# Potential Effects of Transgenic Rice on Farm Households' Nutritional Status in Bangladesh[1]

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(Abstract)

The spread of agricultural biotechnology in developing countries has grown rapidly in recent years. Several transgenic products are under development with potential to address a variety of adverse production conditions. These products have raised hope that yield and quality improvements in rice will accelerate and help in the battle against under-nutrition, especially in areas of prevalent under-nutrition in Asia.

A farm household model is developed and estimated to project ex ante effects of introducing transgenic rice on farm households' nutritional status in Bangladesh. Assuming the yield effects of transgenic rice are similar to that of previous high yield varieties, the model estimates the profit effect of introducing transgenic rice. The profit effect is then translated into effects on farmers' consumption decisions. The results indicate that the total profit elasticity with respect to the percentage of rice area in high yield variety is 0.08. The calorie elasticity with respect to the percentage of rice area in HYV ranges from 0.062 in non-poor to 0.074 in poor households, and the protein elasticity ranges from 0.075 in non-poor to 0.084 in poor. Therefore, the results indicate that transgenic rice is likely to play a significant role in improving farm households' nutritional status in terms of total calorie/protein intake.

Despite many local and international efforts in poverty alleviation, roughly 800 million people in developing countries remain under-nourished (FAO 2003). Under-nutrition results in millions of children suffering from being underweight, stunting, wasting and other nutrient-deficient-related illnesses. At the national level, income losses from various aspects of under-nutrition can be as high as four percent of national income (FAO 2001).

Various factors can cause under-nutrition. Although both natural disasters (e.g. drought, flood) and man made disasters can create temporary food shortages and lead to under-nutrition, under most circumstances, under-nutrition is a manifestation of absolute poverty. Many people living under the poverty line (less than 1 US dollar per person per day) suffer from under-nutrition (FAO 2003). The lack of economic access to an adequate diet is the primary reason for the prevalence of under-nutrition.

The green revolution in Asia greatly reduced the degree of absolute poverty and the magnitude of under-nutrition in that region. Technological innovations, represented by new crop varieties, applications of fertilizer, and irrigation techniques, played a significant role in increasing agricultural productivity. In the post green revolution era, yield growth in major cereals has slowed in many developing countries. Rice is no exception. In Asia, rice—the most important staple crop—accounts for more than 30 percent of total calorie supply and more than half of the calories consumed by the poor (Hareau, Norton, Mills and Peterson 2005). The average annual growth rate of rice yield was about 2.5% from 1961 to 1989 in Asian developing countries. From 1990 to 2002, the growth rate dropped to 1.1% per year (FAOSTAT 2006). While the slow progress in conventional breeding technologies disappointed many, the development of rice biotechnology research in recent years has raised hope that yield and quality improvements in rice will accelerate and help in the battle against under-nutrition.

2005 marks the tenth anniversary of the commercialization of transgenic crops. In 2005 the global area of transgenic crops reached about 90 million hectares up from 1.7 million hectares in 1996, an increase of 50 fold. The estimated global net economic benefits of transgenic crops for farmers reached $6.5 billion in 2004, and $27 billion ($15 billion for developing countries and $12 billion for industrial countries) for the accumulated benefits during the period 1996 to 2004 (James 2005). Currently, the United States is still the leading country in transgenic crop production with 49.8 million hectares planted (55% of global biotech area). The proportion of the global area of biotech crops grown by developing countries, however, has increased annually. More than one-third (38%, up from 34% in 2004) of the global biotech crop area in 2005, equivalent to 33.9 million hectares, was grown in developing countries where growth between 2004 and 2005 was substantially higher (6.3 million hectares or 23% growth) than in industrial countries (2.7 million hectares or 5% growth) (James 2005).

In 2005, 8.5 million farmers in 21 countries planted transgenic crops, among whom 90% are resource-poor farmers from developing countries. China, India, Argentina, Brazil and South Africa—representing all three continents—are the five principal developing countries that produce transgenic crops. The collective impact of these five countries on transgenic development and adoption has been increasing and is likely to continue to play an important role in the future (James 2005).

Transgenic rice has not been commercialized yet on a large scale. *Bt* rice, released in 2005 in Iran, is the only transgenic rice being planted commercially. Research in transgenic rice has proceeded in a number of directions. Ongoing transgenic rice research includes developing varieties with higher yield potential, multiple resistance to disease and insects, tolerance to problem soils, superior grain quality, and higher micronutrient content such as vitamin A, iron, and zinc (IRRI 2003). Some varieties have been released for field trials and demonstrated improved agronomic features. For instance, a survey among US rice growers indicated that transgenic rice performed better than traditional varieties in terms of weed control and the average cost of herbicide treatment subsequently decreased by 50%. The mechanism through which transgenic rice may affect farmers' nutritional status may differ according to each variety's technological characteristics. While nutrient enhanced varieties (e.g. golden rice) may increase individuals' intake of specific nutrients directly, the effects of productivity enhancing varieties are more complex. Because farmers are both consumers and producers, and production and consumption decisions are usually made within a household unit, changes in product price, households' relative income, and profits due to the adoption of transgenic rice can all potentially affect households' ability to acquire food and improve their nutritional status. In principle, in the context of a farm household with multiple outputs/inputs and more than one consumed food item, when substitution and income effects as well as profit effects among different goods interact with each other, the amount by which farm households will increase their total calorie and protein consumption is uncertain. A simple question naturally arises: How much, if any, would the adoption of transgenic rice improve households' total nutrient intake in the developing countries?

