An Ex Ante Analysis of the Effects of Transgenic Rice on Farm Households' Nutritional Vulnerability in Bangladesh

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(Abstract)

Despite concerted efforts at agricultural development over many years, millions of people in developing countries still suffer from poverty and under-nutrition. New crop varieties, such as those released during the green revolution in Asia, increased farmers' income and reduced the level of under-nutrition. In recent years, while the speed of the development of conventional breeding technology has slowed, biotechnology has developed rapidly. In 2005, about 8.5 million farmers in 21 countries grew transgenic crops. Transgenic rice has not been commercially released on a large scale, but progress has been made in developing varieties with potential to increase yield and reduce input costs. In this context, this research aims to provide empirical evidence on the potential effects of introducing transgenic rice on farm households' income and nutritional well-being in Bangladesh—including the impacts on their current nutritional status and nutritional vulnerability over time. To this end, two econometric models are constructed and estimated.

A farm household model is employed to project farm households' production and consumption responses to introducing improved rice varieties such as transgenic rice. The model estimates the profit effect of introducing transgenic rice. The influence of the profit effect on farmers' consumption decisions is then considered. Due to the ex ante nature of this research and data limitations, the effects of transgenic rice are assumed to be similar to that of previous high yielding varieties (HYVs), and the impact of transgenic rice on farm household profit is assumed to be similar to the effect of the percentage of rice area in HYVs and the yield effect of transgenic rice is the same as HYVs. On the production side, the supply of three outputs—rice, all other crops and animal products—and demand of labor and fertilizer were estimated. On the consumption side, both poor and non-poor households' demand for rice, wheat/other food, pulse, oil, vegetables/fruits, meat/egg/ milk, fish, and spices were estimated. Based on the parameter estimates, the calorie intake and protein intake elasticities with respect to introducing transgenic rice were computed. The results indicate that the total profit elasticity with respect to the percentage of rice area in HYVs is 0.08. The calorie elasticity with respect to the percentage of rice area in HYVs 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 households. The results indicate that transgenic rice is likely to play a positive role in improving farm households' nutritional status in terms of total calorie/protein intake. The magnitude, however, is likely to be moderate, if only the profit effect is considered.

A consumption forecasting model is used to examine farmers' nutritional vulnerability—a probabilistic concept defined as "having a high probability now of suffering a shortfall in the future". It is assumed that when exposed to risk, farmers' consumption decisions have already considered their risk coping strategies. The effect of transgenic rice is reflected by its impact on farm income. Farm households' calorie intake in the future (hunger season) was predicted by a multivariate regression function with the logarithmic daily per resident calorie intake as the dependent variable. The independent variables include variables that represent households' income, flood exposure, assets, and demographic composition. Farm households' nutritional vulnerability profiles, based on the estimation of ex ante mean and variance, indicate that vulnerability exists among surveyed rice farm households. The model also predicts that the income increase induced by introducing transgenic rice will reduce each individual household's probability of suffering a future consumption shortfall and subsequently will reduce its vulnerability. The overall vulnerability profile of farm households improves in Bangladesh.

To Songming and my parents

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CHAPTER 1: INTRODUCTION

1.1 Problem statement

Despite many achievements in increasing agricultural productivity over the past few decades, poverty and food insecurity persist in many developing countries. One concern is that while global food supplies are adequate to feed the world's population, many in developing countries do not have access to an adequate diet. According to the Food and Agriculture Organization of the United Nations (FAO), during the 1990-1992 baseline period, an estimated 20 percent of the developing countries' population (approximately 841 million people) did not have enough food to meet their basic nutritional needs. Some 190 million children are underweight, 230 million children are stunted and 50 million children are wasted (FAO, 1996a). Eighty-two countries, mainly in Africa and Asia, were listed as low-income food deficit countries (FAO, 2005). Viewing this situation as unacceptable, governmental representatives from 185 countries plus the European Community participating in the 1996 World Food Summit (WFS) vowed to fight to enable all people, at all times, to have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs. They set the agenda to "eradicate hunger in all countries, with an immediate view to reducing the number of undernourished people to half their present level no later than 2015" (FAO 1996b). Indeed, the number of undernourished people continued to decline in the years that followed the WFS. However, the pace to reduce the number of undernourished people is far below its targeted rate. In 2003, FAO estimated that in developing countries 798 million people were still undernourished in 1999-2001. At this rate, the World Food Summit goal will be reached 100 years later than the 2015 target (FAO, 2003).

The significance of reducing under-nutrition in developing countries cannot be overstated. It is a well established medical fact that adequate nutrition—particularly in one's childhood—plays a crucial role in an individual's biological development. Economically, good nutrition contributes to both the individual's lifetime earnings and the overall growth of an economy by influencing the formation of human capital.

Energy (calorie) and protein deficiency are the most prevalent types of under-nutrition. Evidence from household food surveys in developing countries shows that under-nutrition can cause adults to have smaller and slighter body frames and consequently earn lower wages in physical labor jobs. Other studies have found that a one percent increase in the body mass index (BMI) (weight/height squared), which is considered at present to be the most suitable anthropometric indicator of under- or over-nutrition, is associated with an increase of more than two percent in wages for those toward the lower end of the BMI range (FAO, 2001).

Micronutrient deficiency (mainly iron, vitamin A, iodine, and zinc deficiency) is another type of under-nutrition. It has severe effects on women and children. It is estimated that due to micronutrient deficiencies, 81.92 million preschool children were stunted and 149.43 million preschool children were underweight in 2000 (CGIAR, 2002). During the same period, globally as many as 75 to 251 million preschoolers were affected by vitamin

A deficiency (ACC/SCN, 2002). Surveys suggest that iron deficiency anemia can reduce productivity of manual laborers by up to 17 percent (FAO, 2001).

