From Plot to Plate: Linking Agricultural Productivity

and Human Nutrition in Bangladesh

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Abstract

Recent global food crisis combined with a series of natural disasters had a significant impact on the availability and affordability of food in Bangladesh, threatening to reverse the progress made in poverty reduction and hunger elimination achieved in the past decade. In this paper, we examine the direct and indirect linkages between agriculture and nutrition in Bangladeshi households, with a focus on rice. We first investigate the factors of rice productivity at plot, household, and village level by estimating an endogenous switching model of yield by season. Next we inspect the relationship between income and nutrition using a partial linear model to control for household characteristics. Finally we are able to simulate how increased rice yields and elevated rice price affect consumption decisions and nutritional status of households.

Estimation results indicate that farmers' decision to use irrigation and yield response are determined by different factors, including input intensification, land ownership, education, and access to assets and infrastructure. Household nutrition intake is influenced by household asset, household head characteristics, and consumption of own production. Simulation results suggest increasing rice yield is an effective way to improve nutrition intake in Bangladesh. Our results highlight the importance of input availability and timeliness to increase rice production and achieve self-sufficiency. Government investment in rural infrastructure and service proves to increase both food supply and nutrient intake. In the long run, food security and nutrition can only be achieved through adoption of modern technology developed by agricultural R&D and extension activities. There is no evidence of negative impact of rice price on nutrient intake, implying that households are able to cope with high food prices through shifting to less balanced diets or through cutting expenditure in other activities like education and health care. At the same time, policies targeting vulnerable groups are needed to address food insecurity and malnutrition.

Key words: Bangladesh, nutrition, rice, productivity, endogeneity, elasticity

JEL code: C14, O13, Q12, Q18

1. Introduction

The global food crisis triggered by the depletion of food stocks and the sharp increase in food prices during 2007 and 2008, especially of staples, has raised serious concerns about food and nutrition situation of people around the world, particularly the poor in developing countries. The shrinking availability and affordability of food have detrimental effects on the progress of the achievement of Millennium Development Goals.

Increased world prices of rice and adverse weather in 2007 translated into elevated food prices in Bangladesh, which had a large impact on the income and food security of the population. At household level, net sellers benefited from rising food prices, while for net buyers the high food prices resulted in serious deterioration of food security and severely compromised households' ability to meet their daily dietary requirements. Household real monthly income decreased by 12 percent in 2008 compared to 2005, terms of trade further decreased from the previous year, and real wage rates remained unchanged (Murshid et al. 2008). Food expenditures increased to unprecedented levels and represented 62 percent of total household's expenditures, while the food share was 52 percent in 2005. The poor and food insecure suffered the most, seeing their purchasing power eroded.

Nutritional situation in Bangladesh was already precarious before the food price crisis as the country is at the bottom quartile of the Global Hunger Index (Von Grebmer et al. 2009) and the rates of malnutrition in Bangladesh are among the highest in the world. High food price forced households to shift towards less-balanced diets, resulting in rising prevalence of nutritional deficiency and overall food consumption and exacerbating the persistently high levels of malnutrition in Bangladesh.

The impact of the high prices on the household livelihood was further worsened by the lack of diversification in Bangladesh agriculture and diet. For decades, the crop sector has been overwhelmingly dominated by rice. In 2008, 11.7 million hectares of cultivated land were devoted to rice, which comprises 80 percent of the total cultivated land in Bangladesh, or 95 percent of cereal land (FAO 2010). Rice is the major means of income, grown by more than 70 percent of the households, mostly for subsistence needs (HIES 2005/06). On the demand side, rice is the staple food of typical Bangladeshi diet for 140 million people, and it provides 65 to 75 percent of the population caloric needs (HIES 2005/06). It is also a significant source of other nutrients, with over half of protein, iron, and riboflavin intake needs are met by rice consumption (Murshid et al., 2008). Food security, in the context of Bangladesh, is therefore strongly linked around the production, distribution, consumption, and price stability of rice.

Rice is grown in three overlapping seasons: Aus (March-June), Aman (July-December) and Boro (December-June). In recent years, Boro area has more than quadrupled as area under low-yielding deepwater Aman and Aus has been converted to irrigated Boro due to increased availability of irrigation and drainage facilities. While Aman has historically been regarded by policy makers and farmers as the dominant rice crop, Boro rice has been the leading contributor of rice output. The growth in rice output and yield over the last three decades has been characterized by increasing reliance on irrigated Boro cultivation and using fertilizer-intensive high-yielding varieties (HYVs). Modern HYV coverage was almost complete for Boro by 2007-08 and more than 80 percent of Aman and 70 percent of Aus rice production comes from HYV.

Despite increased reliance on HYV, the output growth in Aman has been rather modest at 1.1 percent per year, reflecting not only loss of area but also slower rate of yield compared to Boro at 6.1 percent per year (Asaduzzaman et al. 2010). The output growth of Aman mainly comes from yield improvement as area has been declining, while the growth of Boro output is a combined result of expanded area and increased yield. Despite Boro increasing output dominance, further output expansion faces challenges of high production cost of input intensive HYVs. Future increase in rice output over the long run faces multiple constraints including little scope of area expansion, limited water resources, declining soil health and productivity, susceptibility to natural hazards, and plateauing yields. Research efforts are needed for yield breakthrough in rice by exploiting new technology and developing drought-resistant varieties.

We aim to study the role of agricultural production in addressing food security and malnutrition. Linkages between crop management and production, especially staple crops, and human nutrition are often not sufficiently explored in the current literature as research in these two areas seldom overlaps. This paper addresses a critical question of studying agricultural production and nutrition as a system, instead of separate parts. The specific objective is to explore how increased rice productivity can make significant contributions towards nutritional status through increasing the food supply and improved access to food.

This study contributes to the literature of supply response and nutrition analysis in several ways. First, it updates the literature of agricultural supply in Bangladesh and presents a possible approach for rural farmers to benefit from favorable rice market conditions through improved input intensification, agricultural research, irrigation, and rural infrastructure. Second, it makes connections between nutrition and production analysis, allowing an assessment of the impact of rice yield on food supply and on human nutrition. Third, it extends traditional supply analysis by addressing the endogeneity of irrigation in production process. At the same time, this study incorporates home production in nutritional analysis. Fourth, it goes beyond simple energy requirement and measures the effects of income and policies on micronutrients consumption in the country,

The paper is organized as follows. Section 2 explains theoretical framework. We summarize data in section 3 and the results of econometrical analysis in section 4. The paper concludes in section 5 with policy recommendations for sustainable strategies to promote long-term food supply and better nutrition intake.

2. Theoretical Framework

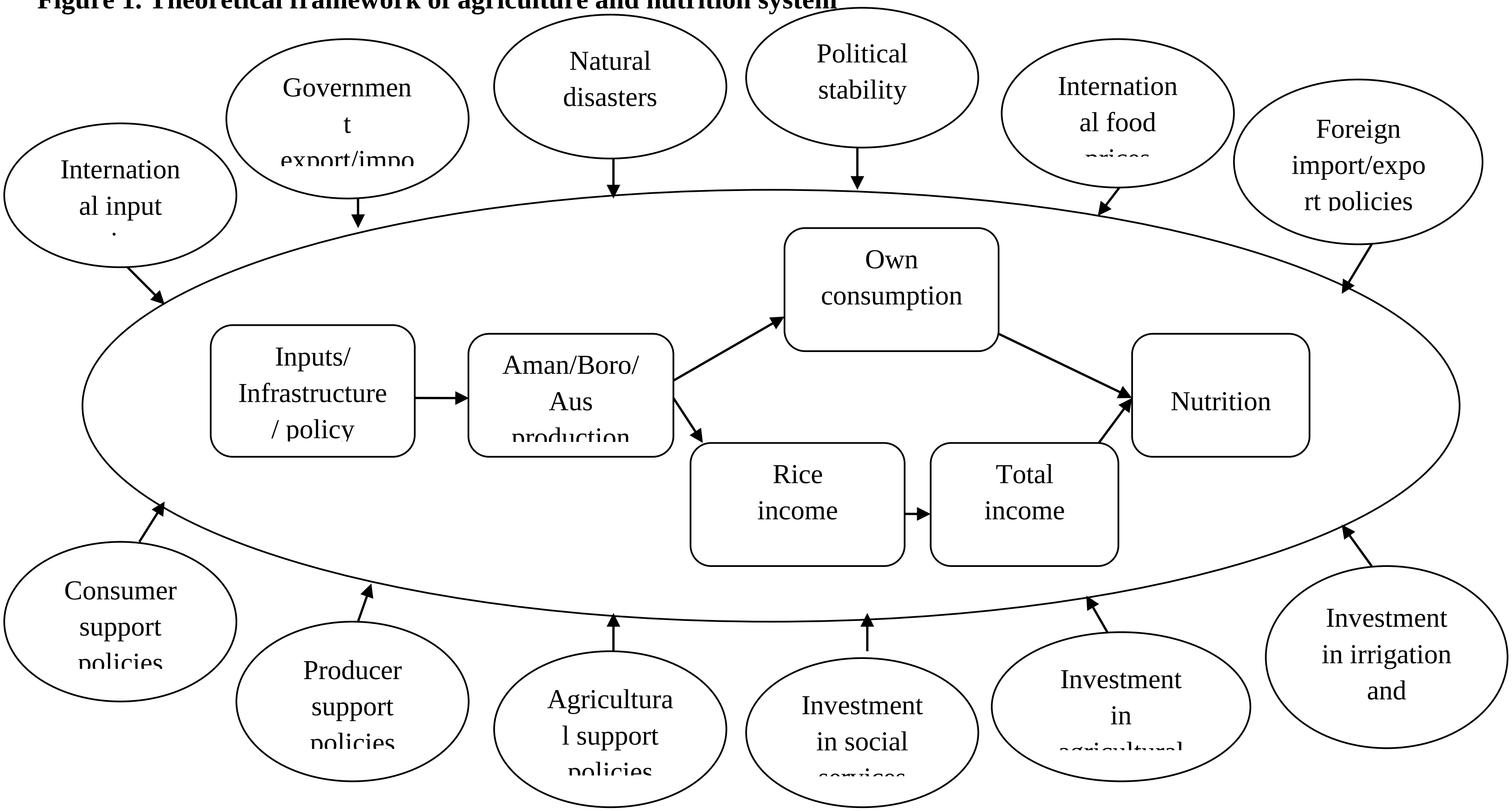
2.1. Outline of framework

Despite significant growth in cereals production, future increase in rice output over the long run faces multiple constraints including little scope of area expansion, plateauing yields, declining soil health and productivity, limited water resources, climate change, population growth, and susceptibility to natural hazards. On the other hand, nutritional status depends on access to food supplied by agriculture, and crop productivity is a main determinant of diets and nutrition status. Therefore, it is appropriate to examine the food supply and nutrient intake in a holistic manner. A link between agriculture and nutrition will help us to understand the determinants of malnutrition and identify ways to improve nutritional status through agricultural development in Bangladesh.

