50 percent of the farming population being landless and tenants. Higher land rents imply that the technological change opens up opportunities for the landed elites to raise their rental income through the tenancy market.

Though technological change significantly raised *employment*, it remained highly skewed in favour of men since only male labour are hired to meet the increased demand. Women, constituting half of total population, have failed to get direct benefit from this technological progress as mostly men are hired to meet the increased demand. The few women (12% of total households) who are hired are paid significantly lower wages than men (Rahman and Routray, 1998). However, the failure to increase women's employment opportunities is not solely due to the nature of the technology. Rather it is social and cultural barriers that restrict their participation and their capacity to obtain benefits from this technological change. The simultaneous increase in wages and in the demand for hired labour due to technological progress may redistribute income but the level of redistribution is unlikely to be sufficiently substantial to bridge the gap between the rich and the poor farmers.

Technological change has significantly contributed to increases in income but it has also contributed to worsening *income inequality*. The concentration of income is estimated to be highest in the 'high adopter' villages (top 10 percent household estimated to control 30 percent of per capita income while the bottom 50 percent control only 19 percent). Gini-decomposition analysis reveals that the cultivation of modern variety crops alone contributes 35 percent to total income inequality.

The adoption of modern technology is also correlated with the incidence of village poverty. All the measures of poverty revealed that poverty is high in 'high adopter' as well as in 'low adopter' villages. It is in the 'medium adopter' villages, characterised by a diversified cropping system, that the incidence of poverty and income inequality is estimated to be lowest.

The findings relating to the *environmental impacts* of modern agricultural technology are not encouraging. The detrimental effects of the modern technology on soil fertility are clear as evidenced from farmers' perception ranking (ranked one, index value 0.79), test results of soil nutrients, and negative growth rate of aggregate output per unit of fertiliser application at regional level for the period 1960/61 – 1991/92. Partially associated with this are the adverse effects on human health as well as decline in open water fisheries that served as a major source of animal protein for the rural poor in Bangladesh (Rahman, 1998). The decline in fisheries resources may also be partly attributed to over-fishing, increased population pressure and poor management. Increases in crop diseases, pests and insect attacks are also evident. In addition, the contamination of water bodies through chemical run-off and eutrophication associated with modern technology, though it cannot yet be conclusively proved, remains a major environmental concern for the future (Rahman, 1998). Arsenic pollution in groundwater, although it is caused by geogenic processes, is brought to the surface through anthropogenic processes stimulated by increased demand for irrigation for the modern variety cultivation in one hand and demand for safe drinking water on the other. Surface soils in intensively irrigated regions now contain high levels of arsenic (Ullah, 1998). In summary, a complex intertwined mix of positive and negative consequences are associated with this highly proclaimed technological breakthrough in agriculture that need to be carefully evaluated in order to pave the way for sounder-based, future agricultural development plans.

Characteristics of 'medium adopter' villages

Analyses of the distributive effects of modern technology diffusion clearly reveal that it is the 'medium adopter' villages that experience least income inequality and the lowest incidence of poverty. In order to identify the conditions associated with the superiority of this category of village, a number of the socio-economic characteristics of the villages studied, classified by adopter category, have been examined. It was found that a number of features distinguish 'medium adopter' villages from the other two categories. Striking differences exist in the proportion of large farmers, farm size, level of irrigation development, level of modern variety adoption, cropping intensity, level of fertiliser use, and level of organic manure used in the 'medium adopter' villages[9].

Therefore, one possible strategy for sustainable agricultural development planning will be to internalise the salient features of the successful 'medium adopter' villages and to replicate and/or create such conditions in 'high adopter' as well as 'low adopter' villages.

Strategies for agricultural development planning and policy options

In this sub-section an integrated agricultural development plan is outlined which incorporates the following policies: (1) balanced modern technology diffusion, (2) crop diversification, (3) soil fertility management, (4) strengthening bottom-up planning and agricultural extension services, (5) rural infrastructure development, (6) price policy prescription, (7) economic diversification. The first three components are interlinked with each other and need to be implemented simultaneously. The remaining four components will smooth the development process by: (a) enhancing effective input delivery and output marketing systems through developing appropriate infrastructure, (b) responding to price signals which reflect more appropriate pricing policies, and (c) engaging in non-agricultural income generating activities through economic diversification.