At the macro level, studies in several Asian countries in the 1990s indicate that the losses to Gross Domestic Product (GDP) from various components of under-nutrition can be as high as three percent of national income (Haddad, 2002). FAO studies show similar results. For instance, anemia alone has been found to reduce GDP by 0.5 to1.8 percent in several countries. Studies in India, Pakistan, Bangladesh and Vietnam estimated conservatively that the combined effects of stunting, iodine deficiency and iron deficiency reduced GDP by 2 to 4 percent. Recent calculations by the FAO suggest that achieving the WFS goal of reducing the number of undernourished people by half by the year 2015 would yield a value of more than US$120 billion (FAO, 2001).

In many cases under-nutrition is a manifestation of absolute poverty. Lack of income directly limits people's access to adequate food. Often, most individuals in developing countries living under the poverty line (less than 1 US dollar per person per day) suffer one or more types of under-nutrition. In other cases, natural disasters, such as drought, flood, and man-made disasters (civil war, etc.) can cause food shortages and result in under-nutrition. Resource poor farmers are often adversely affected by forces beyond their control. Therefore, under-nutrition is also a dynamic concept. Any endeavor to improve their nutritional status should not ignore its dynamic aspects. In fact, it is estimated that globally about 215 million children alone suffer from chronic under-nutrition (IFAD, 2001) and there is increasing nutritional vulnerability among undernourished people. Nutritional vulnerability-- the possibility now that individuals' nutritional consumption in the future will fall below socially accepted standards (Christiaensen and Boisvert, 2000) -- means some people may not suffer under-nutrition now, but in a changing environment, they may be undernourished in the future.

A number of approaches have been employed to tackle the problem of under-nutrition (including both calorie and micronutrient deficiency) in developing countries. For instance, the World Bank recommended that developing countries "take direct aim at micronutrient under-nutrition through consumer education, aggressive distribution of pharmaceutical supplements, and the fortification of common foodstuffs or water" (World Bank, 1994). Similarly, the FAO regarded dietary diversity, food fortification and supplements as the three main strategies for reducing micronutrient deficiency (FAO, 2001). Other studies advocated that more efforts should focus on household level determinants of individual nutrition status, such as food availability, healthy living environment and education for women (Colombo, Johnson, and Shishido, 1978).

Although reforms of income and food distribution systems aiming at helping poor households in general will alleviate a household's under-nutrition situation, in the short run these reforms may not be politically or economically feasible. Continuous progress in boosting agricultural productivity remains one of the basic means of increasing both the food available to farmers and income that may be derived from higher productivity. The agricultural productivity in developing countries witnessed a rapid growth period beginning in the late 1960s. In the following two decades, due primarily to the green revolution, millions of people in Asia and Latin America were able to overcome the threats of starvation and famine. The degree of absolute poverty and magnitude of under-nutrition were greatly reduced. Unfortunately, further yield potentials gradually diminished as the green revolution approached its end. As a result, major crop production in many countries either reached a yield plateau or increased at a decreasing rate. For instance, 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).

During the green revolution, high yield varieties were mainly developed through conventional breeding technologies. As increases in production potentials disappeared and developing countries struggled with the stagnation of agricultural production, interest in biotechnology emerged. Both the public and private sectors have invested enormously in biotechnology, including transgenic crops. Much progress has been made. Globally transgenic crops increased from 1.7 million hectares in 1996 to 90 million hectares in 2005, an increase of 50 fold (Table1.1). The estimated global net economic benefits of the transgenic crops on 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).

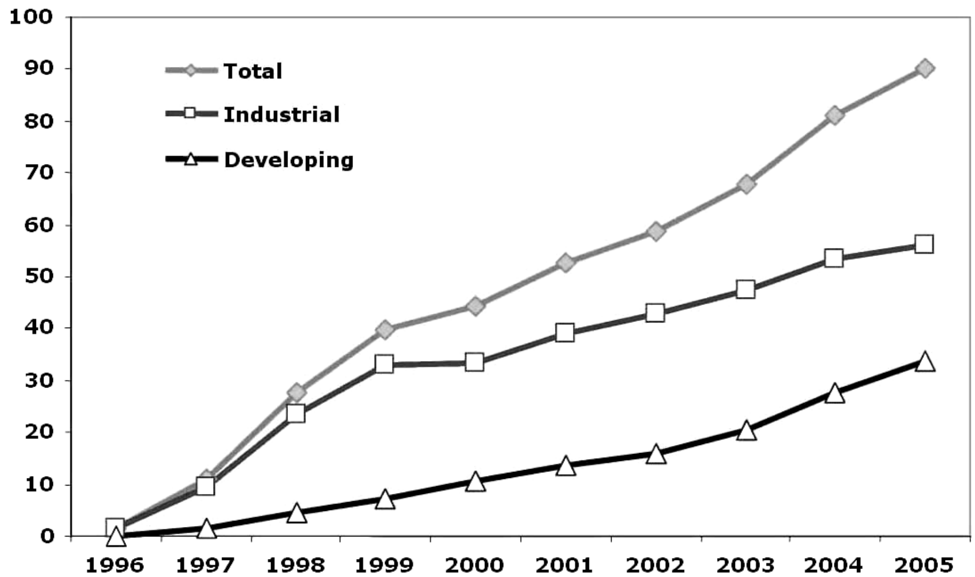
The United States is the leading country in transgenic crop production with 49.8 million hectares planted (55% of global biotech area). The period from 1996 to 2005 also witnessed an annual increase in the proportion of the global area of biotech crops grown by developing countries (Figure 1.1). More than one-third (38%, up from 34% in 2004) of the global biotech crop area in 2005, equivalent to 33.9 million hectares, was 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).