Recent research exploring the potential impacts of transgenic crops focuses primarily on distributional and welfare effects (FAO 2004). For instance, the distributional impacts of Bt cotton in the developing countries have been studied for Argentina (Qaim and de Janvry 2003), China (Pray and Huang, 2003), Mexico (Traxler *et al.* 2003) and South Africa (Kirsten and Gouse 2003). With regards to transgenic rice, Mamaril (2002) used a partial equilibrium model with data from the Philippines and Vietnam to analyze cross-country distributional effects of transgenic rice. Hareau, Norton, Mills and Peterson (2005) used a general equilibrium model to examine the total and distributional effects of transgenic rice in favorable and less favorable ecosystems. Huang, Hu, Rozelle and Pray (2005) used multiple regression to compare farmers' pesticide use in insect-resistant transgenic rice production with that in non-transgenic rice production at the household level. To our knowledge, however, there is no quantitative analysis on the effects of transgenic rice on farmers' income and nutritional status at the household level. The paper aims to provide empirical evidence on this issue. Due to the complexity of technological characteristics of transgenic rice, this paper focuses on productivity enhancing transgenic rice varieties. The paper further assumes that a key measure of a farm household's nutritional status is represented by its total calorie and protein intake.

**Transgenic rice in Bangladesh**

This paper uses transgenic rice in Bangladesh as a case study to investigate the effects of introducing a transgenic crop on farm household nutritional status in a low-income developing country. Bangladesh is not only one of the poorest countries in the world, but it also has one of the highest poverty and under-nutrition rates in the world. In 2004, per capita gross national income in Bangladesh was 440 US dollars (World Bank 2006). Approximately 56% of preschool-age children are stunted, 56% are underweight, and 17% are wasted. According to the classification of child malnutrition by the World Health Organization, a prevalence of underweight above 30% or stunting above 40% is considered very high, while a prevalence of wasting above 15% reflects a critical public health problem. The rates of micronutrient deficiencies, particularly vitamin A, iron, iodine and zinc deficiency are also very high (FAO 1999).

Household surveys have indicated that cereals represent the largest amount of food consumed, followed by fruits/ vegetables and roots/tubers. Fish, milk, meat, eggs, pulses, oil/fats and other highly nutritious foods accounted for less than 10% of the daily energy intake. Rural households had higher consumption of cereals than urban households. Among cereals, rice is the main staple food and contributes approximately 70-80% of total energy intake, 65% of the total protein intake, and 69% of the total iron intake (Ahmed 1993). In addition to its significant contribution to household consumption, rice is the single most important crop in Bangladesh. It accounts for about 77% of total cropped area and two thirds of the value added in crop production (Maclean *et al* 2002).

Modern rice varieties were introduced into the country at the end of 1960s. In the following three decades, although the total area under modern varieties has increased to three-fourths in the dry season and one half in the wet season, varieties released during the initial years of the green revolution remain popular. Insects, diseases, weeds and abiotic stresses (e.g. salinity, cold, heat and drought) are major technical constraints to higher yields. About 175 species of rice insect pests have been recorded in Bangladesh, of which 20 to 30 species are important (Dey *et al.* 1996). In recent years, scientists have not been successful in overcoming these technical constraints through conventional breeding methods. Progress on biotechnology research, including the identification of a submergence tolerance gene, the developing of high-yield salt tolerant varieties, and *Bt* rice to control yellow stem borer, is expected to relieve the production constraints (Hossain, Husain and Datta 2003).

**Theoretic Model**

This paper employs a farm-household model to project a representative farm household's consumption and production responses to introducing new transgenic rice varieties, and to project their effects on farm households' nutritional status. Farm household modeling has long been used in policy analysis. Early seminal contributions include studies by Chayanov (1925), Sen(1966) , Berry and Soligo (1968), and Nakajima (1969). Many achievements in theory and empirical applications were summarized by Singh, Squire, and Strauss (1986). Efforts to enrich the theory and broaden its application continued in the 1990s (Sadoulet and de Janvry 1995).

This paper assumes that a farm household has recursive characteristics in its decision making. That is, a household makes production decisions independently of its consumption decisions. Its consumption decisions, on the other hand, are affected by total profit, which is a direct result of production choices. The recursive assumption can be justified by the fact that many farm households in Asian countries, including Bangladesh, are semi-commercial producers. In many areas, it is common for farmers to sell and purchase through the local market. They also participate in the local labor market through selling family labor or hiring wage labor during different stages of farm production. Therefore, it is not unreasonable to assume that farm households' production and consumption decisions are separable. This recursive feature makes it possible to estimate farm households' production and consumption separately. The paper further assumes that product and factor markets are perfectly competitive.

On the production side of the model, several important characteristics of agricultural production decisions are considered. Multiple inputs (labor, fertilizer) are used to produce multiple outputs (rice, all other crops and animal product); In the short run, some factors are fixed during the production period. The model includes three fixed factors: total land area, percentage of rice area in high yielding varieties (HYVs), and total animal assets. In the long run, fixed factors are variable, and farm households can freely adjust input/output levels to maximize their profits.

Since transgenic rice varieties have not been adopted by farmers, the ex ante nature of this research requires assumptions with respect to the adoption of the transgenic rice and its impacts on agricultural production. This paper assumes that the adoption of transgenic rice varieties and its effects on household production are represented by the fix factor—percentage of rice area in HYVs. It further assumes that the subsequent effect of transgenic rice on a household's production is reflected by the profit effect of this fixed factor. Although the assumption of equating profit effect due to transgenic rice to the profit effect of HYVs needs to be sharpened once field trial data are available for transgenic crops in Bangladesh, it is a useful assumption for illustrating potential effects of the improved varieties, particularly if one can assume that adoption of transgenic rice follows a similar pattern to HYVs.