Deb (2008) measures the level of diversification of crops in Bangladesh and notes little progress in this aspect. Actually, the situation has deteriorated since 2000 and households' reliance on rice as major nutrition source increased. Given the dominant role of rice in income generation and consumption intake of Bangladeshi households, increased rice production could have a significant universal impact on Bangladeshi nutritional status. Therefore, we will focus on rice yield and its role in nutrition intake in this study.

Kataki and Babu (2002) pointed out the similarities between the conceptual models of malnutrition and household food security in areas like food production, security and nutrition intake. The framework of this study is presented in Figure 1. Rice production affects household's nutritional intake mainly through two channels: directly, through own consumption and indirectly, through its contribution to the total household income. Total household rice production in Bangladesh is almost solely dependent on the yields which in turn are influenced by the amounts of agricultural inputs (fertilizers, labor, and irrigation) allocated towards rice production by the household. Rice is a recipient of the majority of agricultural inputs used, a source of nutrition as home consumption, and a contributor of household income through sale of surplus production in the market. Additionally, households allocate large percentage of their total income towards food purchases, mostly rice. When combined together, direct household consumption of own production and food purchases determine the complete nutritional intake of the households.

Figure 1. Theoretical framework of agriculture and nutrition system



Source: Authors.

2.2. Agricultural productivity

To identify the response of farmers to a changing environment, we estimate a yield function and examine how farmers could increase yield through intensified input use and improved public provisions. The common factors typically used in empirical production analysis include irrigation, research investment, extension services, access to capital and credit, agro-climatic conditions, and rural infrastructure. Sadoulet and de Janvry (1994) provide excellent reviews of the methods and empirical studies in explaining the dynamics of supply in agriculture.

We choose a typical Cobb-Douglas functional form to represent the production relation between output and inputs. The Cobb-Douglas function has many advantages which result in its broad applications in empirical work. First, there is an exact dual relationship between the Cobb-Douglas production and profit functions (Sadoulet and de Janvry 1994). Second, the estimated coefficient of an input from a linearized Cobb-Douglas function is the direct elasticity of the input. The following Cobb-Douglas yield function is chosen to represent the production technology of Bangladeshi farmers:

$$\log(\mathrm{y}) = \log(\mathrm{A}) + \sum_{\mathrm{i}} \alpha_{\mathrm{i}} \mathrm{logch} \mathrm{x}_{\mathrm{i}}) + \sum_{\mathrm{j}} \beta_{\mathrm{j}} \mathrm{logch} \mathrm{Z}_{\mathrm{j}}) \qquad (1)$$

Where rice yield *y* is a function of inputs *x*, including labor, fertilizer and irrigation applied per unit of land; Z_{j} includes other fixed and semi-fixed inputs that are exogenous such as household head characteristics, as well as infrastructure and government policies; α_{i} and $\beta_{\mathrm{j}}$are coefficients to be estimated; and *A* is a constant. Please note that some of the *Z* variables are not logged because they are dichotomous.

When estimating the effects of inputs and infrastructure on rice productivity, we need to address the issue of heterogeneity and endogeneity. The endogeneity issue arises when households that choose input intensive production can be endowed with better soil or resources. That is, a household's input use decision is endogenous to irrigation. For example, some unobserved factors that affect the choice of irrigation could also affect farmers' demand for fertilizer. In addition, households using irrigation and not using irrigation are not homogenous with respect to their production behavior. Consequently, the effect of inputs on agricultural productivity may not be independent of irrigation usage. Therefore, estimation methods that pool all observations together to estimate a yield function can be inappropriate and separate functions for irrigated and non-irrigated plots should be specified. Neglecting the possible sample selection bias can lead to misleading results. Endogenous switching regression model is an appropriate solution because it simultaneously addresses both heterogeneity and sample selection bias.

The endogenous switching regression employs a two-stage approach to describe the behavior of a farmer. In the first stage, a probit model is applied to determine a household's irrigation condition based on a number of irrigation specific variables. In the second stage, two separate regression equations are set up to model rice productivity over inputs, household characteristics, and rural infrastructure, conditional on the household's irrigation usage. That is, the observations are sorted over two different groups by selection equation. Following Lokshin and Sajaja (2004), irrigation condition of household i is described as a selection (or constrained) function I_i^*, which is a function of explanatory variables

$$I_i^* = \gamma Z_i + u_i \tag{2}$$

where Z_i is a vector of exogenous variables, γ is a vector of parameters, and u_i is a random disturbance. A household is irrigated (not irrigation constrained) if the selection function is greater than zero. The function that indicates the household's irrigation status is defined as

$$I_i = 1, if\ \gamma Z_i + u_i > 0$$

$$I_i = 0, if\ \gamma Z_i + u_i \leq 0 \tag{3}$$

The rice yield (productivity) function of two groups of households (using and not using irrigation) is modeled as

$$y_{1i} = X_{1i}\beta_1 + \varepsilon_{1i}, if\ I_i = 1$$

$$y_{2i} = X_{2i}\beta_2 + \varepsilon_{2i}, if\ I_i = 1 \tag{4}$$

where y_{1i} and y_{2i} are the rice yield for household using and not using irrigation, respectively; X_{1i} and X_{2i} are vectors of exogenous variables; β_1 and β_2 are vectors of parameters; and ε_{1i} and ε_{2i} are error terms. We assume that u_i, ε_{1i} and ε_{2i} have a tri-variate normal distribution with mean vector of zeros and covariance matrix

$$\Omega = \begin{pmatrix} \sigma_u^2 & \sigma_{1u} & \sigma_{2u} \\ \sigma_{1u} & \sigma_1^2 & . \\ \sigma_{2u} & . & \sigma_2^2 \end{pmatrix} \tag{5}$$

where σ_u^2 is a variance of the error term in the selection equation, σ_1^2 and σ_2^2 are variances of the error terms in the regression equations, σ_{1u} is a covariance of u_i and ε_{1i}, and σ_{2u} is a covariance of u_i and ε_{2i}. The covariance between ε_{1i} and ε_{2i} is not defined, as y_{1i} and y_{2i} are not observed simultaneously. We normalize σ_u^2=1 as γ is estimable only up to a scalar factor.

Because the disturbance terms in Equation (4) are conditional on the sample selection criterion and thus have non-zero expected values, The OLS estimates of β_1 and β_2 will be inconsistent due to sample selection bias (Maddala 1983). Models with endogenous switch can be fitted one equation at a time by either two-step least squares or maximum likelihood estimation. However, both methods are inefficient and require potentially cumbersome adjustments to derive consistent standard errors. To obtain efficient and consistent estimators of the endogenous switching regression model, we use the full information maximum likelihood (FIML) method to fit both selection and regression equations simultaneously. This approach hinges on the assumption of joint normality of the error terms in both equations.

2.3. Nutrient-income elasticity

We estimate nutrition intake as a function of income because past studies find a unidirectional relationship from income to calorie intake, but not the opposite (Dawson 2002). Previous studies on the nutrient-income, especially calorie-income, suggest nonlinear relationships, and the poor has a higher elasticity than the rich (Subramanian and Deaton 1996, Skoufias 2003, Skoufias et al. 2009). In this case, incorrect parameterization of the regression equation might result in inconsistent estimates. In order to get a better sense about how the income elasticity of income varies with income level, we combine the parametric functional form and nonparametric techniques, called semi-parametric partial linear regression, to obtain consistent estimates of the parameters of interest. This approach gives full flexibility in linking income to nutrient intake, while allowing researchers to control for other household and village characteristics.

Following Yatchew (1997, 1998, 2003) and Lokshin (2006), a difference-based semi-parametric estimation is used to fit the partial linear regression model. Consider a semi-parametric partial linear regression is postulated as

$$y_i = m(z_i) + x_i\beta + \varepsilon_i, \ i=1,\ldots,N \quad (6)$$

where z is a random variable, x is a vector of random variable, $E[y|x,z] = m(z) + x\beta$, and ε_i is an independently and identically distributed error term with zero mean and $Var[y|x,z] = \sigma_\varepsilon^2$. The nonlinear function m(z) is a smooth, single-valued function with a bounded first derivative. In this model, the parametric linear part $x\beta$ and nonparametric part $m(z)$ are additively separable.