Table1.1 Global status of transgenic crops

Rank	Country	Area (million hectares)	Biotech crops
1*	USA	49.8	Soybean, Maize, Cotton, Canola, Squash, Papaya
2*	Argentina	17.1	Soybean, Maize, Cotton
3*	Brazil	9.4	Soybean
4*	Canada	5.8	Canola, Maize, Soybean
5*	China	3.3	Cotton
6*	Paraguay	1.8	Soybean
7*	India	1.3	Cotton
8*	South Africa	0.5	Maize, Soybean, Cotton
9*	Uruguay	0.3	Soybean, Maize
10*	Australia	0.3	Cotton
11*	Mexico	0.1	Cotton, Soybean
12*	Romania	0.1	Soybean
13*	Philippines	0.1	Maize
14*	Spain	0.1	Maize
15	Colombia	<0.1	Cotton
16	Iran	<0.1	Rice
17	Honduras	<0.1	Maize
18	Portugal	<0.1	Maize
19	Germany	<0.1	Maize
20	France	<0.1	Maize
21	Czech Republic	<0.1	Maize

Note: * 14 biotech mega countries growing 50,000 hectares, or more, of biotech crops.
Source: Clive James, 2005

Figure 1.1 Global area (million hectares) of biotech crops, 1996-2005: Industrial and developing countries



Source: Clive 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 has been increasing and is likely to continue to play an important role in the future adoption and acceptance of biotech crops worldwide (James, 2005).

Transgenic rice has not yet been commercialized 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 diseases 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%.

In terms of reducing farm households' nutritional vulnerability, 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, the substitution and income effects—induced by rice price changes—and the profit effect on different goods will interact with each other. It is therefore unclear whether farm households will increase their total calorie and protein consumption or not. Simple questions naturally arise: how much, if any, would the adoption of transgenic rice improve households' current total nutrient intake in developing countries? Over a longer period, will it improve households' future nutrition status after farmers adjust to the initial impact of transgenic rice? These questions warrant further investigation.

In recent years, there have been a number of studies on the economic impact of transgenic crops. Recent research exploring the potential impacts of transgenic crops focuses, however, primarily on distributional and welfare effects (FAO, 2004). For instance, the distributional impacts of *Bt* cotton in 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 regressions to compare farmers' pesticide use in insect-resistant transgenic rice production with that in non-transgenic rice production at the household level. Two issues remain unclear: i) there are few quantitative results in the literature on the effects of transgenic rice on farmers' income at the household level, and ii) little is known about the effects of transgenic rice on farm households' nutritional vulnerability. Therefore, this paper aims to provide empirical evidence on these issues. Due to its complexity, the research focuses on productivity enhancing transgenic rice varieties. For the sake of simplicity, the paper assumes that a farm household's nutritional status is represented by its total calorie and protein intake.

Bangladesh is chosen for the research for two reasons. Bangladesh represents the typical situation facing developing countries, especially south Asian countries, in their fight to reduce poverty and under-nutrition. Bangladesh is not only one of the poorest counties in the world, but its under-nutrition rate is among the highest in the world (FAO 1999). According to FAO reports, approximately 56% of preschool-age children are stunted, 56% are underweight and 17% are wasted (FAO 1999). The rates of micronutrient deficiencies, particularly vitamin A, iron, iodine and zinc, are also very high (FAO 1999). "Significant progress has been made in cereal production in Bangladesh over the past few decades. However, rapid population growth and resulting high and growing food requirements pose a difficult challenge given the limited availability of cultivable land in Bangladesh. Re-occurring disasters further complicate the stability of food production" (FAO 1999). Obviously, more efforts are needed to improve the population's nutritional status. Another practical reason for focusing on Bangladesh is that a set of farm household survey data was available for Bangladesh at the time the research started. An International Food Policy Research Institute (IFPRI) research project—the coping strategies in Bangladesh, 1998-99—conducted a household survey in 1998-1999. Although the original objective for collecting the household data was different from this research, many data IFPRI collected, such as household information, education, employment and training, agricultural activity, fishing and livestock activity, allocation of family labor, social assistance, household assets, credit, housing and sanitation, non-food spending, food expenditure and consumption, are valuable and will contribute to research in this dissertation.

1.2 Objectives

The overall goal of this research is to examine the effects of transgenic rice on reducing farm households' nutritional vulnerability in Bangladesh. To achieve this goal, the following specific objectives are examined:

1. To project a representative farm household's production and consumption responses to the adoption of new transgenic rice varieties.
2. To project the impact of the profit effect on farm households' current nutrient intake.
3. To project farm households' future nutrient consumption responses to income changes.
4. To project farm households' nutritional vulnerability before and after the adoption of transgenic rice.

1.3 Assumptions and hypotheses

A number of assumptions are employed in this research.

1. An individual farm household is the consumption and production decision making unit.
2. An individual farm household maximizes its utility as a consumer and maximizes its profit as a producer.
3. Both product and factor markets are perfectly competitive.

4. It is an open economy. Price does not change.
5. In the short run, no risk is considered in farm households' agricultural production and consumption. In the long run, it is assumed farm households' production behavior will not change and their consumption will consider risk factors.
6. At the macro level, no income redistribution occurs among different farm households during the research period.
7. Certain technical constraints are met. That is, the demand system satisfies homogeneity, symmetry and budget constraint conditions. The supply system satisfies homogeneity and symmetry conditions.

The following hypotheses are tested in this investigation:

1. The introduction of transgenic rice improves farm households' current nutritional status.
2. Farm households are less nutritionally vulnerable when farmers adjust their future consumption due to the effect of transgenic rice on income.

1.4 Overview of the research framework

This research consists of two related components. The first component focuses on the static dimension of the effect of transgenic rice on farm households' nutritional well-being—the current nutritional status. The second component focuses on the effect of transgenic rice on nutritional vulnerability. The proposed two part methodology is as follows.

First, a theoretic farm household model is constructed and the corresponding econometric models are specified. Both the production and consumption decisions of a farm household are considered. The profit effect of introducing transgenic rice is estimated from the production side of the model. The profit effect is then assumed to affect farmers' consumption decisions. Both price and income elasticities are estimated from the consumption side of the model. Based on these estimates, calorie and protein elasticities of food items with respect to introducing transgenic rice are computed, and the impact of transgenic rice on households' nutrient intake is examined.

Second, a consumption forecasting model is used to examine farmers' nutritional vulnerability. Vulnerability—a probabilistic concept—is defined as "having a high probability now of suffering a shortfall in the future". It is assumed that when exposed to risk, farmers' consumption decisions have already considered their risk coping strategies. The effect of transgenic rice is reflected in its impact on farm income. Farmers' future nutrient consumption is further assumed to be log normally distributed. The ex ante mean and variance of farmers' future consumption are estimated based on the information in the current period. The probability of each household's future consumption is derived. Using the estimated probability, each household's vulnerability is examined and the overall vulnerability profile is constructed.