When production decisions are made, output prices are unknown. A farm household's production decisions therefore are based on expected output prices and profit. In the model, the output price of the previous year is used as the expected output price. Mathematically, given expected output price vector $p_a^e$ and input price vector $p_x$ , farm households choose a vector of output level $q_a$ and a vector of input level $x$ to maximize expected profit $E(\pi)$ (equation (1)), subject to the available production technology (equation (2)). The production technology is represented by the production function, which assumes the usual neo-classical properties. In the equations, *w* denotes the wage rage and *l* denotes the total labor input (both family labor and hired labor). $z^q$ denotes the fixed factors.

$$\underset{q_a, x, l}{Max} E(\pi) = p_a^{e}{}' q_a - p_x{}' x - wl \qquad (1)$$

$$s.t.: \; g(q_a, x, l; z^q) = 0 \qquad (2)$$

Household production can be solved from the first order conditions. The effect of transgenic rice on expected profit can be identified through the elasticity of expect profit with respect to the percentage of rice area in HYVs ( $z_r$ ):

$$\gamma = \frac{\partial E(\pi)}{E(\pi)} \frac{z_r}{\partial z_r}$$

On the consumption side, given the level of profit $\pi *$, a farm household is assumed to choose among the consumption of food $c_F$ , non food items $c_{NF}$ , and leisure $c_l$ to maximize its utility (equation (3)), subject to the full income (Becker 1965) constraint (equation (4)) and the time constraint (equation (5)).

$$\underset{c_F, c_{NF}, c_l}{Max} \quad u\left(c_F, c_{NF,} c_l; z^h\right) \tag{3}$$

$$\text{s.t. :} \qquad p_F c_F + p_{NF} c_{NF} + wc_l = \pi + wT + R = E \tag{4}$$

$$c_l + l = T \tag{5}$$

In the model, leisure is broadly defined as the household consumption of home time, including family maintenance (cooking, cleaning), reproduction (taking care of children), socialization, and leisure. *T* is household's total time endowment. *R* is the total income from other sources. $z^h$ is household characteristics that affect household consumption.

Households' food demand can be derived from the first order condition. The elasticity of quantity demand for *i*th commodity ( $q_i$ ) with respect to total expenditure E can be expressed as $\eta_i = \frac{\partial q_i}{\partial E}\frac{E}{q_i}$.

To examine the impact of introducing transgenic rice on households' nutritional status, each household's food consumption is converted into its consumption of calories and protein. Since calorie/protein contents vary from one food item to another, defined as the calorie (or protein) content of a unit of food i, a household's total calorie (or protein) intake then can be expressed as:

$$q_c = \sum_i a_i q_i \tag{6}$$

A change in total calorie (protein) intake induced by the changes in consumption quantities of individual food items can be written as:

$$dq_c = \sum_i a_i dq_i \qquad (7)$$

Define $c_i = \frac{a_i q_i}{q_c}$ as the calorie (protein) share of *i*th food consumed, the elasticity of total calorie/protein intake with respect to full income E then can be written:

$$\frac{\partial q_c}{\partial E}\frac{E}{q_c} = \frac{\sum_i^n a_i \partial q_i}{\partial E}\frac{E}{q_c} = \frac{\sum_i^n a_i q_i}{q_c}\frac{\partial q_i}{q_i}\frac{E}{\partial E} = \sum_i^n c_i \eta_i \qquad (8)$$

An important feature of the farm household model is that it is an integrated model of both production and consumption. When there is a change in an exogenous variable, the model recognizes the fact that farm households respond both in their production decision and consumption decision. In this research, by integrating the production side and consumption side of the model, household's calorie (or protein) consumption elasticity with respect to the change in the percentage of rice area in HYVs ($E_c$) can be computed as:

$$E_c = \left.\frac{\partial q_c}{\partial z_r}\frac{z_r}{q_c}\right|_{\pi=\text{variable}} = \left.\frac{\partial q_c}{\partial z_r}\frac{z_r}{q_c}\right|_{\pi=\text{constant}} + \left(\frac{\partial q_c}{\partial E}\frac{E}{q_c}\right)\left(\frac{\partial E}{\partial \pi}\frac{\pi}{E}\right)\left(\frac{\partial \pi}{\partial z_r}\frac{z_r}{\pi}\right) \qquad (9)$$

In equation (9), *Ec* is the elasticity when farm profit is allowed to vary. It consists of two terms. The first term represents, when profit is held constant, how household total calorie (protein) intake changes in response to introducing transgenic rice. Since the fixed factor—the percentage of rice area in HYVs —doesn't enter the household's consumption function, no direct effect exists and this term thus becomes zero. The second term shows the case when profit is allowed to vary in the household's consumption decision. In the model, when other things held constant, transgenic rice will affect a household's consumption and its nutritional status through the profit effect derived from the production decision.

Rearranging equation (9), $E_c$ becomes $E_c = \sum_{i}^{n} c_i \eta_i \left( \frac{\pi}{E} \right) \gamma$ . This formula is used to compute the value of calorie (protein) elasticity.

**Empirical specification**

The estimation of the production side of the model follows the profit function approach developed by Lau, Lin and Yotopoulos (1978). The restricted profit function in this paper adopts the widely used trans-log functional form. In comparison with other functional forms, the trans-log profit function can be regarded as a second degree approximation of any function and does not suffer from the same restrictions on elasticities as the Cobb-Douglas and other functions do.

Outputs considered in the model include rice, all other crops, animal products, denoted by *i=1, 2, 3,* respectively. Inputs include labor and fertilizer, denoted by *i=4, 5,* respectively. Fixed factors are total land area, percentage of rice area in HYVs, animal asset, denoted by *m=1, 2, 3,* respectively. In the model, introducing of transgenic rice is represented by the percentage of rice area in HYVs. The restricted trans-log profit function is thus specified in terms of expected prices and fixed factors:

$$\log E(\pi) = \alpha_0 + \sum_{i=1} \alpha_i \ln p_i^e + \sum_{m=1} \beta_m \ln z_m + \frac{1}{2} \sum_i \sum_j \beta_{ij} \ln p_i^e \ln p_j^e + \frac{1}{2} \sum_m \sum_n \gamma_{mn} \ln z_m \ln z_n + \sum_i \sum_m \delta_{im} \ln p_i^e \ln z_m \quad (10)$$