The balanced adoption of modern agricultural technology along with crop diversification should be one of the major policies. This is based on the experience of 'medium adopter' villages, which have achieved a balance between modern varieties of rice and wheat as well as with non-foodgrain crops. This suggestion contrasts with almost all earlier evaluations of the 'Green Revolution' that suggested spreading modern technology to its fullest extent.

Additionally, the adoption of an effective pricing policy is pivotal to enhancing crop diversification by reducing the price risks associated with non-foodgrain production. On distributional grounds, subsidies are suggested on animal power services and output prices that can be implemented across the board. Also, the development of crop insurance policies, through public and private insurance agencies, and of marketing, transportation and infrastructural facilities, are proposed to reduce harvesting and marketing risks to encourage crop diversification.

Human resource development, to provide technical skills in growing non-foodgrain crops, to raise awareness of the adverse environmental impacts of technological change, and to improve enterprise development skills, are also proposed to encourage greater crop and other forms of economic diversification. Improving the technical know-how of farmers can be achieved by: (a) strengthening the existing agricultural extension network, utilising a bottom-up planning approach, and (b) collaborating with national and regional level NGOs working at the grassroots level.

The key to success in realising this planning strategy is co-ordination between the major facilitators: relevant government agencies, NGOs, financial institutions and the farming communities. The development programs of individual agencies must be co-ordinated in order to enable the farming and rural communities to reap the full benefit from their interventions. This implies substantial changes in the attitudes of government agencies towards development programs along with a major restructuring of individual program scheduling, budgeting, and implementation strategy.

In conclusion, Bangladesh needs agricultural technologies that are more labour-intensive, which provide more equal opportunities for men and women, reduce income inequalities and poverty and impose fewer negative impacts on the environment. A properly designed crop diversification policy and its effective implementation would be an important first step toward the goal of achieving sustainable development. The implementation of an economic diversification policy and the improvement of rural infrastructure would enhance this process.

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MULTIFACETED IMPACTS OF TECHNOLOGICAL CHANGE IN AGRICULTURE

ECONOMICS IMPACTS	SOCIAL/DISTIBUTIONAL IMPACTS	ENVIRONMENTAL IMPACTS	IMPACT ON SUSTAINABILITY
Impact on Crop Production • Aggregate crop production: increase	**Impact on Regional Equity** • Regional foodgrain production: increase • Regional inequity: increase	**Impact on Soil Fertility** • Soil fertility: decline	**Trend in Foodgrain Yield** • Long-run modern rice yield: declining • Long-run modern wheat yield: increasing
Impact on Prices • Labour wage: increase • Fertiliser price: increase • Land rent: increase • Output price: increase	**Impact on Employment** • Hired labour demand: increase • Total labour demand: increase	**Impact on Other Selected Components of Environment** • Human health: increased hazards • Fish production: decline • Insect/pest attack: increase • Crop disease: increase • Water quality: deteriorate	**Prospects for Sustainability** Foodgrain production sustainability: undetermined
Impact on Input Demand • Fertiliser demand: increase • Animal power demand: increase	**Impact on Gender Equity** • Employment: Skewed in favour of male labour		

- Pesticide use demand: increase
- Agril. credit demand: increase

<u>Impact on Income</u>

- Crop income: increase
- Agricultural income: increase
- Non-agricultural income: lower

- Family female labour supply: increase

<u>Impact on Income Distribution and Poverty</u>

- Income distribution: higher inequality
- Poverty: higher poverty

Note: Based on the analytical results obtained from utilising equation (1) through (17) and other subsequent qualitative analyses mentioned in Sections 13.3 – 13.5.

Figure 13.1: Synthesis of socio-economic and environmental impacts of technological change in agriculture in Bangladesh, 1996

Source: Rahman (1998).