Following the differencing approach suggested by Yatchew (1997), the first step is to sort the data by ascending values of *z* (in this case per capita income). The first order difference of Equation (6) yields

$$y_i - y_{i-1} = [m(z_i) - m(z_{i-1})] + (x_i - x_{i-1})\beta + (\varepsilon_i - \varepsilon_{i-1}), \ i=2,\ldots,N \quad (7)$$

If z_i and z_{i-1} are close enough in the sorted data, the nonparametric part $[m(z_i) - m(z_{i-1})]$ will approach zero. Accordingly, the difference Equation (7) on the sorted data will remove the nonparametric componentm(z_i). Under standard assumptions, the parameters in Equation (7) can be estimated as $\hat{\beta}$ with OLS. Subtracting the estimated parametric part from both sides of Equation (6)

$$y_i - x_i\hat{\beta} = x_i(\beta - \hat{\beta}) + m(z_i) + \varepsilon_i \cong m(z_i) + \varepsilon_i, \ i=1,\ldots,N \quad (8)$$

Because $\hat{\beta}$ converges quickly to β, the consistency optimal rate of convergence, and construction of confidence intervals for *m* remain valid and could be estimated by nonparametric estimation of nonlinear function *m*. It is achieved by locally tri-cubic weighted regression so that the points close to x_i gets the highest weight and points farther away receive less weight. The procedure is repeated to obtain the smoothed value for every point in the data. This approach is superior to the polynomial method because of its distinctive feature of locality. Unlike polynomial method with constant coefficients globally, local smoothing ensures that events occurred at one extreme of the explanatory variable won't transmit to the fitted value on the other extreme.

3. Data

The data we used are based on a sample of 1,237 households in 50 villages surveyed in 2005/06 as part of the International Food Policy Research Institute (IFPRI) Chronic Poverty and Longer Term Impact Study in Bangladesh project. The four IFPRI survey sites are marked in Figure 3.1. These sites are (1) Saturia thana, Manikganj district; (2) Jessore Sadar thana, Jessore district; (3) Gaffargaon thana, Mymensingh district, and (4) Pakundia and Kishoreganh Sadar thana, Kishoreganj district. Unlike HICES, this survey is not nationally representative. The survey collects extensive socioeconomic information as well as detailed information on household production and consumption activities which come very useful for our analysis. Specifically, the production module includes information on the quantities and value of crops harvested and detailed information about the amounts and cost of major crop inputs (labor, fertilizers, rent). The survey also includes data on access to community and social services (e.g., roads, electricity, water, markets, schools, and health facilities).

The food expenditure section contains important information on the value and quantities of food consumed disaggregated by food item and food groups and reported for the last 3 and 7 days. In addition, it also distinguishes the sources of the consumed food, disaggregating further by purchases, own production source, and other sources (i.e. gifts from neighbors and relatives). We use standard conversion tables to convert the reported food quantities consumed into their caloric, macronutrient and micronutrient composition. The conversion has been done for the following macronutrients and micronutrients: protein, fat, calcium, iron, riboflavin and beta-carotene in order to be able to assess the nutrient value of the households' consumption patterns.

Figure 3.1. Map of Bangladesh and IFPRI survey sites

Source: Author's preparation based on map from http://www.mapsofworld.com/bangladesh/bangladesh-political-map.html.

3.1. Production patterns

Rice is the predominant crop grown by the 73 percent of households reporting crop cultivation. Over 80 percent of cultivated area is devoted to rice cultivation to generate three quarters of total production value. An important part of household income comes from selling rice. On average, rice accounts for 10.3 percent of total household income, of which 6.5 percent is from boro, 1.1 percent is from Aus and 2.7 percent is from Aman. Among rice-growing households, the majority of Aman and Boro harvest is saved for the households' own consumption. Only 6.4 percent of Aus, 17 percent of Aman and 24 percent of Boro make its way to the market.

Rice plays a vital role in poor households, representing 81.3 percent of crop production and 10 percent of household income. Households in higher income brackets display a larger diversity in crop production, allocating more land to high value-added vegetable, fruits, spices and cash crops. However, rice is still the dominant crop for rich Bangladeshi households: 78.7 percent of crop land is used for rice production among the richest quintile, providing 67 percent of crop production and 7.8 of total income. Poor households tend to allocate slightly more rice output for own consumption and less for sale, but the share of own consumption is overall high across all income quintiles.

The descriptive statistics of household rice production are summarized in Table 1. First, Bangladeshi rice farmers operate on extremely small and fragmented plots. An average household operates about 0.75 hectare of crop land, of which 0.64 hectare is devoted for rice cultivation. On average, a household works on 5-6 plots, of which about 3 plots are for rice production, and each plot is about 0.1 hectare. Aman and Boro are the major seasons for rice production, accounting for 43.6 and 46.5 percent of total annual rice cultivated area. Average rice yield at plot level reaches 3.6 and 5.8 tons per hectare for Aman and Boro, respectively. Families allocate about 67.6 man days of labor per hectare for rice, and use additional 60 man days. High-yield varieties are widely adopted and more than 96 percent of rice plots are using HYV seeds.

Urea is the main fertilizer and its consumption reaches 161 kilo per hectare for Aman and 240 kilo per hectare for Boro. Boro also shows intensive demand for phosphate and potassium fertilizers and manure. Compared with the recommended fertilizer amount (MOA 2004), nitrogen fertilizer application, mainly urea, is close to the optimal amount, suggesting possible decreasing returns to additional urea use. The quantity of TSP consumption is somewhat below the recommended amount for Boro, but falls short by one half for Aman and two-thirds for Aus. There is an acute shortage in MP fertilizer use in rice production as the actual usage is only 20-30 percent of the suggest amount. It is suspected that the possible overuse of urea and underuse of TSP and MP could be caused by the fixed nominal price of urea (Asaduzzaman et al. 2009).

Table 1. Descriptive statistics of rice production

Variables	Aman	Aus	Boro	All
Plot inputs				
Area (hectare)	0.09	0.11	0.10	0.10
Output (tons)	0.29	0.30	0.52	0.40
Yield (ton/hectare)	3.64	2.78	5.81	4.57
Share in rice area (%)	43.6	9.9	46.5	100.00
Sale price (taka/kg)	10.2	9.2	9.5	9.8
Family labor (man days/hectare)	65.9	46.3	73.7	67.6
Hired labor (man days/hectare)	56.5	38.5	67.8	60.0
Urea (kg/hectare)	161.2	129.8	240.4	195.0
TSP (kg/hectare)	53.4	37.6	114.0	80.1
MP (kg/hectare)	17.1	15.3	37.4	26.4
Manure (kg/hectare)	210.3	257.1	380.9	294.3
HYV variety dummy (yes=1)	0.937	0.973	0.989	0.964
Household characteristics				
No. of rice plots	3.0	2.8	3.1	3.0
Number of crop plots	5.6	5.7	5.1	5.4
Aman/Aus/Boro area (hectare)	0.29	0.30	0.30	0.29
Total rice area (hectare)	0.62	0.92	0.60	0.64
Total cultivated area (hectare)	0.73	1.00	0.72	0.75
Share of own land in cultivated land (%)	59.3	62.2	59.4	59.7
Household head is male (yes=1)	0.95	0.96	0.95	0.95
Household head education (categorical)	1.0	1.1	1.0	1.0

Household head age (years)	47.9	51.6	47.9	48.3
Household size (persons)	4.6	5.3	4.6	4.7
Amount of crop loan (taka)	1295	1805	1360	1374
Amount of total loan (taka)	14217	12696	15304	14566
Per capita asset (taka)	14477	11344	14834	14338
Value of irrigation equipment (taka)	2708	1384	2736	2594
Household access to facility				
Travel time to primary school (minutes)	10.0	9.2	9.9	9.9
Travel time to secondary school (minutes)	18.1	17.5	18.2	18.1
Travel time to health center (minutes)	24.5	25.2	24.9	24.7
Travel time to agricultural extension (minutes)	37.4	36.3	37.6	37.4
Travel time to telephone (minutes)	34.6	34.8	34.6	34.6
Travel time to transportation (minutes)	7.6	8.1	7.5	7.6
Travel time to market (minutes)	6.0	5.2	6.0	5.9
Irrigation in rice crop dummy (yes=1)	0.836	0.603	0.997	
Community infrastructure				
Paved road dummy (yes=1)	0.289	0.192	0.289	0.267
Dirt road dummy (yes=1)	0.667	0.769	0.667	0.690
Road access in a year (months)	10.8	10.6	10.7	10.7
Urea price in Aman/Boro (taka/50 kg)	310.9		329.4	
TSP price in Aman/Boro (taka/50 kg)	758.2		776.7	
MP price in Aman/Boro (taka/50 kg)	687.8		705.1	
Number of fertilizer depots in the community	0.4	0.5	0.4	0.4
Distance to fertilizer depot (km)	1.9	1.9	2.0	1.9
Share of households with tube well irrigation in the community (%)	47.3	40.6	47.5	45.9
Canal dummy (yes=1)	0.02	0.00	0.02	0.02

Source: Authors' calculation from IFPRI survey (2005/06).

About 60 percent of cultivated land is owned by the household. The majority of household heads are male, received at least primary education, and in their late 40s. Households report to have small amount of loans for crop production, accounting for less than 10 percent of total household loans. A typical rice farming household invests about 2,600 taka in irrigation equipment, including pumps. About 84 percent of households irrigate their crop land in Aman, while nearly all households use irrigation for Boro. Most facilities are within one hour travel time: 10 minutes to primary school, 6-8 minutes to transportation and market. But there are still difficulties to access health care, agricultural extension, and telecommunication, which are about 25-37 minutes away.

At community level, only about one quarter of communities has pucca (paved) road and 70 percent of communities have kucha (dirt) road, accessible in more than 10 months of a year. There is less than one fertilizer depot in the community, which is usually 1.9 kilometers away. Fertilizer price is higher in Boro, which could be attributable to the high demand in the season and limited access to distribution centers. Irrigation remains in short supply: less than half of the households in the community have tube well irrigation and only less than 2 percent reported canal availability.

3.3. Nutrient consumption patterns

Households rely to a large degree on purchases for their food consumption, and to a lesser degree on own production. On average, 43 percent of household calories comes from own production, 52 percent from purchases and 5 percent from gifts from neighbors and relatives. Rice is the dominant staple in nutrition intake: it provides 67 percent of energy, 48.5 percent of protein, 62.5 percent of iron, and 46 percent of riboflavin. Animal based food plays a marginal role in protein intake, as only 14 percent of protein comes from fish and 13 percent from livestock products. In terms of macronutrients, edible oils are the primary source of fats in the diet. In spite of its small consumption share, fish is the major source of calcium (41 percent), followed by vegetables and meat and dairy. Beta-carotene (Vitamin A) intake is mostly concentrated in the vegetables, explaining 94 percent of total beta-carotene intake. Of all the food groups, vegetables are the key for micronutrients, which provides almost all beta-carotene, above a quarter of calcium and riboflavin, and one-fifth of iron intake. The reliance of rice for nutrients is inversely related to income level, as rich households switch to high value, more nutritious food like meat, dairy and fish increase with income.