Denote $s_i = p_i q_i / \pi$ as the share of output sales (a positive number) or an input purchase (a negative number) in profit. The trans-log system can be estimated in terms of share equations:

$$s_i = \alpha_i + \sum_j \beta_{ij} \ln p_j + \sum_m \delta_{im} \ln z_m \qquad (11)$$

The complete demand systems approach is employed to estimate farm households' food consumption. The most commonly used demand systems include the Linear Expenditure Systems (LES) developed by Stone (1953), the Almost Ideal Demand System (ALIDS) developed by Deaton and Muellbauer (1980), and the Generalized Almost Ideal Demand System (GAIDS) by Bollino (1990). Other complete demand systems, such as the Rotterdam model by Barnett (1979), the translog model of Christensen, Jorgenson, and Lau (Sadoulet and de Janvry 1995), are also found in the literature. In this paper, the ALIDS model is used. Since demographic variables (e.g. family size, age composition, etc.) usually play a role in farm households' consumption patterns, the "demographic translating" approach is used to include demographic variables in the model (Pollak and Wales 1992). The ALIDS model is specified as follows.

$$w_i = \alpha_{0i} + \sum_{k=1}^{K} \lambda_{ik} Z_k + \sum_{j=1}^{n} \delta_{ij} \ln p_j + \beta_i \left( \ln x - \sum_{k=1}^{n} \alpha_{0k} \ln p_k - (1/2) \sum_{i=1}^{n} \sum_{k=1}^{n} \delta_{ik} \ln p_i \ln p_k \right) \qquad (12)$$

where $p=(p_1,\ldots,p_N)$ is a $(N\times 1)$ vector of prices for food groups i, i=1,…,8. $w_i$ is the budget share for the ith goods consumed. It is also assumed that there is no interaction between demographic variables and prices.

Symmetry and homogeneity restrictions are imposed on the profit function and demand system, respectively, during estimation. Additive errors with zero expectations and finite variance are added to equations (10), (11), and (12). Production and demand systems are estimated separately. Within each system, the covariances of the errors of any two of the equations for the same farm may not be zero, but the covariances of the errors of any two equations corresponding to different farms are assumed to be identically zero. Under these assumptions, the iterated seeming unrelated regression routine (Zellner 1962; Barten 1969) is used to estimate the joint equations.

**Data**

The household survey data used in this paper were collected by the International Food Policy Research Institute (IFPRI) in its research project: Coping Strategies in Bangladesh, 1998-99.The original data was collected at three points in time over the period November 1998 to December 1999, and cover the production and consumption information of 757 households in seven flood-affected rural areas (Del Ninno 2001). This research focuses on 347 rice households.

For production estimation, outputs are aggregated into three commodity groups: rice, all other crops, and animal products. The components of each group are listed in Appendix A. For each aggregate output, a Tornqvist-Theil price index is computed. In the computation, farm-gate product price for year 1998, treated as the expected price, and product quantity for year 1999 are used. Only hired labor is included as labor input. Wage rates from various production activities, such as agriculture, kitchen gardening, and fishing, and corresponding labor input in 1999 are used to compute a Tornqvist-Theil price index for wages. Similarly, a fertilizer price index is computed for two types of fertilizer.

For consumption estimation, food items are divided into eight subgroups: rice, wheat and other food, pulses, oil, vegetables and fruits, meat/egg/milk, fish, and spices. To convert food consumption into calorie and protein intake, the average calorie/protein content of all individual food items within each subgroup is used as the calorie/protein content for each subgroup.

To make different households comparable in their consumption, household consumption is adjusted by per adult equivalent consumption. An adult equivalent number is computed for each household. The adult equivalence scale used in this paper is shown in table 1: the first adult in the household is given a weight of 1 in term of consumption and the additional adults are given a weight of 0.7. Infants less than 5 years old are given a weight of 0.3. Children and elderly are given a weight of 0.5.

**Table 1. Adult Equivalence Scale**

| Description | Age Category | Adult Equivalence Scale |
|---|---|---|
| Infants | Less than 5 | 0.3 |
| Children | >=5 & <16 | 0.5 |
| Adults | >=16 & <=65 | first adult: 1<br>additional adults: 0.7 |
| Elderly | over 65 | 0.5 |

Based on the situation in Bangladesh, a farm household’s poverty line is set at 0.75 US dollar per adult equivalent per day. A household is thus considered to be poor if its per adult equivalent consumption per day is less than the poverty line. The poverty prevalence of surveyed rice farm households was computed. Among a total of 347 households, 232 are poor and 115 are non-poor, which account for 66.86% and 33.14%, respectively. The high percentage of poor households illustrates the existence of poverty in Bangladesh.

**Results**

Before the household model was estimated, the household food consumption pattern was analyzed using descriptive statistics (table 2). On average, a poor household spends 8347.16 taka per adult equivalent per year while a non-poor household spends 15438.86 taka per adult equivalent per year. Poor and non-poor households exhibit similar patterns in food consumption. In both households, rice is the most important food item. Rice expenditure accounts for 39.78% and 27.79% in poor and non-poor households, respectively. Poor households, however, spend an even larger proportion of their total food expenditure on rice than non-poor households do. Vegetables and fruits is the second important food item, accounting for 19.95% and 23.83% of poor and non-poor households' total food expenditures, respectively. Other important foods include wheat and other food, meat/egg/milk, and fish. Non-poor households' expenditures on all of these other important foods exceed poor households' expenditures. In particular, non-poor households consume more animal products and processed food than poor households do.