1.5 Organization of the dissertation

The dissertation includes seven chapters. Chapter One discusses the research problem, research objectives, and the overall research framework. Chapter Two presents an overview on the development of biotechnology (including transgenic rice) and its potential application in Bangladesh. Chapter Three describes the methodology used in this research. It first reviews the literature on farm household and nutritional vulnerability. Then, it presents the conceptual framework for a theoretically separable farm household model and a consumption forecasting model. Chapter Four describes the empirical specifications of the two models proposed in Chapter three. Chapter Five discusses the data and Chapter Six presents the estimation results. Chapter Seven concludes this dissertation with policy implications and thoughts on future research.

CHAPTER 2: TRANSGENIC RICE: AN OVERVIEW AND ITS POTENTIAL APPLICATIONS IN BANGLADESH

2.1 Agricultural biotechnology and transgenic rice

2.1.1 Introduction

Biotechnology can be defined either broadly as "any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products for specific use", or narrowly as the application of " (a) In vitro nucleic acid techniques, including recombinant deoxyribonucleic acid (DNA) and direct injection of nucleic acid into cells or organelles, or (b) Fusion of cells beyond the taxonomic family, that overcome natural physiological reproductive or recombination barriers and that are not techniques used in traditional breeding and selection"(Secretariat of the Convention on Biological Diversity, 2000), or as "a range of different molecular technologies such as gene manipulation and gene transfer, DNA typing and cloning of plants and animals" (FAO, 2004). In its broad definition, biotechnology includes applications not only in agriculture, but also in industry and other sectors. This research focuses on the tools and techniques that are commonly used in agriculture and food production.

The development of modern technology can be traced to the 1950s when the DNA structure was discovered by Watson and Crick in 1953, and detachable and movable genes were identified. Gene transfer through recombinant DNA techniques, use of embryo rescue and photoplast fusion in plant breeding and artificial insemination in animal reproduction were available in the 1970s. The 1980s witnessed insulin as the first commercial product from gene transfer, tissue culture for mass propagation in plants and embryo transfer in animal production. In the 1990s, extensive genetic fingerprinting of a wide range of organisms was successfully completed. The first field trials of genetically engineered plant varieties were conducted and the first transgenic crop variety was commercially released in 1992. Bioinformatics, genomics and proteomics started to develop in the late 1990s (Van der Walt, 2000; FAO, 2004).

2.1.2 Modern agricultural biotechnologies

In agriculture, modern biotechnology has been used to understand, characterize and manage genetic resources and to breed and produce crops and trees (FAO, 2004). Compared with conventional technologies, modern biotechnology is more efficient in terms of identifying desirable traits and breeding varieties with desirable traits. This efficiency is because knowledge of the identity, location, impact and function of genes affecting different traits becomes available through the study of genomics. Equipped with this information, the comparison across organisms of physical and genetic maps and DNA sequences will significantly reduce the time needed to identify and select potentially useful genes (FAO, 2004). Reliable information also paves the way for sound selection and breeding.

Among other advanced techniques, molecular markers and genetic engineering techniques are widely used to produce crops with desired traits. Molecular markers are identifiable DNA sequences, found at specific locations of the genome and associated with the inheritance of a trait or linked gene (FAO, 2004). Marker-assisted breeding (MAS) is one application of the molecular markers technique. Marker-assisted selection enables scientists to locate and select for genes affecting traits of economic importance in plants and animals. The time period under MAS is much less than under conventional breeding. Once desirable genes are identified, they can be transferred by traditional breeding methods within species with molecular markers being used to track the desired gene. MAS has been successfully used to produce a number of new crop varieties. For instance, traditional varieties of pearl millet—a cereal grown in Africa and Asia under rain fed and dry land environments—are open-pollinated, and agronomic characteristic are not stable. Hybrid varieties have higher yield potential than traditional varieties, but are more vulnerable to a plant disease called downy mildew. India released hybrid varieties in the late 1960s. Farmers who adopted the hybrid varieties were ultimately affected by a downy mildew epidemic. Poor farmers, who normally adopted the varieties later, were affected most. Scientists in the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) were able to successfully use molecular genetic tools to reduce the risks associated with adoption of higher-yielding pearl millet hybrids and extend the useful economic life for poorer farmers. They mapped the genomic regions of pearl millet that control downy mildew resistance, straw yield potential, and grain and straw yield under drought stress conditions. They then used conventional breeding and marker-assisted selection to transfer several genomic regions conferring improved downy mildew resistance to existing varieties and eventually developed new varieties which are downy resistant.