Table 2. Sources of nutrients

	Calories	Protein	Fat	Calcium	Iron	Riboflavin	Beta-carotene
Source							
Own Consumption	43.3	39.4	16.3	26.7	41.7	38.9	22.1
Purchases	51.9	52.5	77.6	60.5	50.0	53.5	50.0
Gift/Relatives	4.8	8.1	6.1	12.8	8.3	7.6	27.9
Food Group							
Rice	66.3	48.5	6.1	8.2	62.5	45.8	0.0
Other cereals	3.7	4.0	0.0	1.3	6.3	4.2	0.0
Pulses	1.5	5.1	0.0	1.8	2.1	5.6	0.5
Edible oils	5.9	0.0	53.1	0.0	0.0	0.0	0.0
Vegetables	7.6	11.1	8.2	27.4	20.8	23.6	94.3
Fruit	2.2	1.0	6.1	1.7	2.1	2.1	1.8
Meat, dairy, eggs	2.7	13.1	10.2	11.6	2.1	15.3	2.0
Fish	2.2	14.1	6.1	41.2	2.1	1.4	0.0
Spices	1.0	2.0	2.0	5.6	4.2	2.1	0.6
Other	6.8	1.0	6.1	1.0	0.0	0.7	0.8
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: Authors' calculation from IFPRI survey (2005/06).

The descriptive statistics of nutrition intake and its possible determinants are included in Table 3. A typical Bangladeshi relies heavily on own produced rice for nutrition consumption. A substantial portion of total calorie intake, 34.6 percent, comes from own produced rice. Together with rice from purchased and other sources, rice contributes to about two-thirds of total energy consumption. Similarly, rice is the major source of protein, iron, and riboflavin.

Table 3. Descriptive statistics of nutrient intake

Variable	min	mean	max
Nutrition intake			
Energy per capita (kcal)	469	2656	11327
protein per capita (gram)	13.53	65.28	285.73
Fat per capita (gram)	2.25	32.81	174.29
Calcium per capita (milligram)	44.86	553.16	3064.39
Iron per capita (milligram)	3.88	31.54	149.11
Riboflavin per capita (milligram)	0.19	0.95	5.54
Beta-carotene per capita (milligram)	81.84	4361	52001
Household characteristics			
Household head is male (yes=1)	0.00	0.89	1.00
Household head age (years)	18.44	46.29	90.49
Household head education (categorical)	0	0.99	4
Household size (persons)	1	4.34	19
Per capita asset (taka)	50	12472	352314
Rice price (taka/kg)	10	19	23
Travel time to transportation (minutes)	1	7.23	40
Share of rice sale in total income (%)	0	10.25	96.59
Source of nutrients from rice			
Share of calorie from own produced rice (%)	0	34.61	96.04
Share of calorie from purchased rice (%)	0	30.08	88.86
Share of protein from own produced rice (%)	0	26.01	95.80
Share of protein from purchased rice (%)	0	23.43	89.37
Share of fat from own produced rice (%)	0	3.82	43.80
Share of fat from purchased rice (%)	0	3.30	26.02
Share of calcium from own produced rice (%)	0	5.03	78.50
Share of calcium from purchased rice (%)	0	4.67	40.96
Share of iron from own produced rice (%)	0	33.16	95.63
Share of iron from purchased rice (%)	0	28.36	89.83
Share of riboflavin from own produced rice (%)	0	25.14	96.84
Share of riboflavin from purchased rice (%)	0	22.26	82.08
Share of beta-carotene from own produced rice (%)	0	0	0
Share of beta-carotene from purchased rice (%)	0	0	0

Source: Authors' calculation from IFPRI survey (2005/06).

The nutritional deficiency rate is calculated by comparing household nutrition intake with the national guidelines for daily recommended amount of nutrients (Murshid et al., 2008). As seen in Table 4, a median adult equivalent person in Bangladesh reaches only 72 percent and 69 percent of his/her calorie and protein recommended daily allowance. Poor nutrient intake results in the prevalence of undernourishment and malnutrition. The proportion of undernourished people, defined as the share of the population with insufficient dietary energy intake, reaches 25 percent in this sample, which is close to 27.0 percent reported by FAO for 2003-05 (FAO 2008). In addition, there are large nutritional deficiencies in several important nutrients, ubiquitous among households in our sample regardless of income levels. Consumption of fat, calcium, riboflavin, and beta-carotene only reaches less than or about half of the required amounts.

Table 4. Nutrient adequacy rate (%)

	Poorest Quintile	2nd quintile	3 rd quintile	4th quintile	Richest quintile	Bangladesh
Calories	68	69	74	71	74	72
Protein	64	64	73	68	77	69
Fat	42	42	47	42	47	44
Calcium	40	43	53	49	59	49
Iron	90	89	97	96	98	94
Riboflavin	27	28	29	29	33	29
Beta-carotene	61	53	63	49	50	55
The proportion of undernourished people (%)	29	26	23	24	21	25

Source: Authors' calculation from IFPRI survey (2005/06).

The patterns of nutritional adequacy are consistent across income levels, but more severe among poorer households. Nutrient adequacy rates improve markedly with income (with the exception of beta-carotene), which comes from increased consumption of non-staple, high nutrient content foods. Twenty nine percent of people located in the bottom quintile of income distribution are undernourished, but these rates remain high even for the highest quintile with 21 percent being undernourished. The high levels of calorie malnutrition across the income distribution spectrum are a reflection of high national poverty rates. The nutrient deficiency problem intensifies among poor households, with a median adult equivalent person in the lowest income quintile meeting only 42, 40 and 27 percent of his/her daily recommended intake of fat, calcium and riboflavin. Somewhat surprisingly, poorer households report higher beta-carotene adequacy ratio compared to richer households (61 percent in the poorest quintile vs. 50 percent in the richest quintile). This could be explained by the fact that most poor households obtain beta-carotene from vegetables and fruits produced in the household, partially meeting their requirement for this micronutrient.

4. Econometric Results

4.1. Yield function estimation

Irrigation can positively impact yields and lead to increases in food supply. High yield in the farm helps raise rural employment, increases farm income and lower real price. Increases in production and real income in turn mean higher energy intake and better nutrition access. A study in India's agricultural sector (Binswanger and Quizon 1986) estimated that the expansion of irrigation area increased aggregate output by 2.7 percent and incomes of the landless by 2.9 percent. Aggregate price dropped by 5.8 percent, resulting in a considerable consumer welfare surplus among all urban households, especially the urban poor with an income gain of 6 percent. In addition, irrigation facilities help to reduce the loss from adverse weather (drought and flood) and stabilize price as farmers are less dependent on rainfall. Naturally, we expect households with irrigation access to behave differently from those without irrigation.

We first compare the plots which are and are not irrigated in Table 5. Since more than 99 percent of households reported using irrigation for Boro, we only report Boro as one group without further disaggregation. About 84 percent of Aman area and 67 percent Aus area is irrigated. This is consistent with national trend of over 90 percent of Boro area being irrigated in 2004-05 (BBS, various years). Higher yield is observed among irrigated plots for Aman. Farmers with irrigated Aman plots report substantially higher fertilizer use, allocate more land for Aman production, take less crop loans, own more assets, are further away from transportation, and have more access to paved road but not dirt road. In the case of Aus, there is little yield difference between irrigated and non irrigated plots. Similarly to Aman, higher fertilizer use is observed in irrigated plots, with the exception of TSP. This is especially the case for manure, whose application in irrigated plots is 5 times of their non-irrigated counterparts. Compared to their non irrigated counterparts, irrigated plots have higher likelihood to be owned by an operating household with more educated household head, who takes less crop loans but have 50 percent more wealth. Although irrigated Aus plots are not close to transportation, they have better road condition.

Table 5. Comparison of irrigated and non irrigated plot

	Aman			Aus			
	Not irrigated	Irrigated	Total	Not irrigated	Irrigated	Total	Boro
No. observations	260	1601	1861	121	246	367	1926
Share in rice area (%)	7.0	36.6	43.6	3.3	6.6	9.9	46.5
Yield (ton/hectare)	3.0	3.7	3.6	2.8	2.8	2.8	5.8
Urea (kg/hectare)	134.0	176.4	170.5	126.2	139.0	134.8	247.2
TSP (kg/hectare)	32.7	59.5	55.7	40.0	36.7	37.8	115.4
MP (kg/hectare)	7.9	18.3	16.8	13.8	15.5	15.0	37.8
Manure (kg/hectare)	91.0	159.9	150.2	59.1	276.9	205.1	374.8
HYV variety dummy (yes=1)	0.946	0.936	0.937	0.967	0.976	0.973	0.989
Share of own land in cultivated land (%)	65.3	65.4	65.3	66.6	72.7	70.7	64.4
Share of Aman/Aus/Boro in cultivated land (%)	31.7	35.9	35.3	30.3	31.3	31.0	56.1
Household head education (categorical)	0.9	1.0	1.0	0.7	1.2	1.1	1.0
Amount of crop loan (taka)	1654	1260	1315	1669	911	1161	1524
Per capita asset (taka)	10957	17248	16369	8215	13191	11551	17050
Travel time to agricultural extension (minutes)	38.2	36.7	36.9	36.3	36.3	36.3	37.0
Travel time to transportation (minutes)	6.7	8.0	7.9	6.6	8.3	7.7	8.0
Paved road dummy (yes=1)	0.254	0.387	0.368	0.017	0.024	0.022	0.395
Dirt road dummy (yes=1)	0.715	0.600	0.616	0.950	0.976	0.967	0.585
Urea price (taka/50 kg)	312.3	312.4	312.4				326.3
TSP price (taka/50 kg)	765.5	758.1	759.1				773.0

Source: Authors' calculation from IFPRI survey (2005/06).