**Table 2. Households' Individual Food Expenditure Shares in Total Food Expenditure**

| Food Group | Poor | Non-Poor |
|---|---|---|
| Rice | 39.78% | 27.79% |
| Wheat and Other Food | 15.17% | 15.84% |
| Pulses | 3.59% | 3.38% |
| Oil | 3.06% | 2.95% |
| Vegetables and Fruits | 19.95% | 23.84% |
| Meat/Egg/Milk | 7.25% | 11.97% |
| Fish | 6.90% | 10.23% |
| Spices | 4.29% | 4.00% |
| Total Food Expenditure | 100% | 100% |

A household's total nutrient intake depends on the amounts of food consumed by its members and the nutrient content of each food item. Table 3 shows the contribution of various food items to a representative household's total calorie intake. Among the surveyed households, rice, wheat and other food, and vegetables and fruits are the most important three food groups, among which rice is the most important one. Rice accounts for 64% of households' calorie intake in poor households and 57% in non-poor households. This ratio is consistent with the 70-80% ratio suggested in other surveys (Ahmed 1993). The calorie share of meat/egg/milk and fish are 2.54% and 1.5% in poor households, respectively, and are 4.27% and 1.97% in non-poor households, respectively. The low percentage indicates that the actual consumption of animal products is not big enough to have a large impact on its calorie share in total calorie intake.

**Table 3. Share of Individual Food Items in Household Total Calorie Intake**

| Food Items | Calorie Content (kcal/100g) | Household Annual Total Consumption (kg) | | Calorie Share of ith Food Consumed | |
|---|---|---|---|---|---|
| | | Poor | Non-Poor | Poor | Non-Poor |
| Rice | 352.00 | 997.2801 | 1151.427 | 64.11% | 57.00% |
| Wheat/Other Food | 357.32 | 241.9091 | 310.4116 | 15.79% | 15.60% |
| Pulse | 342.29 | 54.9707 | 75.91057 | 3.44% | 3.65% |
| Oil | 900.00 | 17.29456 | 30.32699 | 2.84% | 3.84% |
| Vegetables/Fruits | 64.92 | 648.5738 | 1206.232 | 7.69% | 11.01% |
| Meat/Egg/Milk | 141.42 | 98.34644 | 214.4509 | 2.54% | 4.27% |
| Fish | 114.11 | 50.31819 | 122.5093 | 1.05% | 1.97% |
| Spices | 275.34 | 50.63624 | 68.67196 | 2.55% | 2.66% |

Compared with non-poor households, poor households depend more on rice consumption for calorie intake. The calorie share of rice in poor household is about seven percent higher than in non-poor households. Non-poor households consume more vegetables & fruits and more meat/egg/milk for calorie intake.

Farm households' protein intakes follow a consumption pattern similar to calorie intake. Rice accounts for 41.74% of total protein intake in poor households and 32.66% in non-poor households (table 4). There is about 9% difference between poor and non-poor households, which indicates that poor households depend more on rice for protein than non-poor households do. In poor households, the second largest protein source is wheat and other food, which accounts for 18.19% of total protein intakes. In non-poor households, meat/egg/milk is the second largest protein source and contributes 17.73% of total protein intakes. The protein share of meat/egg/milk in poor households is five percent less.

**Table 4. Share of Individual Food Items in Household Total Protein Intake**

| Food Items | Protein Content (g/100g) | Household Annual Total Consumption (kg) | | Protein Share of *i*th Food Consumed | |
|---|---|---|---|---|---|
| | | Poor | Non-Poor | Poor | Non-Poor |
| Rice | 6.77 | 997.2801 | 1151.427 | 41.73% | 32.66% |
| Wheat/Other Food | 12.16 | 241.9091 | 310.4116 | 18.19% | 15.82% |
| Pulse | 25.93 | 54.9707 | 75.91057 | 8.81% | 8.25% |
| Oil | 7.88 | 17.29456 | 30.32699 | 0.84% | 1.00% |
| Vegetables/Fruits | 2.35 | 648.5738 | 1206.232 | 9.41% | 11.87% |
| Meat/Egg/Milk | 19.73 | 98.34644 | 214.4509 | 12.00% | 17.73% |
| Fish | 19.26 | 50.31819 | 122.5093 | 5.99% | 9.89% |
| Spices | 9.62 | 50.63624 | 68.67196 | 3.01% | 2.77% |

When transgenic rice is introduced into farm production, farm households will make production decisions with respect to output supply and input demand. Estimation of the trans-log profit function indicates that, when calculated at the household average level, the elasticity of expected profit with respect to the percentage of rice area in HYVs is 0.08. That is, when the percentage of rice area in HYVs increases by 1%, the expected profit increases by 0.08%. This result indicates that transgenic rice—assumed to be similar to the adoption to other HYVs—would have a positive effect on a farm household's profit. The impact of the profit increase on households' nutritional status then is translated through income changes affecting households' nutrient intake. Both income elasticities and calorie and protein shares of individual food items will affect a farm household's total calorie and protein intake.

Estimates of demand and income elasticities of both poor and non-poor farm households' food consumption are attached in Appendix B. The results indicate for both types of households that the income elasticities of vegetables/fruits, meat/egg/milk, and fish are greater than one, and the income elasticity of rice is less than one. The elasticities imply that as income increases, on average both poor and non-poor farm households tend to spend more on animal products and vegetables/fruits, and less on rice. For instance, as income increases by 1%, a poor household will increase its meat/egg/milk expenditure by 1.59% and increases its rice expenditure by 0.88%. Similarly, a non-poor household will increase its meat expenditure by 1.08% and rice expenditure by 0.51%. The result also indicates that the impact of income on the same food item vary by households. Income increase by 1%, rice expenditure will increase by 0.88% among poor households and by 0.51% among non-poor households. Therefore, income will have larger impact on poor households in rice.

The estimates of income elasticities indicates that as income increases, on the one hand, demand for animal products increases more than proportionally to income, and therefore the expenditure share of animal products increases as income increases. On the other hand, demand for staples (including rice) increases less than proportionally to income, the expenditure share of staples decreases as income increases. Since currently rice provides most calorie intakes for the surveyed households, a decline in the expenditure share of rice may decrease farm households' total calorie intakes.