ANNEX

Table 13.1: Definition of the variables used in the models

MVYLD	= weighted average yield per ha of all modern varieties of rice (ton/ha)
LVYLD	= weighted average yield per ha of all local varieties of rice (ton/ha)
WHTYLD	= weighted average yield per ha of all varieties of wheat (ton/ha)
FOODYLD	= weighted average yield per ha of all varieties of rice and wheat (ton/ha)
FERTRATE	= fertiliser used per ha of gross cropped area (kg/ha)
PESTRATE	= pesticide used per ha of gross cropped area (Tk/ha)
CI	= cropping intensity (%)
SEED	= improved seed of rice and wheat distributed per ha of gross cropped area (kg/ha)
RAIN	= actual total annual rainfall (mm)
DENS	= population density per ha of gross cropped area (persons/ha), a proxy measure for population pressure
HCAP	= percent of literate population (%), a proxy measure for human capital
CREDIT	= agricultural credit disbursed per ha of gross cropped area (‘000 Tk/ha)
ROAD	= road density per sq km of land area (km/km^2), a proxy measure of infrastructure at the macro or regional level
RDQLTY	= ratio of unpaved road to paved road (unit less), a proxy measure of the quality of road indicating accessibility
GVFOOD	= gross value of all varieties of rice and wheat per ha of gross cropped area (‘000 Tk/ha)
CROP	= value of rice (all varieties), wheat, jute, sugarcane, potato, pulses, oilseeds at 1984/85 prices of all region (‘000 taka)
LAND	= area under all crops included in output (CROP) is considered as the land area under cultivation (ha)
LABORFORCE	= agricultural labour force of the region constructed from census data with trend extrapolation model (persons)
LIVESTOCK	= total draft animals of the region estimated using linear trend extrapolation from livestock census data (number)
FERTILISER	= total fertiliser (urea, phosphate, potash, and gypsum) use in the region weighted at 1984/85 prices (taka)
MVAR	= amount of cultivated land under modern varieties of rice and wheat (ha)
PMVAR	= proportion of cultivated land under modern varieties of rice and wheat (%)
IRRIG	= amount of cultivated land under irrigation (ha)
PIRRIG	= proportion of cultivated land under irrigation (%)
LABOR	= number of days of total labour used in crop production (days)
WAGE	= labour wage at the farm-level (taka/day)

FP	= fertiliser price at the farm-level (taka/kg)
FERT	= amount of fertiliser used by the household (kg)
ANIMP	= animal power price at the farm-level (taka/pairday)
ANIMAL	= amount animal power service used by the household (pairday)
OUTP	= price of crop output at the farm-level (taka/kg)
QTY	= amount of crop produced by the household (kg)
PEST	= amount of pesticide used by the household (taka)
AGCR	= amount of agricultural credit borrowed by the household (‘000 taka)
CAPL	= value of farm capital excluding land asset (‘000 taka)
AMLND	= amount of land cultivated by the household (ha)
OWNLND	= amount of land owned by the household (ha)
LANDPC	= amount of land owned per capita (ha)
LANDRENT	= amount of land rent per ha of cultivated land (‘000 taka)
TNC	= the amount of cultivated land rented-in (ha)
WORK	= number of working members in the household (persons)
WORKW	= number of female working members in the household (persons)
FAMILY	= number of family members in the household (persons)
SUBP	= subsistence pressure measured as number of family members in the household (persons)
EDUCH	= completed years of formal schooling of the head of household (years)
EXPCE	= years of experience of farmer in crop production (years)
AGE	= age of the farmer (years)
INFRA	= index of underdevelopment of infrastructure (the higher the index the more underdeveloped is the infrastructure)
SOIL	= index of soil fertility (the higher the index the better is the soil fertility)
INCM	= total family income of the household (‘000 taka)

Notes

[1] The present study is extracted from the first author's Ph.D. dissertation submitted at the Asian Institute of Technology (AIT), Bangkok, Thailand. The focus of this paper is on elaborating the approach utilised for analyzing the mulitfaceted impacts of technological change in agriculture. As such, details of the anaytical results are avoided while a synthesis of the results is provided at the end of the paper (for details, see Rahman, 1998).