The dependent variables of the Cobb-Douglas production function are Aman and Aus yields with and without irrigation. The inputs include both traditional inputs (family and hired labor, manure) and modern inputs (fertilizer and HYV seeds). In addition to household head characteristics (gender, age, and education), we also include household characteristics such as household land ownership, per capita assets, loans for crop production, and share of rice in total harvested land. Community-level variables are used to capture village infrastructure, including road surface, distance to fertilizer depot, agricultural extension, and transportation, fertilizer price and village dummy. We introduce three additional variables that affect household's decision whether to use irrigation or not, and these variables are values of household irrigation equipment, share of tube well irrigation in the village, and the existence of canal in the village. Because production and inputs are measured in their logarithmic forms, all the estimated parameters are the elasticities of these inputs (if the inputs are continuous). As for dummy variables with coefficient c, the appropriate measure for the proportional effect on yield is exp(c)-1 when dummy value changes.

Based on economic theory, we expect the coefficients of inputs, including labor, fertilizer, manure, and HYV seeds, to be positive. The quality of the labor force is reflected by the variable of household head literacy, and a literate farmer should be more able to quickly adopt new technology and produce efficiently. The sign of the literacy variable is expected to be positive. Land ownership encourages farmers to invest in their plots to improve land productivity in the long run, and its sign should be positive. Household asset and crop loans represent household wealth, and they are expected to improve rice yield as richer farmers can afford to purchase more and higher quality inputs. The percentage of land allocated to Aman/Aus/Boro production is included to capture the relative importance or specialization of specific rice in the household. If a household is more reliant on rice production for income generation, in other word, more specialized in rice cultivation, it tends to allocate more resources to rice cultivation, be more efficient, and report higher yield. Since access to fertilizer depot, extension, and transportation are measured in travel time, the expected sign of these variable are negative. Compared to no motorable road, paved or dirt road allows modern transportation to connect farmers to market and thus improve yield. The effect of fertilizer price is hard to predict. High fertilizer price could suppress its usage, or has little effect because farmers already made the decision of fertilizer quantity before planting. We expect existence of irrigation facilities to encourage household irrigation use in Aman and Aus production.

The estimation results of the endogenous switching model for Aman and Aus are summarized in Table 6. In Aman production, the decision to irrigate is affected by hired labor, urea and MP quantity, role of rice, household wealth, road, and household and community irrigation facilities (Column 3). A household is more likely to irrigate its Aman plots if it uses less hired labor and/or more assets. Fertilizer usage is positively correlated with the probability of irrigation, suggesting that heavy users of fertilizer are more likely to irrigate their plots. The share of rice in total crop land positively impacts the irrigation decision, reflecting the fact that rice is water intensive. Improved road surface and easy access to extension service increase a household's likelihood of using irrigation. The coefficients of household irrigation equipment and community tube well irrigation are significant and of the expected sign, indicating the importance of peer effects in the village and the household's wealth.

Table 6. Endogenous switching model regression results

	Aman			Aus		
	Irrigated	Not irrigated	Switch equation	Irrigated	Not irrigated	Switch equation
Plot inputs (per hectare)						
Family labor	0.077	0.107	-0.035	-0.002	0.031	-0.121
	(0.011)***	(0.034)***	(0.037)	(0.028)	(0.038)	(0.111)
Hired labor	0.019	0.029	-0.037	0.016	0.017	0.005
	(0.005)***	(0.012)**	(0.014)**	(0.009)*	(0.010)*	(0.028)
Urea quantity	-0.019	0.017	0.066	0.045	0.016	0.023
	(0.007)***	(0.016)	(0.019)***	(0.016)***	(0.080)	(0.104)
TSP quantity	0.005	0.024	0.006	-0.003	-0.017	-0.092
	(0.005)	(0.010)**	(0.014)	(0.008)	(0.010)*	(0.028)***
MP quantity	0.011	-0.010	0.047	-0.003	0.019	-0.026
	(0.004)**	(0.012)	(0.015)***	(0.008)	(0.011)*	(0.023)
Manure quantity	0.017	0.007	-0.004	-0.005	-0.032	0.087
	(0.005)***	(0.013)	(0.017)	(0.008)	(0.011)***	(0.028)***
HYV dummy	0.832	0.892	-0.109	-0.115	-0.161	-2.747
	(0.062)***	(0.189)***	(0.200)	(0.140)	(0.194)	(0.506)***
Household characteristics						
Share of own land	0.014	0.011	-0.007	0.000	0.011	0.064
	(0.005)***	(0.012)	(0.016)	(0.015)	(0.012)	(0.036)*
Male head				-0.633	-0.026	-0.409
				(0.158)***	(0.209)	(0.584)
Primary school	-0.056	-0.038	0.181	0.058	-0.145	0.713
	(0.035)	(0.099)	(0.113)	(0.065)	(0.081)*	(0.235)***
Secondary school	-0.008	-0.074	0.140	0.169	-0.207	0.920
	(0.033)	(0.094)	(0.110)	(0.057)***	(0.070)***	(0.243)***
Higher education	-0.014	0.060	0.331	0.054	0.128	0.463
	(0.064)	(0.201)	(0.248)	(0.106)	(0.168)	(0.350)
Head age	-0.003	-0.002	-0.002	-0.004	0.001	0.001
	(0.001)***	(0.003)	(0.004)	(0.002)**	(0.003)	(0.008)
Crop loan amount	0.001	-0.002	-0.003	-0.005	-0.007	0.012
	(0.002)	(0.006)	(0.007)	(0.005)	(0.005)	(0.016)
Land share of Aman/Aus	0.308	0.427	0.221	0.321	0.159	-0.207
	(0.027)***	(0.065)***	(0.079)***	(0.049)***	(0.068)**	(0.155)
Per capita asset	-0.016	-0.096	0.175	0.131	0.025	0.836
	(0.016)	(0.053)*	(0.057)***	(0.035)***	(0.052)	(0.124)***
Community and household Infrastructure						
Paved road	-0.064	-0.103	1.543	-0.189	0.032	0.269
	(0.131)	(0.283)	(0.359)***	(0.172)	(0.772)	(0.871)
Dirt road	-0.096	-0.140	0.970			
	(0.122)	(0.234)	(0.306)***			
Distance to fertilizer depot	0.006	-0.000	-0.005	-0.028	-0.094	-0.067
	(0.004)	(0.015)	(0.016)	(0.013)**	(0.022)***	(0.042)
Travel time to extension	0.038	-0.113	-0.444	0.267	0.297	-0.207
	(0.026)	(0.106)	(0.104)***	(0.070)***	(0.082)***	(0.213)
Travel time to	-0.020	-0.009	0.241	0.024	-0.182	0.340

transportation						
	(0.017)	(0.049)	(0.055)***	(0.031)	(0.046)***	(0.122)***
Urea price	1.033	-2.144	6.851			
	(0.335)***	(1.073)**	(1.226)***			
TSP price	-0.052	-0.839	1.426			
	(0.203)	(0.927)	(0.820)*			
Household value of irrigation equipment			0.017			-0.024
			(0.007)**			(0.006)***
Community share of households w/ tube well irrigation			0.061			0.033
			(0.036)*			(0.041)
Community canal dummy			-0.227			
			(0.291)			
Constant	-5.914	17.677	-49.974	-2.716	-1.285	-7.721
	(2.321)**	(9.864)*	(9.995)***	(0.604)***	(0.587)**	(0.000)
rho1	-0.159			13.441		
	(0.148)			(31.100)		
rho2	-0.228			-13.212		
	(0.287)			(27.717)		
LR test of joint independence of equations (p-value)	0.200			0.000		
Observations	1861			367		

Note: Standard errors in parentheses, *** for p<0.01, ** for p<0.05, * for p<0.1.

Source: Authors' calculation from IFPRI survey (2005/06).

Among irrigated plots in column (1), higher Aman yield is observed among plots receiving more labor, with coefficients of 0.078 for family labor and 0.016 for hired labor. Manure use has a large effect on Aman yield with an elasticity of 0.02, twice the size of the chemical fertilizer MP at 0.01. The mixed effects of chemical fertilizer imply possibly unbalanced use of fertilizer in Aman production. Plots using HYV seeds report an impressive 130 percent higher yield than local varieties. The sign of the age variable shows that older farmers have more knowledge and experience with traditional practice but are less willing to learn and adopt new technology, especially when applying new technology in irrigated plots. Households owning more crop land and/or allocating more land to rice report higher Aman yield.

For Aman plots without irrigation in column (2), labor and TSP are important determinants of Aman yield. If TSP or labor usage is increased by 1 percent, the Aman yield is expected to increase by 0.024 and 0.138 percent, respectively. Although yields of irrigated land tend to be 25 percent higher than non irrigated plots, HYV seeds in the non irrigated plots perform well with far higher yield. The impacts of HYV seeds need to be interpreted with care since the majority of plots (97-98 percent) are planted with HYV varieties. Similar to the case of irrigated land, the more land allocated to Aman, the higher yield. Rich households exhibit low Aman yield, which may reflect the fact that rich households have more diversified sources of income and thus can allocated less man time towards labor intensive Aman production.

Regardless of irrigation, Aman yield is responsive to labor and fertilizer application, HYV seeds adoption and reliance on Aman rice (expressed as share of Aman area in total crop area). The nitrogen effect on yield is negative and significant, indicating that there is excess application and that Aman varieties are not responsive to higher dose of urea. On the other hand, the use of phosphorous fertilizers (TSP) or potassium fertilizer (MP) can be further increased to boost yield. The opposite signs of the coefficients of urea price suggest that farmers probably make decision of fertilizer and irrigation decision jointly. Once farmers choose to irrigate the plot, they purchase fertilizer even if chemical fertilizer gets more expensive during Aman season, resulting in higher yield. On the other hand, fertilizer demand for non irrigated plots is very elastic. When urea price in the village increases, farmers opt to use less or no fertilizer in the non irrigated plot which results in a lower yield. The coefficients of educational levels are not significant, may be explained by the low average educational level.