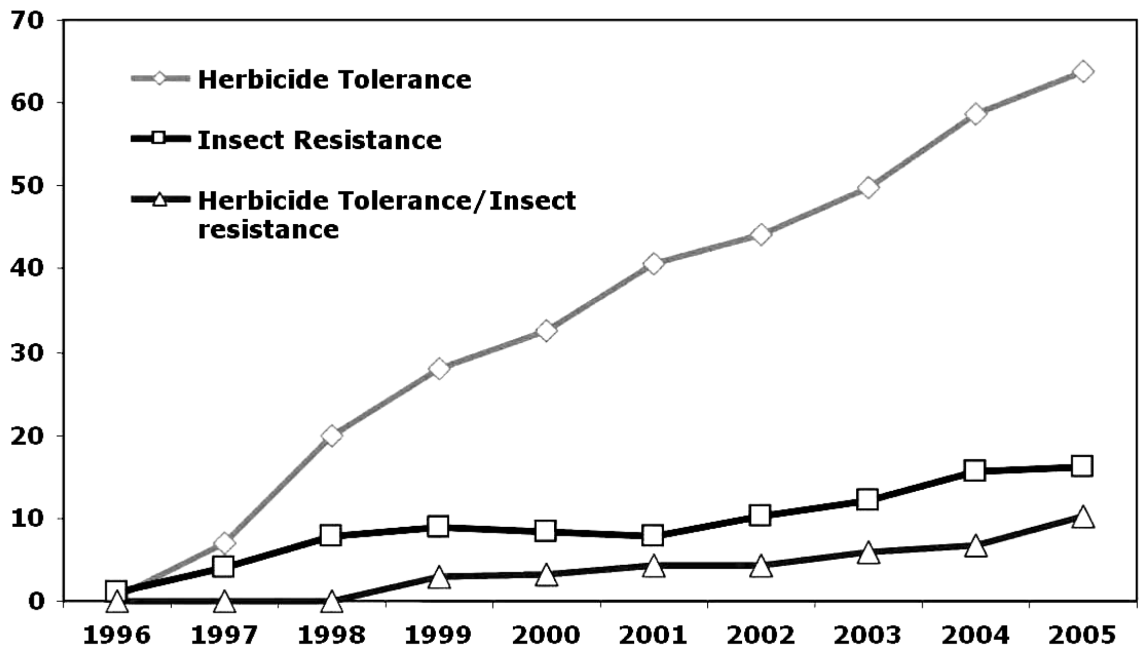
Recombinant DNA techniques, also know as genetic engineering or genetic modification, refer to the modification of an organism's genetic make-up using transgenesis, in which DNA from one organism or cell (the transgene) is transferred to another without sexual reproduction. Genetically modified organisms (GMOs) are modified by the application of transgenesis or recombinant DNA technology, in which a transgene is incorporated into the host genome or a gene in the host is modified to change its level of expression. Genetic engineering enables scientists to transfer desired traits within or between species. Three distinctive types of genetically modified crops exist: (a) "distant transfer", in which genes are transferred between organisms of different kingdoms (e.g. bacteria into plants); (b) "close transfer", in which genes are transferred from one species to another of the same kingdom (e.g. from one plant to another); and (c) "tweaking", in which genes already present in the organism's genome are manipulated to change the level or pattern of expression. Once the gene has been transferred, the crop must be tested to ensure that the gene is expressed properly and is stable over several generations of breeding. This screening can usually be performed more efficiently than for conventional crosses because the nature of the gene is known, molecular methods are available to determine its localization in the genome and fewer genetic changes are involved (FAO, 2004). New crop varieties produced by genetic engineering methods are called "transgenic crops".

Since the first release of commercial transgenic crops in 1996, herbicide tolerance has consistently been the dominant trait followed by insect resistance and stacked genes for the two traits. Genetically engineered herbicide-tolerant crops feature a gene from the soil bacterium Agrobacterium tumefaciens, which makes the recipient plant tolerant to the broad-spectrum herbicide glyphosate. Introduced to a crop plant, the technology can facilitate weed management in farmers' fields. It can reduce production costs through the substitution of glyphosate for an array of more expensive (and more toxic) herbicides. The timing and choice of herbicide is simplified for herbicide tolerance crops because glyphosate effectively controls both broad-leaved weeds and grasses and has a fairly broad window for the timing of application. Insect resistant crops have genes from the common soil bacterium Bacillus thuringiensis (*Bt*). *Bt* has been inserted into cotton plants, causing them to produce a protein that is toxic to certain effects. In 2005, herbicide tolerance, deployed in soybean, maize, canola and cotton, occupied 71% or 63.7 million hectares of the global biotech 90.0 million hectares, with 16.2 million hectares (18%) planted to *Bt* crops and 10.1 million hectares (11%) to the stacked genes (Figure 2.1). The latter was the fastest growing trait group between 2004 and 2005 at 49% growth, compared with 9% for herbicide tolerance and 4% for insect resistance (James, 2005).

2.1.3 Development of transgenic rice varieties

Rice is grown as a major staple crop in many Asian countries. Iran was the first country to commercialize *Bt* rice in 2005, and several hundred farmers grew *Bt* rice on approximately four thousand hectares. Although transgenic rice has not yet been commercially released on a large scale, a number of transgenic varieties have been developed and field tested. In 2002, a study identified 307 rice biotechnology patents from 404 organizations that were filed (Brooks and Barfoot, 2003). China has already field tested transgenic rice in pre-production trials and is expected to approve transgenic rice in the near future.

Figure 2.1 Global area (million hectares) of biotech crops, 1996 to 2005: by trait



Source: Clive James, 2005

Each transgenic rice variety usually has one or more technological features. Depending on their technological characteristics, transgenic rice varieties can be broadly classified as varieties with the potential to address biotic/abiotic stresses and to increase production productivity, or varieties with enhanced nutrient contents. In rice production, biotic stress normally refers to production constraints such as weed, insect/pest and disease. Abiotic stress normally refers to climate and soil factors that adversely affect rice production. Constraints such as salinity and drought are serious threats to sustainable food production. Transgenic varieties demonstrating biotic/abiotic stress resistant traits would mitigate some of the major constraints. *Bt* rice, herbicide resistant rice and drought resistant rice are among the varieties that have the potential to impact yield and input cost.

Bt rice is an insect resistant variety. When a *Bt* gene is inserted into rice, it produces proteins with insect toxin to stem borer—the most important rice insect in Asian countries. Transgenic *Bt* rice has the potential to affect both the yield and insecticide cost. It is reported that uncontrolled stem borers can cause annual yield losses of 5 to 10 percent with occasionally outbreaks up to 60%. *Bt* hybrid rice had higher yield in outbreak years up to 28.9% compared with non-*Bt* varieties (Tu *et al.*, 2000). Hareau *et al.* (2005) estimated the expected output increases due to introducing transgenic *Bt* rice range from 1 percent in unfavorable environment to 3.16% in favorable environment in major Asia rice countries. In rice production, the insecticide cost used to control stem borer accounted for about 7 to 8 percent of the total material cost in China (Huang *et al.*, 2003) and 8.1 to 10.3% of the total number of pesticide applications in Vietnam and Philippines (Heong, Escalada and Mai, 1994). Farmers will likely benefit from the reduced cost upon the adoption of *Bt* rice. Currently, *Bt* rice is the only commercialized transgenic rice. In addition to *Bt* rice, research is also underway at various (mostly public) institutions to develop transgenic rice varieties resistant to other insects/pests and diseases, including bacterial leaf blight (Xa21), rice blast, rice hoja blanca virus, rice tungro spherical virus, rice yellow mottle virus, rice ragged stunt virus, and the brown planthopper (Coffman, McCouch, and Herdt, 2004).