Using the results from the estimation of a farm household's profit function and demand system, farm households' calorie and protein intake elasticities with respect to the percentage of rice area in high yield variety were computed. The results indicate that the calorie elasticities range from 0.062 to 0.074 and protein elasticities ranges from 0.075 to 0.084 among households (table 5). The effects of the introducing transgenic rice on nutritional status vary by households. According to the results, as the percentage of rice area in HYVs increases by one percent, the calorie intake will increase by 0.074% in poor households and by 0.062% in non-poor households. Similarly, the protein intake will increase by 0.084% in poor households and 0.075% in non-poor households.

**Table 5. Calorie and Protein Intake Elasticity with respect to the Percentage of Rice Area in HYVs**

| Elasticity | Household Type | |
|---|---|---|
| | Poor | Non-Poor |
| Calorie Elasticity | 0.074 | 0.062 |
| Protein Elasticity | 0.084 | 0.075 |

In summary, in terms of improved nutritional status, transgenic rice is likely to play a positive role in improving farm households' nutritional status. Although the magnitude is moderate, poor households will benefit more from the adoption of transgenic rice than non-poor households. In this research, limited by the available data, the introduction of transgenic rice is represented by the percentage of rice area in high yield varieties. By using the percentage of rice area, this research assumes the effects of transgenic rice on farm household profit and on rice yield will be same as other high yield varieties. The effects on yield of such transgenic rice varieties as drought resistance were not considered in the model. If the yield increase by transgenic rice is considered, it is possible that the impact of transgenic rice on farm households' nutrient intakes will be larger than the ones produced in table 5.

## Conclusion

The rapid development in biotechnology has produced a number of potential transgenic crop varieties in recent years. Although it has not been released on a large scale, transgenic rice, with its potentials to address adverse production conditions, has given people expectations for improving poor farm households' well-being in developing countries, in particular, in improving farmers' nutritional status in the context of prevailing under-nutrition in countries such as Bangladesh.

This paper utilizes a farm household model to examine the potential nutritional effects of transgenic rice if the adoption of transgenic rice follows a similar pattern to previous high yield rice varieties. The results show that transgenic rice is likely to play a significant role in improving farm households' nutritional status. The magnitude, however, may be moderate if only the profit effect is considered.

In this research, data availability was a major constraint in the model design and empirical specification. A number of assumptions regarding the adoption of transgenic rice were made. In the future, as yield and adoption data of transgenic rice are available, assumptions can be refined. Various technological characteristics of transgenic rice varieties can be modeled.

## References


Ahmed, A. 1993. *Patterns of Food Consumption and Nutrition in Rural Bangladesh*. Dhaka: International Food Policy and Research Institute.

Barnett, W.A. 1979. "Theoretical Foundations for the Rotterdam Model." *Review of Economics Studies* 46: 109-130.

Barnum, H.N., and L. Squire. 1979. "An Econometric Application of the Theory of the Farm-Household." *Journal of Development Economics* 6: 79-102.

Barten A P. 1969. "Maximum Likelihood Estimation of a Complete System of Demand Equations." *European Economic Review* 1:7-73.

Becker, G.S. 1965. "A Theory of the Allocation of Time." *Economic Journal* 75: 493-517.

Berry, A., and R. Soligo. 1968. "Rural-Urban Migration, Agricultural Output and the Supply Price of Labor in a Labor Surplus Economy." *Oxford Economic Papers* 20: 230-249.

Bollino, C. 1990. "A Generalized Version of the Almost Ideal and Translog Demand Systems." *Economic Letters* 34: 127-129.

Chayanov, A.V. 1966. *The Theory of Peasant Economy.* Thorner *et al., eds.* Homewood IL: Richard D. Irwin.

Deaton, A., and J. Muellbauer. 1980. "An Almost Ideal Demand System." *The American Economic Review* 70(3): 312-326.

Dey, M.M., M.N.I. Miah, B.A.A. Mustsfi, and M. Hossain. 1996. "Rice Production Constraints in Bangladesh: Implications for Further Research Priorities." In Evenson, R.E., R.W. Herdt and M. Hossain, eds. *Rice Research in Asia: Progress* *and Priorities*. Manila, Philippines: CAB International in association with the International Rice Research Institute (IRRI), pp. 171-191.

Del Ninno, C. 2001. *Coping Strategies in Bangladesh: Survey Documentation.* FMRSP Data Documentation Report No.1. International Food Policy Research Institute.

United Nations, Food and Agriculture Organization. 1999. *Nutrition Country Profiles-Bangladesh*. Rome.

United Nations, Food and Agriculture Organization. 2001. Rome. Available at http://www.fao.org/docrep/meeting/003/Y0688e.htm.

United Nations, Food and Agriculture Organization. 2003. *The State of Food Insecurity in the World 2003.* Rome.

United Nations, Food and Agriculture Organization. 2004. *The State of Food and Agriculture 2003-04.* Rome.

FAOSTAT. 2006. Rome. Available at http://faostat.fao.org/faostat/collections?version=ext&hasbulk=0&subset=agriculture

Hareau, G.G., G.W. Norton, B.F. Mills, and E. Peterson. 2005. "Potential Benefits of Transgenic Rice in Asia: A General Equilibrium Analysis." *Quarterly Journal of International Agriculture* 44(3):229-246.

Hossain, M., M. Husain, and S.K. Datta. 2003. "Rice Biotechnology: Opportunity, Perceived Risk and Potential Benefits to Bangladesh." Unpublished. IRRI.

Huang, J., R. Hu, S. Rozelle, and C. Pray. 2005. "Insect-Resistant GM Rice in Farmers' Fields: Assessing Productivity and Health Effects in China." *Science* 208: 688-690.