Aus production shares similar story as Aman. Decision of using irrigation is affected by fertilizer use and household assets. Additionally, land ownership and household head schooling also increase the probability of using irrigation. For irrigated Aus, urea application boosts yield with an elasticity of 0.05. Compared to households whose heads do not attend school, household heads with secondary education report a yield bonus of 18 percent in irrigated fields, and average yield is higher among younger household heads. Having more resources, proxied by household assets, help boost irrigated Aus yield. Average yield can be 0.13 percent higher if per capita asset increases by 1 percent. The signs of fertilizer and schooling coefficients are negative, exhibiting little yield advantage by using fertilizer or improved labor quality in the non irrigated Aus plots. There are some commonalities between irrigated and non irrigated Aus. First, yield can be increased if more labor is hired for intensive production. Second, the more land a household allocates to Aus, the higher the yield is. Third, a proximity to fertilizer depot location improves production. This is especially the case for non-irrigated Aus production, with an elasticity of 0.09. Fourth, extension service does not help increase Aus yield, regardless of irrigation conditions. This suggests that probably extension officers do not provide training or information specifically designed for Aus due to its relatively smaller role in rice production. The likelihood ratio test for joint independence of the switching and yield equations is reported in the last line of the table. Test results demonstrate that the yield and switching models are interdependent for Aus but not for Aman.

In order to test for endogeneity, the results of instrumental variable (IV) estimation are summarized in Table 7. Similar to the endogenous models defined above, the instrument is the dummy variable of irrigation usage, formulated as a linear function of household irrigation equipment, adoption of tube well irrigation in the village, and existence of canal. The coefficients of Aman and Aus are consistent with the results from the endogenous switching model reported in Table 6. Likelihood ratio tests compare results from single equation instrumental regression using limited information maximum likelihood (LIML) and three-equation endogenous switching model, and the results suggest the latter is preferred because it uses full information of selection and heterogeneous continuous equations.

Table 7. Instrumental variable regression results

	Aman	Aus	Boro
Plot inputs (per hectare)			
Family labor	0.084	-0.012	0.031
	(0.013)***	(0.038)	(0.008)***
Hired labor	0.026	0.025	0.004
	(0.007)***	(0.013)**	(0.003)
Urea quantity	-0.029	0.052	0.021
	(0.013)**	(0.028)*	(0.007)***
TSP quantity	0.005	-0.036	-0.020
	(0.006)	(0.029)	(0.005)***
MP quantity	-0.001	0.005	0.010
	(0.007)	(0.010)	(0.003)***
Manure quantity	0.013	0.013	0.004
	(0.007)*	(0.022)	(0.003)
HYV dummy	0.858	-0.310	0.151
	(0.080)***	(0.218)	(0.094)
Household characteristics			
Share of own land	0.014	0.024	-0.005
	(0.006)**	(0.026)	(0.005)
Male head	0.099	-0.153	0.032
	(0.127)	(0.212)	(0.055)
Primary school	-0.129	0.190	-0.088
	(0.051)**	(0.172)	(0.026)***
Secondary school	-0.089	0.231	0.015
	(0.054)*	(0.146)	(0.025)
Higher education	-0.111	0.229	-0.045
	(0.091)	(0.294)	(0.049)
Head age	-0.003	-0.004	-0.002
	(0.001)**	(0.003)	(0.001)**
Crop loan amount	-0.000	-0.009	0.000
	(0.003)	(0.012)	(0.002)
Land share of Aman/Aus/Boro	0.269	0.292	0.079
	(0.043)***	(0.103)***	(0.028)***
Per capita asset	-0.062	0.194	0.022
	(0.031)**	(0.123)	(0.012)*
Community and household Infrastructure			
Paved road	-0.291	0.500	0.002
	(0.227)	(0.523)	(0.079)
Dirt road	-0.228	0.488	-0.034
	(0.182)	(0.442)	(0.073)
Distance to fertilizer depot	0.006	-0.049	0.005
	(0.005)	(0.021)**	(0.004)
Travel time to extension	0.095	0.059	-0.022

	(0.050)*	(0.105)	(0.022)
Travel time to transportation	-0.068	0.098	-0.022
	(0.032)**	(0.113)	(0.015)
Urea price	-0.458		0.524
	(0.775)		(0.198)***
TSP price	-0.035		-0.104
	(0.259)		(0.150)
Dummy irrigation	1.471	-1.192	4.975
	(0.694)**	(0.869)	(4.383)
Constant	1.620	-2.763	-6.017
	(4.449)	(1.896)	(4.734)
Observations	1861	367	1926
Durbin test (p-value)	0.006	0.019	0.283
Wu-Hausman test (p-value)	0.006	0.024	0.287

Note: Standard errors in parentheses, *** for p<0.01, ** for p<0.05, * for p<0.1.
Source: Authors' calculation from IFPRI survey (2005/06).

IV estimation for Boro is also reported. We observe the contribution of input intensification on Boro yield. Yield could increase by 0.03 percent if family labor is increased by 1 percent. Yield increases by 0.02 and 0.01 percent if urea and MP use is raised by 1 percent. Additional application of TSP does not yield extra output, indicating a possible mismatch of TSP with local soil conditions. Similar to Aman production, younger household heads report higher yield. Household's reliance on Boro, or specialization in Boro production, is an important factor to improve yield. Boro yield is affected by household assets, with an elasticity of 0.022. An extra 1 percent more per capita resources that a household has translates into 0.02 percent of additional average yield. The insignificance of crop loans underscores the ineffectiveness of credit markets, suggesting that loans used for crop cultivations are not well targeted to achieve yield enhancement despite that near 20 percent of households report taking crop loans.

The results of this study echo an efficiency analysis of Aman and Boro rice by Coelli, Rahman and Thirtle (2002). They find that labor input is greater and the owner-operator mode is more efficient in Aman season due to the nature of its labor intensive production. Education was not correlated with efficiency but the correlation between household age and efficiency is negative. Their results reveal that poor infrastructure causes low efficiency scores. The importance of rice is positively associated with efficiencies, which may be the result of economy of scale. The weak results of extension suggest future training activities should be scaled up and coordinated for rural households to reach full production potential. The efficiency study and this paper both points to possible measures to increase productivity and efficiency, including input intensification, land tenure, investment in rural infrastructure, specialization in rice production, and improved extension system.

4.2. Nutrition function estimation

We estimate the nutrition intake as a partial linear function as specified by Equation (6). The dependent variables are per capita intake of energy, protein, fat, calcium, iron, riboflavin, and beta-carotene. The explanatory variable in the nonlinear part, z, is per capita income in logarithmic terms. The linear component allows us to examine the effect of other variables that influence a household's nutritional intake. These variables describe the household, including household head characteristics, household size, per capita assets, market price of rice, travel time to transportation, and share of rice sale in total income. Given the important role of own production in a household's nutrient consumption, we include the share of own produced rice in total nutrient intake in the linear component.

Compared to males, women and girls have disadvantages in an agrarian economy using primarily human labor, and male-headed households should report higher nutrition consumption. We expect education to improve household food consumption quantity and quality. Larger households usually imply high dependency ratio and low food security, and its sign is expected to be negative. Numerous studies have found positive correlation between household wealth and nutritional status. The sign of rice price should be negative in most cases. High food price, expressed as rice price in the market, can erode a household's disposable income and force the household to take lower quality food, resulting in deteriorated nutrition reading. Since rice from home production contributes to about a quarter of energy intake, households consuming less home produced products are more vulnerable to price fluctuation and thus report lower nutrition scores. Net rice sellers benefit from high food price and we expect positive coefficients for rice sale in total income. The regression results of the linear part are presented in Table 8, with all continuous variables expressed in logarithmic format.

Table 8. Linear part of nutrition function

	Calorie	Protein	Fat	Calcium	Iron	Riboflavin	Beta-carotene
Male head	0.080	0.092	0.067	0.119	0.092	0.089	0.099
	(0.036)**	(0.039)**	(0.045)	(0.054)**	(0.039)**	(0.043)**	(0.099)
Head age	0.003	0.002	0.001	0.000	0.003	0.002	0.002
	(0.001)***	(0.001)***	(0.001)	(0.001)	(0.001)***	(0.001)**	(0.002)
Primary school	-0.000	-0.002	0.032	0.015	-0.003	0.007	0.014
	(0.028)	(0.030)	(0.035)	(0.041)	(0.030)	(0.033)	(0.076)
Secondary school	-0.048	-0.039	0.055	0.010	-0.039	-0.027	-0.009
	(0.030)	(0.032)	(0.037)	(0.045)	(0.032)	(0.035)	(0.082)
Higher education	-0.088	-0.054	0.044	-0.011	-0.146	-0.085	-0.226
	(0.051)*	(0.054)	(0.063)	(0.075)	(0.055)***	(0.059)	(0.138)
Household size	-0.220	-0.226	-0.294	-0.275	-0.220	-0.198	-0.136
	(0.026)***	(0.028)***	(0.033)***	(0.039)***	(0.029)***	(0.031)***	(0.072)*
Per capita asset	0.056	0.082	0.133	0.140	0.054	0.092	0.065
	(0.012)***	(0.013)***	(0.015)***	(0.018)***	(0.013)***	(0.014)***	(0.032)**
Rice price	-0.102	-0.091	-0.031	0.062	-0.151	-0.060	0.039
	(0.083)	(0.088)	(0.103)	(0.123)	(0.089)*	(0.097)	(0.207)
Travel time to	0.028	0.017	0.010	-0.010	0.033	0.018	0.019
transportation	(0.015)*	(0.016)	(0.019)	(0.023)	(0.017)**	(0.018)	(0.042)
Share of own produced rice in	0.005	0.005	0.002	0.004	0.003	0.004	
total intake	(0.002)**	(0.002)*	(0.003)	(0.004)	(0.002)	(0.003)	

Share of income from rice	0.002 (0.002)	0.002 (0.003)	0.005 (0.003)*	0.005 (0.004)	-0.000 (0.003)	-0.002 (0.003)	0.008 (0.006)
Observations	1235	1235	1235	1235	1235	1235	1235
R-squared	0.224	0.263	0.398	0.251	0.207	0.193	0.211

Note: Standard errors in parentheses, *** for p<0.01, ** for p<0.05, * for p<0.1.