Weeds are one of the most important constraints in rice production due to yield losses and the high cost associated with weed control (Hareau, 2005). Despite manual or chemical control efforts, average annual yield losses due to weeds at the farm level are estimated at 7 to 26 percent, with an average of 16 percent (Oerke *et al.*, 1994; Savary *et al.*, 2000). Herbicide resistant rice has been on major biotechnology companies' top research agenda. It is reported that in the United States 80 percent of the rice field trials conducted by Monsanto and Bayer focused on herbicide resistance. Improved weed control with herbicide resistant rice varieties has increased yields between 5 and 10 percent in the United States (Oard *et al.*, 1996).

Drought resistant rice addresses the drought constraint in rice production, especially in rain-fed ecosystems. Dey and Upadhyaya (1996) estimated that the average annual yield losses caused by drought was 3 percent for the favorable environment and 7, 17, and 1 percent for the rain-fed lowland, upland, and deepwater ecosystems of the unfavorable environment, respectively. Hareau *et al.* (2005) assumed that drought resistant varieties would recover 50 percent of the losses in favorable environments and 60 percent in unfavorable environments. Research work on salinity resistant and submergence tolerance transgenic rice has also been reported (Garg *et al.*, 2003; Coffman, McCouch, and Herdt, 2004).

Research on nutritionally enhanced transgenic rice varieties aim at improving the content levels of such nutrients as iron, zinc and vitamin A. Golden Rice gathers the most publicity., First developed by Dr. Ingo Potrykus at the Swiss Federal Institute of Technology and Dr. Peter Beyer at the University of Freiburg, golden rice has a strain that produces beta-carotene in the grain itself. Beta-carotene colors rice grains yellow, which gives it the name "golden rice". Since beta-carotene is a source for vitamin A, golden rice has the potential to address the vitamin A deficiency in developing countries.

From an agronomic perspective, work on nutritionally enhanced varieties and on other traits can complement each other. For instance, in the case of trace minerals (iron and zinc, in particular), mineral-dense crops offer various agronomic advantages, such as greater resistance to infection (which reduces dependence on fungicides), greater drought resistance, and greater seedling vigor, which in turn, is associated with higher plant yield.

2.1.4 Factors that affect farmers' adoption of transgenic crop varieties

Whether farmers in developing countries ultimately benefit from modern biotechnology depends on many factors. Available transgenic varieties and the potential market are likely to be the two most important factors in farmers' adoption decisions. Currently, most transgenic crop varieties are produced by private firms. Private companies have invested an enormous amount of money in the research. Information on the world's top ten transnational bioscience corporations shows that their total annual expenditure on agricultural biotechnology research and development is nearly $3 billion (FAO, 2004).

By comparison, the total annual budgets of the three largest agricultural research systems in developing countries—Brazil, China and India—are less than half a billion dollars each (Byerlee and Fischer, 2002). Therefore, it is not surprising that the private sector has developed all the transgenic crops that have been commercialized in the world to date, with the exception of those in China (FAO, 2004).

The dominance of the private sector in agricultural biotechnology research and development raises concerns on how to protect farmers' interests. The profit maximizing behavior of private companies may cause them to neglect crops and/or traits that are of particular importance to the poor. Field trial data indicate that very little applied biotechnology research has been focused on staple food crops, which are of great importance in developing countries. Almost two-thirds of the field trials in industrialized countries and three-quarters of those in developing countries focus on herbicide tolerance and insect resistance or a combination of the two traits together. Although insect resistance is an important trait for developing countries, herbicide tolerance may be less relevant in areas where farm labor is abundant. Agronomic traits of particular importance to developing countries and marginal production areas, such as potential yield and abiotic stress tolerance, are the subject of very few field trials in industrialized countries and even fewer in developing countries. More than 11,000 field trials of 81 different transgenic crops have been performed since 1987 when the first trials were approved, with only 15 percent in developing or transition countries. The small percentage of field trials in developing countries reflects the perceived lack of commercial potential in these markets and the difficulties their governments have had in establishing a regulatory system for bio-safety (FAO, 2004).

Private companies also seek all possible means to protect their investment in biotechnology research. On technical grounds, the private sector has higher incentives in developing hybrid varieties. Biologically, hybridization techniques enable private companies to prevent or at least partially prevent unauthorized use of their product. Farmers who save and replant hybrid seeds are likely to suffer significant loss in yield and quality. Firms also often resort to intellectual protection laws to force the premium added on bio-products. Since patents and trademarks can legally prevent unauthorized use, a high level of protection can provide more incentives for the private sector to invest in research and development of agricultural biotechnology. Lack of intellectual property rights (IPR) or low level of enforcement may, on the other hand, delay the dissemination of transgenic products.

Once transgenic products are marketed, public attitudes towards biotechnology can directly affect the size of the market. In this regard, they will likely play an important role in determining how widely transgenic crops will be adopted by farmers (FAO, 2004). Available surveys show that public attitudes vary across countries. In general, Europe is where people have held the strongest opposition to biotechnology since its inception. The attitude is more tolerant in America, Asia and Oceania. Transgenic crops gain more support in developing countries where the need to have enough food to meet the biological requirement is likely to overcome the bias against transgenic crops. However, few people fully support or oppose transgenic crops without expressing their concerns on economic, environmental and ethical impacts (FAO, 2004).