IRRI. 2003. Project summary and highlights: Improving the productivity and livelihood for fragile environments. Available at http://www.irri.cgiar.org/science/progsum/prog2002.asp.

James, C. 2005. "Global Status of Commercialized Biotech/GM Crops: 2005." *ISAAA Briefs* No. 34. Ithaca, NY: ISAAA.

Kirsten, J., and Gouse, M. 2003. "The Impact of Agricultural Biotechnology in South Africa." In N. Kalaitzandonakes, ed. *The Economic and Environmental Impacts of Agbiotech: A Global Perspective.* New York, USA: Kluwer-Plenum Academic Publishers.

Lau, L.J., W.L. Lin, and P.A. Yotopoulos. 1978. "The Linear Logarithmic Expenditure System: An Application to Consumption-Leisure Choice." *Econometrica* 46:843-868.

Maclean J.L., D.C. Dawe, B. Hardy, and G.P. Hettel, eds. 2002. *Rice Almanac: Source Book for the Most Important Economic Activity on Earth*. Wallingford, UK: CAB International in association with the International Center for Tropical Agriculture (CIAT), the West Africa Development Association (WARDA) and the Food and Agriculture Organization (FAO).

Mamaril, C.B.C. 2002. "Transgenic Pest Resistant Rice: An Economic Evaluation of an Adoption Impact Pathway in the Philippines and Vietnam for Bt Rice." MS thesis, Virginia Tech.

Nakajima, C. 1969. "Subsistence and Commercial Family Farms: Some Theoretical Models of Subjective Equilibrium." In C.F. Wharton, ed. *Subsistence Agriculture and Economic Development*. Chicago: Aldine Publishing Company.

Pollak, R.A., and T.J. Wales. 1992. *Demand System Specification & Estimation*. New York: Oxford University Press.

Pray, C.E., and Huang, J. 2003. "The Impact of Bt Cotton in China." In N. Kalaitzandonakes, ed. *The Economic and Environmental Impacts of Agbiotech: A Global Perspective*. New York, USA: Kluwer-Plenum Academic Publishers.

Qaim, M., and de Janvry, A. 2003. "Genetically modified crops, corporate pricing strategies, and farmers' adoption: the case of Bt cotton in Argentina." *American Journal of Agricultural Economics* 85: 814-828.

Sadoulet, E., and A. de Janvry. 1995. *Quantitative Development Policy Analysis*. Baltimore: Johns Hopkins University Press.

Sen, A.K. 1966. "Peasants and Dualism with and without Surplus Labor." *Journal of Political Economy* 74:425-450.

Singh, I., L. Squire, and J. Strauss, eds. 1986. *Agricultural Household Models: Extensions, Applications, and Policy*. Baltimore and London: Johns Hopkins University Press.

Stone, J. 1953. *The Measurement of Consumers Expenditures and Behavior in the United Kingdom, 1920-1938,*Vol. 1. Cambridge: Cambridge University Press.

Traxler, G., Godoy-Avila, S., Falck-Zepeda, J., and Espinoza-Arellano, J. 2003. "Transgenic cotton in Mexico: economic and environmental impacts." In N. Kalaitzandonakes, ed. *The Economic and Environmental Impacts of Agbiotech: A Global Perspective.* New York, USA: Kluwer-Plenum Academic Publishers.

World Bank. 2006. Key Development Data & Statistics. Available at http://devdata.worldbank.org/external/CPProfile.asp?PTYPE=CP&CCODE=BGD

Zellner, A. 1962. “An Efficient Method of Estimating Seemingly Unrelated Regressions and Tests for Aggregation Bias.” *Journal of the American Statistical Association* 57(298): 348-368.

**Appendix A. Components of Aggregated Outputs**

| Commodity Subgroup | Components |
|---|---|
| Rice | *B.aman(M),B.aus(L),B.aus(mi),B.mam(L),T.aman(H),T.aman(L),T.aus(L),boro(L),boro(hyv)* |
| All Other Crops | Other Major Cereals<br>*bojra(Pearl millet), kawn (Italian millet), joar(Great millet),maize,wheat(L),wheat(hy),Others*<br><br>Pulses and Oil Seeds<br>*GrKali (soybean), MsKali(black gram), chickpea, keshari (chickling vetch), mashur(lentil), motor(field pea), mung Mustard, sesame, tishi(linseed), other seeds*<br><br>Vegetables and Fruits (including spices)<br>*arraharr, bean, brboti, caulibd, caulifl (cauliflower), chching, chkumra(wax gourd), corolla, cucumber, danta, dantask (danta shak), dherosh, eggplant, jhinga (ribbed gourd), kachu, kachusk, kalmisk, khejrosh, klojam, lalsk, lausk, mula, mulask, otvgtble (other vegetables), palngsk (palang shak), potato, puisk (pui shak), pumpkin, stkumra (sweat gourd), stpotato (sweat potato), tomato, tutfal, vegetable, wtkumra (water gourd)*<br><br>*chilli, dhania, garlic, onion*<br><br>*ChNut, GrBanana (green banana), K. lemon, Banana, Coconut, Grpapaya, Guava, Jkfruit(Jack fruit), Khejur, Lemon, Lichies, mango, orange, Otfruit(other fruits), Otlemon (other lemons), pan, Papaya, Shupari(betel), Tall(palm)*<br><br>Fiber and other crops<br>*Jute, bamboo, Tobacco, Sugar cane* |
| Animal Product | Egg<br>Milk<br><br>Fish<br>*Ilish, Koi, Magur, Shingi, Khalse, Shol/Gajar/Taki, Telapia/Puti/Swarputi, Chingri, Rui/Katal, Tengra/Baim, Mala/Kachki/Dhela/Chapila, Other (Large), Other (Small), Sea fish, Other sea fish,* |