Source: Authors' calculation from IFPRI survey (2005/06).

The coefficients of household head gender are large and significant for 5 out of 7 nutrients, implying that female-headed households face more challenges in meeting their nutritional requirement than their male-headed counterparts. Education shows little connection with nutritional level of the household. The signs of household head gender and education are consistent with the results of Bouis and Novenario-Reese (1997). Household head age is positively associated with the amount of four nutrients: energy, protein, iron, and riboflavin. This is perhaps the result of better social network and improved social status in the community gained over time. Low nutrition intake is reported among large households, with elasticities ranging from -0.136 for beta-carotene to -0.294 for fat. Household wealth is another variable that's universally related to nutrition. Per capita calorie, protein, and fat intake are 0.06, 0.08, and 0.13 percent higher among households with 1 percent additional asset than those at sample average. A partial equilibrium analysis by Anriquez, Daidone and Mane (2010) estimates partial elasticities of calorie intake with respect to household size is -0.265 in rural Bangladesh, close to -0.22 in this study. They also report large and positive coefficients of household assets in determining dietary energy consumption. Bouis and Novenario-Reese (1997) remark that consumers try to protect their calorie intake when faced with an increase in rice price by substituting with other high energy food or reducing expenditures for non-food items. Iron consumption is not immune to rice price increase.

We fail to observe any negative effects from road access. The coefficients of own produced rice are positive and significant for energy and protein equations, because households consuming their own produce are relatively shielded from fluctuations in food price. A recent study in Bangladesh nutrition vulnerability (Verma and Hertel 2009) also reports smaller nutritional fluctuations among agricultural population under volatile food prices. Households that rely on large amounts of rice for their food consumption are probably able to meet their calorie requirement. However, severe malnutrition could occur because rice lacks fat or other micronutrients like beta-carotene. Coefficients of share of rice income are of the expected sign for most nutrients, but only significant in fat consumption. As observed by Otsuka (2000), in areas where unfavorable conditions may discourage rice production, households might derive income from other sources such as growing cash crops or working for nonfarm sectors and hence compensate for the income difference across agroecological conditions.

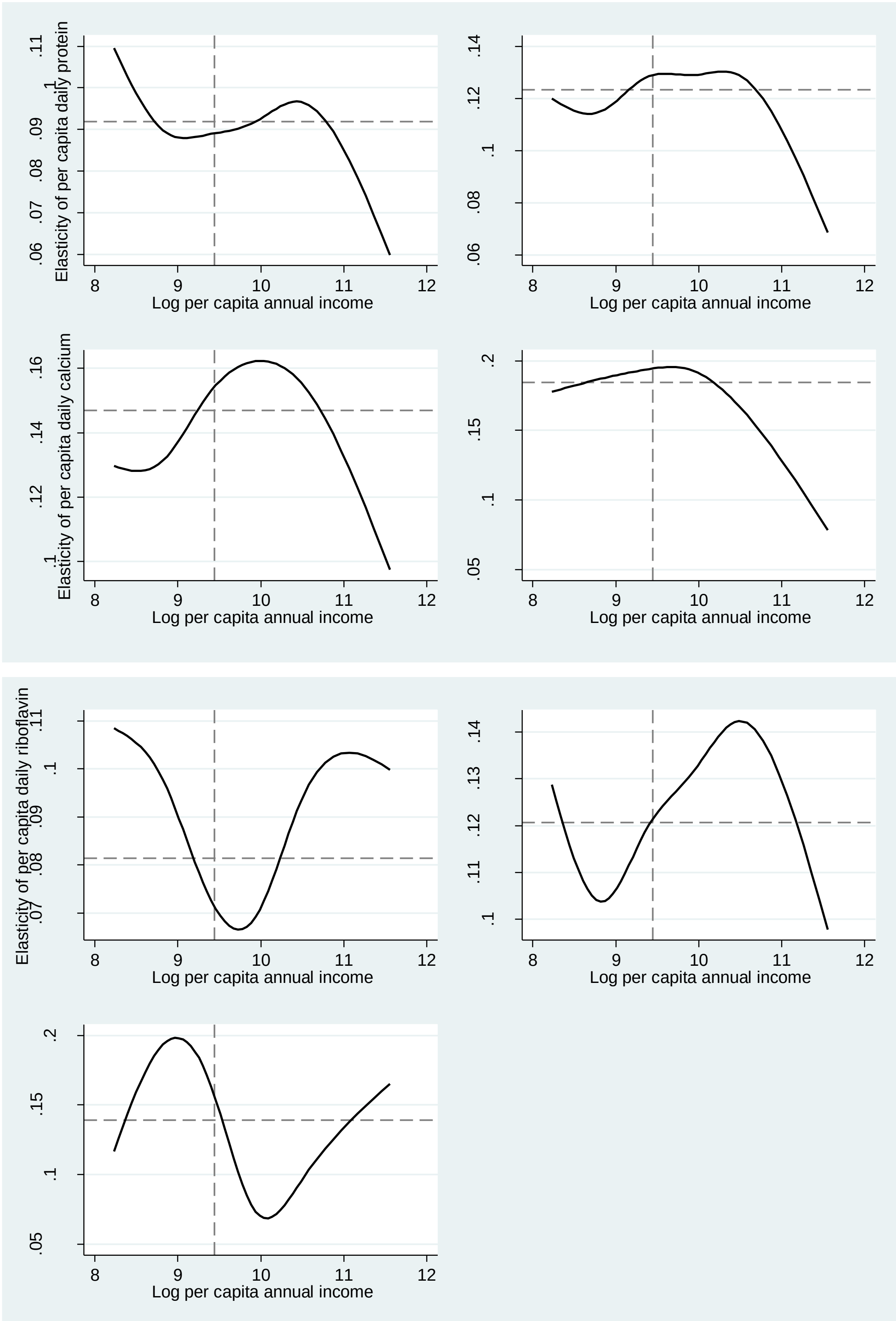
The nonlinearities in the relationship between nutrients and income are illustrated in Figures 2. The vertical line is the median of per capita income (after logarithmic transformation), and the horizontal line is the median of elasticity of nutrient intake with respect to per capita income. In general, the nutrient-income elasticities appear to be linear near the median of income, but this is not the case at both extremes of income. The range of y-axis is altered for better observation of the nonlinearity of the elasticities.

The calorie-income elasticity is higher at low income, which is consistent with conventional wisdom that high income groups switch to high value foods for additional taste but not the low income groups. Other micronutrients intake, together with calorie, can better reflect diet quality and nutritional adequacy. The income elasticities of these micronutrients are expected to be more elastic than that of calorie, as shown in the graphs of calcium, riboflavin, and beta-carotene. This is because people purchase more micronutrients rich food, rather than basic staples, as income rises. Similar patterns are observed in India (Subramanian and Deaton 1996), Bangladesh (Bouis and Novenario-Reese 1997); Indonesia (Skofias 2003) and Mexico (Skoufias et al. 2009).

The average calorie elasticities fall between 0.06 and 0.11, which is a small range with low median elasticities when compared with other studies in the region (Bouis and Novenario-Reese 1997; Dawson 2002; Dawson and Tiffin 1998). Bouis and Haddad (1992) argue that an upward bias exists in the estimates of income elasticities of calorie due to poorly defined food groups or measurement errors. They find that the calorie-income elasticity that is estimated using a nutrition monitor survey is considerably smaller than that of a household expenditure survey, even based on the same households.

There are two types of nutrient-income elasticities development when per capita income increases. In the graphs of protein, fat, and calcium, the elasticities are increasing around the median then decrease quickly as income increases. Elasticities of calorie, iron, riboflavin, and beta-carotene display a different pattern. Although elasticities remain linear at the neighborhood of median, there are two distinct “kinked” points in each graph. Take calorie as an example, the elasticity declines at low income, increases gradually around median income, and decreases again at high income level. Consistent with Skoufias et al.’s results (2009), another feature of calorie elasticity is that average elasticity below the median income (to the left of median income line) is greater than the average calorie elasticity above the median income.

Figure 2. Income elasticities of nutrition



Note: Standard errors in parentheses, *** for p<0.01, ** for p<0.05, * for p<0.1.
Source: Authors' calculation from IFPRI survey (2005/06).

We simulated the effects of increased agricultural productivity and government intervention on nutrition using the parameters estimated in the nutrition equations. According to the framework, rice production can affect nutrition directly through additional consumption of rice produced at home, or indirectly through increased income from rice sale. The impact from direct channel plays a dominant role in assessing the impact of rice yield because of the small nutrition-income elasticities, under the assumption that farmers don't change their allocation of extra production to home consumption.

The first scenario is to assume all Aman plots are irrigated, which will increase rice output by 1.8 percent. Using median elasticities, the percentage change of calorie is estimated to be 0.59 for the whole sample, ranging between 0.48 in the poorest quintile and 0.72 in the richest (Table 6.5). Increases from Aman yield improvement are observed in other nutrients as well: average protein intake increases by 0.46 percent, fat 0.09 percent, calcium 0.12 percent, iron 0.57 percent, and riboflavin 0.44 percent. The second scenario simulates the nutritional outcome of a 5 percent increase in Aman yield. Calorie and iron consumption is boosted by 0.74-0.77 percent, while protein and riboflavin intake increased by nearly 0.6 percent. If all Boro fields are planted with hybrid rice (scenario 3), which shifts yield by 0.8 ton/ha, calorie and protein intake can be lifted by 2.5 and 1.9 percent, respectively. Overall, richer households disproportionally benefit from the increased yield, as they tend to obtain nutrients from home production of rice instead of market purchase. Because rice does not contain any beta-carotene, changes in rice output does not have any direct impact on its level in food. However, beta-carotene status can be changed through substitution effects of rice with vegetables and fruits which are beyond the scope of this study.