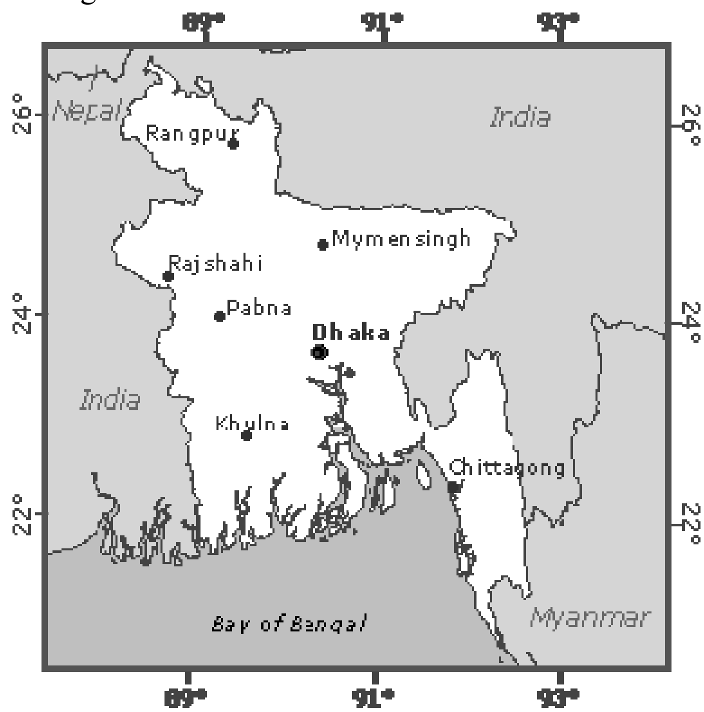
From consumers' perspectives, a strict regulatory system is preferred. However, there is a need to establish appropriate transparent, predictable, science-based regulatory procedures, and harmonize regulatory procedures at regional and international levels (FAO, 2004). Regulatory requirements add substantial costs to the research and development of transgenic crops. Biotechnology firms can expect to spend up to $10 million for a new transgenic product to develop the portfolio of health, environmental and agricultural biosafety information required by the regulatory authorities of a typical industrialized country. Absent or poorly functioning biosafety regulatory systems constitute a major barrier to the development and diffusion of transgenic crops by private companies and the public sector. Private companies will neither invest in transgenic crop research tailored to the needs of a particular country nor attempt to commercialize an existing product there unless a transparent, science-based regulatory system is in place (FAO, 2004).

2.2 Country profile – Bangladesh

2.2.1 Introduction

Bangladesh is located in the northeastern part of South Asia with a total land area of 147,570 square kilometers. It shares borders with India on the west, north and northeast, and with Myanmar on the southeast. Its southern border is bounded by the Bay of Bengal. Bangladesh is administratively divided into 6 divisions, 64 districts and 490 sub-districts (BBS, 1998).

Figure 2.2 Map of Bangladesh



Source: FAO country profile

Approximately 90% of Bangladesh land area is low, flat river delta areas created by a total of 230 rivers and their tributaries flowing across the country down to the Bay of Bengal (World Bank, 1989). Geographically, Bangladesh is located in the tropical region with three main seasons. The hot season starts from March through May, characterized by hot and highly humid weather. The monsoon season, which accounts for 80% of the total annual rainfall ranging from 1,200 to 2,500 mm, usually runs from June through September (Maclean *et al.*, 2002). Each year the monsoon season is likely to cause flooding in Bangladesh. The flood level varies year by year. In most times, as flood recedes, essential soil nutrients are left in the land. Occasionally it can also cause severe damage as in 1988 and 1998. In addition to flooding, Bangladesh is plagued by other natural disasters such as cyclones, tidal surges, droughts and tornados (FAO, 1999). Following the monsoon season is the more enjoyable cool season from October to February.

In 2004, Bangladesh had a total population of 149.7 million. Its annual population growth rate is approximately 1.7%. The GDP was 47.6 million US dollars. In 2004, per capita gross national income in Bangladesh was 440 US dollars (World Bank, 2006). Bangladesh remains to be one of the poorest countries in the world.

Bangladesh is an agriculture-based country. Crop and forest areas account for 80% and 15% of total land areas, respectively. Cropping intensity varies from region to region. In the mid-1990s, the cropping intensity was 175%. In 1999-2000, nearly 50% of the net cropped land was double cropped, and 13% triple cropped. The salinity- affected basins have lower cropping intensity. Agriculture employed more than 60% of the country's active labor force and accounted for 30% of GDP in 2000. Crop production plays a significant role in the agricultural sector. Approximately, 57% of the agricultural share in GDP came from crop production. Rice is the single most important crop, which accounts for about 77% of total cropped area and two thirds of the value added in crop production (Maclean *et al.*, 2002).

2.2.2 Food energy supply and demand

Bangladesh has not been able to achieve the balance between energy supply and energy requirements for food. FAO indicated that in 1969-71 the dietary energy supplies (DES) did not cover the requirements of 23% of the population. The gap increased to 34% in 1990-92. Therefore, the proportion of the "undernourished" population has increased (FAO, 1999). Rapid population growth, changes in the demographic age composition (i.e. improvements in child survival and increased life expectancy), and increases in height have all contributed to the widening in the gap by requiring more food energy in recent decades (Table 2.1).

Table 2.1 Total population, urbanization, energy requirements and dietary energy supplies (DES) per person and per day in 1965, 1995 and 2025

Year	1965	1995	2025
Total population (thousands)	58312	118229	179980
Percentage urban (%)	6.2	18.3	37.3
Per capita energy requirements (kcal/day)	2114	2153	2226
Per capita DES (kcal/day)*	2100	2063	--

Note: * Three-year average calculated for 1964-66 and 1994-96
Source: FAO Nutrition Country Profiles- Bangladesh.1999.

Nutrient supply—including calorie, protein and fat—fluctuated over the past years. In 2002, daily per capita calorie supply in Bangladesh was 2205 kcal, which was similar to the level in 1970. In a number of years, daily per capita calorie supply was below 2000 kcal. Table 2.2 presents the nutrient supply since 1970 in Bangladesh.