## Appendix B. Estimates of Demand Price/cross Price Elasticities and Income Elasticity of Food Items

| | | Price of | | | | | | | | Income Elasticity |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Rice | Wheat/ Others | Pulse | Oil | Vegetables/ Fruits | Meat/Egg/Milk | Fish | Spices | |
| Rice | Poor | -0.4813 | 0.0744 | 0.0149 | -0.0362 | -0.3372 | -0.0232 | -0.0736 | -0.0156 | 0.8777 |
| | | (0.1014) | (0.0640) | (0.0234) | (0.0139) | (0.0599) | (0.0416) | (0.0363) | (0.0189) | (0.0638) |
| | Non-Poor | -0.2403 | 0.0771 | 0.0620 | 0.0234 | -0.3654 | 0.0266 | -0.0678 | -0.0262 | 0.5107 |
| | | (0.1831) | (0.1140) | (0.0380) | (0.400) | (0.1266) | (0.1064) | (0.0813) | (0.0409) | (0.1049) |
| Wheat/Other food | Poor | 0.1613 | -0.8948 | -0.0909 | -0.0539 | -0.0543 | 0.0045 | -0.0284 | 0.0004 | 0.9651 |
| | | (0.1655) | (0.1872) | (0.0586) | (0.0361) | (0.1368) | (0.0941) | (0.0800) | (0.0469) | (0.1144) |
| | Non-Poor | -0.0434 | -0.9670 | -0.1726 | 0.0876 | -0.1180 | -0.0163 | -0.0538 | 0.1229 | 1.1606 |
| | | (0.2018) | (0.2409) | (0.0685) | (0.0721) | (0.1865) | (0.1612) | (0.1155) | (0.0762) | (0.1268) |
| Pulse | Poor | 0.0065 | -0.4300 | -0.2285 | 0.0476 | -0.2358 | -0.2044 | 0.0154 | -0.2495 | 1.2785 |
| | | (0.2574) | (0.2480) | (0.2340) | (0.1227) | (0.2448) | (0.1782) | (0.1423) | (0.1445) | (0.1539) |
| | Non-Poor | 0.4272 | -0.7568 | -0.2409 | 0.0084 | -0.5997 | -0.1844 | -0.2328 | 0.7578 | 0.8212 |
| | | (0.3186) | (0.3232) | (0.2971) | (0.2108) | (0.3114) | (0.2735) | (0.1783) | (0.2426) | (0.1754) |
| Oil | Poor | -0.3155 | -0.1960 | 0.0845 | -0.4956 | 0.1226 | 0.1053 | 0.0244 | 0.1862 | 0.4842 |
| | | (0.1775) | (0.1783) | (0.1437) | (0.1547) | (0.1713) | (0.1263) | (0.0996) | (0.1236) | (0.1046) |
| | Non-Poor | 0.0585 | 0.4814 | 0.0006 | -0.1874 | -0.8305 | -0.4937 | -0.0187 | -0.1015 | 1.0913 |
| | | (0.3886) | (0.3929) | (0.2430) | (0.3287) | (0.3870) | (0.3312) | (0.2175) | (0.2652) | (0.2193) |
| Vegetables/ Fruits | Poor | -0.7327 | -0.0509 | -0.0334 | 0.0020 | -0.2206 | -0.0525 | 0.0408 | 0.0186 | 1.0286 |
| | | (0.1146) | (0.1020) | (0.0433) | (0.0259) | (0.1329) | (0.0697) | (0.0575) | (0.0345) | (0.0796) |
| | Non-Poor | -0.6266 | -0.0906 | -0.0988 | -0.1071 | 0.0663 | -0.3500 | -0.0340 | 0.0018 | 1.2391 |
| | | (0.1484) | (0.1237) | (0.0438) | (0.0471) | (0.1860) | (0.1175) | (0.0882) | (0.0479) | (0.1003) |
| Meat/Egg/Milk | Poor | -0.4102 | -0.1020 | -0.1118 | 0.0098 | -0.2562 | -0.5726 | -0.0936 | -0.0501 | 1.5866 |
| | | (0.2257) | (0.1969) | (0.0879) | (0.0533) | (0.1951) | (0.1949) | (0.1180) | (0.0712) | (0.1591) |
| | Non-Poor | -0.1020 | -0.0084 | -0.0610 | -0.1213 | -0.6580 | 0.1302 | -0.1114 | -0.1521 | 1.0839 |
| | | (0.2508) | (0.2136) | (0.0768) | (0.0805) | (0.2354) | (0.2707) | (0.1483) | (0.0857) | (0.1812) |
| Fish | Poor | -0.6238 | -0.1240 | 0.0047 | -0.0170 | 0.0474 | -0.0838 | -0.4996 | -0.0832 | 1.3792 |
| | | (0.2086) | (0.1767) | (0.0741) | (0.0444) | (0.1704) | (0.1245) | (0.1451) | (0.0592) | (0.1522) |
| | Non-Poor | -0.4584 | -0.1326 | -0.0990 | -0.0169 | -0.1345 | -0.1798 | -0.3536 | -0.1086 | 1.4834 |
| | | (0.2263) | (0.1805) | (0.0589) | (0.0622) | (0.2091) | (0.1744) | (0.1952) | (0.0645) | (0.1857) |
| Spices | Poor | -0.0562 | 0.0471 | -0.1868 | 0.1279 | 0.1609 | -0.0172 | -0.0842 | -0.6487 | 0.6571 |
| | | (0.1720) | (0.1653) | (0.1206) | (0.0881) | (0.1624) | (0.1202) | (0.0947) | (0.1464) | (0.1006) |
| | Non-Poor | -0.2986 | 0.5225 | 0.6367 | -0.0703 | 0.0822 | -0.4375 | -0.2220 | -1.1480 | 0.9349 |
| | | (0.2886) | (0.3034) | (0.2050) | (0.1943) | (0.2869) | (0.2574) | (0.1645) | (0.3141) | (0.1580) |

Note: Numbers in parentheses are asymptotic standard errors.