[2] Essentially, this is an outcome of the exercise conducted at national-level to examine the regional equity. The five levels are: 'very high', 'high', 'medium', 'low', and 'very low' level, respectively.

[3] Regions from the two extremes, 'very high' and 'very low' level are avoided. The justification is that the Chittagong region, falling under the 'very high' level, is already transforming into an urban-industrial region and the regions under 'very low' level, namely, Khulna and Faridpur regions, suffer from agro-ecological and other biophysical constraints.

[4] The crop groups are: local Aus rice, modern Aus rice, local Aman rice, modern Aman rice, local Boro rice, modern Boro rice, local wheat, modern wheat, jute, potato, pulses, spices, oilseeds, vegetables, and cotton. Pulses in turn include lentil, gram, chola, and khesari. Spices include onion, garlic, chilly, dhania, ginger, and turmeric. Oilseeds include sesame, mustard, and groundnut. Vegetables include brinjal, cauliflower, cabbage, arum, beans, gourds, radish, and leafy vegetables.

[5] The 12 specific environmental impacts of technological change are: (1) reduce soil fertility, (2) affects human health, (3) reduce fish catch, (4) increase disease in crops, (5) compact/harden soil, (6) increase insect/pest attack, (7) increase soil erosion, (8) increase soil salinity, (9) contaminate water source, (10) increase toxicity in soil, (11) creates water logging, and (12) increase toxicity in water.

[6] In identifying the significant variables explaining regional variation using eq. (14), the technology indicators (PMVAR and PIRRIG) were found to significantly (p<0.01) positively influence foodgrain output (GVFOOD) emphasising their crucial role in regional crop production. BASR (1989) and Alauddin and Tisdell (1991) also attributed differential access to irrigation as the major reason for regional variation in crop production growth (For details, see Rahman, 1998).

[7] In the estimation of aggregate crop production function utilising eq. (1), technology variable (PMVAR as well as PIRRIG) was found to be significantly (p<0.01) positively associated with crop production over time. The estimate of 'returns to scale' using conventional inputs reveals 'constant returns to scale (1.08 ≈ 1.00)' prevails in crop sector in Bangladesh. When non-conventional factors, such as technology, infrastructure and education variable is incorporated, an 'increasing returns to scale (1.17 > 1.00)' to crop sector is observed. The output elasticity of this technology variable is estimated at about 0.09 (For details, see Rahman, 1998).

[8] The technology variable (PMVAR) is estimated to be significantly (p<0.01) positively related to labour wage, fertiliser price (positive but not significant), animal power price, land rent, and output prices (eq. 2 through 4). The joint estimation input demand equation (eq. 6 through 10) revealed that PMVAR is significantly (p<0.01 and p<0.05) related to fertiliser, labour, and animal power demand, respectively. Also, PMVAR is significantly (p<0.10) related to agricultural credit demand (eq. 11) and PIRRIG is significantly (p<0.01) related to pesticide use (eq. 12), respectively (for details, see Rahman, 1998).

[9] The proportion of large farmers (owning land > 2.00 ha) in 'medium adopter villages (MAV)' are 16% as compared to 6 – 7% in 'high adopter villages (HAV)' and 'low adopter villages (LAV)'. Average farm size in MAV is 0.96 ha as compared to 0.68 and 0.62 ha in HAV and LAV, respectively. The irrigation level is strikingly similar between HAV (62%) and LAV (60%) of total land area. Area under modern varieties is 75%, 47% and 32% in HAV, MAV and LAV, respectively. The cropping intensity is highest in MAV (190%) followed by HAV (177%) and LAV (160%). Fertiliser use is highest in HAV (224 kg/ha) followed by MAV (206 kg/ha) and LAV (164 kg/ha). Organic manure use rate is highest in MAV (1.5 ton/ha) as compared to 1.1 ton/ha in HAV and only 0.2 ton/ha in LAV, respectively (for details, see Rahman, 1998).