Table 9. Simulation of the impact of agriculture on nutrition intake (%)

Rice	Poorest Quintile	2nd quintile	3 rd quintile	4th quintile	Richest quintile	Bangladesh
Scenario 1: All Aman plots irrigated						
Calorie	0.48	0.54	0.67	0.57	0.72	0.59
Protein	0.39	0.43	0.51	0.44	0.52	0.46
Fat	0.08	0.08	0.10	0.08	0.09	0.09
Calcium	0.12	0.11	0.14	0.11	0.12	0.12
Iron	0.46	0.51	0.64	0.55	0.69	0.57
Riboflavin	0.39	0.40	0.50	0.42	0.51	0.44
Scenario 2: Aman yield increase by 5%						
Calorie	0.58	0.67	0.80	0.88	0.95	0.77
Protein	0.47	0.52	0.61	0.68	0.69	0.59
Fat	0.10	0.10	0.12	0.13	0.12	0.12
Calcium	0.14	0.14	0.16	0.16	0.15	0.15
Iron	0.55	0.63	0.76	0.84	0.92	0.74
Riboflavin	0.46	0.49	0.59	0.65	0.67	0.57
Scenario 3: Convert HYV to hybrid rice in Boro, yield increase by 15%						
Calorie	1.98	2.21	2.49	2.75	3.00	2.48
Protein	1.61	1.73	1.90	2.12	2.18	1.90
Fat	0.33	0.34	0.39	0.39	0.39	0.37
Calcium	0.48	0.45	0.51	0.51	0.48	0.48
Iron	1.88	2.09	2.38	2.63	2.90	2.37
Riboflavin	1.58	1.63	1.85	2.04	2.12	1.83
Scenario 4: Direct transfer to the lowest 40%, increase income by 5%						

Calorie	0.42	0.43	0.00	0.00	0.00	0.43
Protein	0.57	0.59	0.00	0.00	0.00	0.60
Fat	0.67	0.70	0.00	0.00	0.00	0.73
Calcium	0.93	0.93	0.00	0.00	0.00	0.93
Iron	0.37	0.38	0.00	0.00	0.00	0.37
Riboflavin	0.51	0.55	0.00	0.00	0.00	0.58

Source: Authors' calculation from IFPRI survey (2005/06).

In the last scenario, we assume a cash transfer program providing an extra 5 percent income to the bottom 40 percent of population. This amounts to an increase of real income by 5.8-9.4 taka per person, which brings a significant increase in nutritional status for the low income group. On average, calorie and protein intake increase by 0.4-0.6 percent. What's impressive is the remarkable improvement in fat and calcium consumption among the poor: fat intake increases by 0.67-0.7 percent, and calcium intake by 0.93 percent. This exercise highlights the importance of social safety net provision that targets the poor to achieve fast and effective nutritional improvement.

5. Conclusion

The recent food price hike exacerbates malnutrition and deprivation in Bangladesh, especially among the poor population who spends 50-60 percent of their expenditure on food. High food price could reverse the progress made in poverty reduction and hunger elimination in the past decade. This study analyzes how rice productivity can be promoted to increase food supply through input intensification and possible government interventions. The results of endogenous switching model suggest that farmers' decision of using irrigation is affected by household asset, education, land ownership, road access, and community irrigation infrastructure. Factors that contribute to rice yield improvement include input intensification (suitable fertilizer and irrigation), land ownership, education, and reliance or specialization in rice production (share of land allocated for rice), household asset, and road access. Partial linear models indicate that nutrition intake is determined by household size, age of head, asset, and consumption of own production. Female-headed households appear to face more challenges to meet their nutrition requirement.

These findings have important implications for policy debates on how to promote Bangladeshi rice supply and reduce malnutrition in the future. In order to facilitate supply response and achieve food security, agricultural sector needs to be put on top of the political agenda for several reasons. First, the negative impact of high food prices on income and nutrition that is projected to continue through the near future could be moderated by supply responses over the medium term, if a responsive environment is fostered. As the majority of the poor in Bangladesh live in rural areas and depend on agriculture, household food security and nutritional situation can be improved substantially through augmented production and productivity. Progress in agricultural productivity increases food supply and brings additional income to farming households. High yields also help lower market price and benefit urban poor and rural landless population. These effects in turn improve the quantity and quality of food consumption and nutrition of the household. Torlesse, Kiess, and Bloem (2003) provide evidence that progress in child nutrition is associated with low prices of rice because households are able to increase the quantity and quality of their diet due to increases in real income. Hence, production oriented efforts need to continue to ensure progress in poverty reduction, food security, and nutrition.

Second, there is a considerable scope for improving paddy production in Bangladesh to achieve self sufficiency. Bangladesh has a comparative advantage in producing rice for domestic consumption, compared with imported rice (Deb, Hossain, and Jones 2009). Studies in other Asian countries point out that land income is positively associated with modern variety adoption and availability of irrigation (Otsuka 2000). Given the high responsiveness of rice production to fertilizer and irrigation, farmers could considerably increase their outputs and incomes if proper policies are implemented and modern input applications are increased. However, issues in fertilizer supply, availability and timely distribution can significantly hamper the production of fertilizer-dependent HYV rice, despite reduced urea price due to high subsidy (Asaduzzaman et al. 2009). Crop specialization should be encouraged to optimize input use and increase profitability of agricultural production.

Third, this study has shown substantial impacts of government investment on improving rural infrastructure (markets, roads, irrigation, and fertilizer distribution center), public services (education), and targeted agricultural extension services. Road improvement in Bangladesh can help rural households through lowering transportation expenses on outputs and inputs, better accessibility to schools, and more favorable prices (Khandker, Bakht, and Koolwal 2009). Experience in many developing countries has shown that investments in rural roads can yield high returns to poverty reduction (Fan 2008). Transportation improvement is also an effective instrument to combat poverty, cutting average poverty rate by 3-6 percent in Bangladesh (Khandker, Bakht, and Koolwal 2009). In addition, poor households appear to benefit more from upgraded living conditions than their wealthier counterparts. Thus, a clear and coherent strategy for the infrastructure sector development and expansion can effectively lead to expanded food supply, poverty reduction, and mitigated food price rises.

Fourth, investment in agricultural research and development (R&D) is another way to increase rice supply and meet the growing demand in the country. Public investment in agricultural R&D in Bangladesh has remained low compared to other South Asian countries (ASTI 2010). Past experience in other developing countries has indicated that government investment in agricultural R&D has high return in agricultural productivity and poverty reduction (Nin Pratt, Yu, and Fan 2009; Fan 2008). The remarkable yield advantage of modern varieties calls for substantial investment in agricultural R&D and agricultural extension to promote wide adoption of high fertilizer responsive and high-yield varieties. Hybrid rice has been proven to increase Boro yield significantly by up to 1.4-1.7 ton/ha, and net return of hybrid rice is about 1.2 times higher than inbred varieties (Hossain 2008). However, the promotion of modern technologies and crop diversification should be tailored to crop specific conditions to enhance the impact of R&D investment. For instance, one-third of the land is deeply flooded for part of the year, making it not suitable for dwarf varieties. Development of high-yield deepwater varieties can effectively increase rice output in the country. Research efforts are needed for yield breakthrough in rice by exploiting new technology and developing drought-resistant varieties.

Fifth, our analysis indicates that there exist positive relationships between nutrient consumption and household income. When a household income increases, it tends to consume more nutrients and is less likely to have malnourished household members. However, the relationship between income and nutrition is not linear. As experiences in other developing countries show, households change their food composition when income increases, which usually involves decreasing consumption of cereal and increasing consumption of food with high value and high nutrient content (like meat, fish, and dairy products). Thus one straightforward way to improve nutrition is by increasing household income through income transfer, i.e. food for work, or other government programs that raise household disposable income. This approach directly helps the poor and can successfully improve micronutrient consumption among the high deficiency group.

Sixth, high rice price only has a significant direct impact on iron intake, but not on other nutrients. The insignificant coefficients of rice price on nutrient intake imply that households are able to cope with high food prices in a small price range by employing strategies to protect calorie intake first. These strategies include shifting to less balanced diets by substituting with cheaper, low nutrient content food, and cutting expenditure in other activities like education and health care. This could have potentially harmful consequences that are irreversible, preventing the household to escape poverty in the future, especially when price soars for most food groups in a short period of time. For example, if a household cuts children's education the next generation will have less opportunity to increase income level and escape poverty. Government policies should identify channels through which households receive their nutrients when faced with high food prices and develop programs to help poor households acquire vital nutrients to achieve nutrition sufficiency. Complementary programs are needed to address the reduction of social services when families are forced to cut budget for other essential services.

Seventh, vulnerable groups, such as female-headed households, landless population, or families with high dependency ratio, require special attention for them to participate in and benefit from economic growth. From a policy perspective, safety net programs can address food insecurity by responding to both the needs of vulnerable groups through a combination of immediate assistance and long-term investment (von Braun, Vargas-Hill and Pandya-Lorch 2009). A Bangladeshi study by Bhagowalia et al. (2010) suggests that improving child nutrition through women empowerment is an effective investment in fighting poverty and malnutrition in the long run. At the same time, targeted cash transfers to vulnerable groups can temporarily support the purchasing power of the poor without interrupting domestic market or discourage food production. Empowerment of the disadvantaged groups should be incorporated in government policies, including quality education and training, basic health, access to resources, employment, information, and appropriate technologies.

Finally, this study focused on the estimation of rice productivity and income-nutrition elasticities at the household level. There are key questions remain unanswered, including intra-household nutrition distribution, agroecological conditions, trends of production and nutrition status, risks associated with climate change, and existing government policies targeting agricultural production and nutrition. It is hoped that future research will integrate additional data to directly evaluate the impact of high food price and economy recession in rural households.

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