Table 2.2 Daily per capita nutrient supply in Bangladesh from 1970-2002

Year	*Calorie/Cap/Day (Kcal)*	*Protein/Cap/Day (g)*	*Fat/Cap/Day (g)*
1970	2,200.20	46.9	15.7
1971	2,023.10	43.8	14.9
1972	1,850.40	41.4	14.3
1973	1,931.60	44.6	14.7
1974	1,990.60	45.1	14
1975	1,877.20	42.5	13.9
1976	2,016.60	44.6	16.3
1977	1,847.80	41.8	13.2
1978	1,975.60	45.2	14.6
1979	2,027.80	45.2	15.1
1980	1,969.60	43.9	14.4
1981	1,945.60	42.5	14.7
1982	1,980.80	43.1	15.8
1983	2,004.20	43.8	16.6
1984	1,976.60	43.2	15.7
1985	2,017.30	44.8	18
1986	2,018.60	43.2	17.2
1987	2,090.90	44.6	19.7
1988	2,066.10	44.6	19.6
1989	2,046.20	44	20
1990	2,071.10	44.8	16.9
1991	2,073.70	44.4	18.8
1992	2,064.90	43.9	21.3
1993	1,960.80	41.9	19.2
1994	1,948.70	42.3	18.4
1995	1,983.00	42.6	19.9
1996	1,984.00	42.8	20.3
1997	2,025.40	43.2	24.8
1998	2,095.60	43.5	31.2
1999	2,176.60	48.1	21.8
2000	2,174.70	46.7	26.6
2001	2,188.50	47.2	27.2
2002	2,205.00	48.1	23.5

Source: FAOSTAT data, 2006.

Household surveys indicate that cereals represented the largest amount of food consumed (436 g/capita/day) followed by fruits/vegetables (126g/capita/day) and roots/tubers (72 g/capita/day). Fish, milk, meat, eggs, pulses, oil/fats and other highly nutritious foods accounted for less than 10% of the daily energy intake of 1868 kilo calorie (kcal). Food consumption patterns among rural households were different than urban households. The same surveys found that rural households had higher consumption of cereals and lower consumption of pulses, milk, meat, fish, oils /fats than their urban counterparts. The overall consumption level of non-grain and highly nutritious foods is very low in Bangladesh.

Among cereals, rice is the main staple food and contributes approximately 70 to 80% of total energy intake, 65% of the total protein intake and 69% of the total iron intake (Ahmed, 1993). Although wheat is sometimes consumed in the northern wheat producing region and in urban areas in the form of processed food, wheat accounts only for a small percentage of the total food consumption. Some studies even suggest wheat is an inferior good in Bangladesh (Ahmed, 1993).

Food consumption patterns vary according to the agricultural production cycle. Post-harvest intakes could be 23% higher than pre-harvest intakes (FAO, 1999). In the period before new crops are harvested, prices are normally higher and off-farm opportunities are limited. Farm households are more vulnerable in terms of obtaining enough food to meet their nutritional requirements. In particular, net purchasers of rice and other foods are most vulnerable to seasonal patterns in food availability and are also most negatively affected by price increases and disasters (HKI, 1996).

2.2.3 Rice production and its constraints

Rice is grown in different ecosystems. Rice ecosystems in Bangladesh include upland, irrigated, rainfed lowland, medium-deep stagnant water (50-100cm), deepwater (>100 cm), tidal saline, and tidal nonsaline. Rainfed lowland dominates rice ecosystems in the country. A survey in the mid-1990s showed that rainfed lowland accounted for approximately 57.5% of the total rice area, while irrigated, deepwater and upland ecosystems accounted for 24.5%, 11.4%, and 6.5%, respectively (Maclean *et al*., 2002). The irrigated rice ecosystem is normally regarded as a favorable ecosystem while the other ecosystems are less favorable ecosystems.

In Bangladesh, rice is grown throughout the year. Aus, boro and aman are the most common rice varieties. With overlapping or short turnover periods, aus is usually planted in March and harvested in July, and aman from July to December, and boro from January to June (Dey *et al.*, 1996). Aman rice comprises two types: broadcast aman and transplant aman. Broadcast aman is planted (sometimes mixed with aus) in the pre-monsoon season and harvested in November-December. Aus is planted in April-May and harvested in July-August. Boro is the dry season variety, which is planted in December-February and harvested in April-May. Broadcast aman and aus grow in deepwater and upland rice ecosystems, respectively. Boro and transplanted aus are grown under irrigated ecosystems. Transplanted aman is grown primarily under rainfed lowland conditions with some in deepwater environments (Dey *et al.*, 1996).

Modern rice varieties were introduced in Bangladesh in 1966/67 for the boro rice season and in 1968/69 for the aus and aman seasons (Dey *et al.*, 1996). Over the last three decades more and more low-yield traditional varieties were gradually replaced by high-yield modern varieties. The planting area of high-yielding boro rice increased from 0.8 to 3.4 million ha. During the same period planting areas of aus rice declined from 3.4 to 1.3 million ha and that of deepwater aman rice declined from 2.1 to 0.7 million ha. Currently, modern varieties account for about 95% of irrigated boro rice, about 60% of transplanted aman, and about 40% of aus. Deepwater rice is exclusively local varieties (Maclean *et al.*, 2002). The adoption of modern varieties has been the main source of growth in rice production and yield. Over time, the rice yield increased from 1.7 t/ha in 1968 when the modern varieties were first introduced to about 3.5 t/ha in 2001-02 (Hossain, 2004). Rice production reached 36 million ton in 2000, an increase of 2.5%/year over the last decade, and 5%/year over the last five years in spite of a devastating flood in 1998 (FAOSTAT, 2006).

In rice production, actual farm yield is normally different from the theoretical potential yield or the highest yield under favorable experimental conditions. There are three types of yield gaps (Widawsky and O'Toole, 1996; Lin and Shen 1996). Yield gap I is the difference between the potential yield of the existing farm varieties under favorable environments and the highest yield at favorable experimental conditions. This yield gap is usually caused by varietal traits and biophysical environments beyond farmers' control. Yield gap II is the difference between actual farm yield and the potential yield of the farm varieties under favorable environments. Yield gap II is the one most relevant to a household's farming practice. Both technical (biotic and abiotic constraints) and socioeconomic constraints can cause yield gap II. Yield gap III is the difference between the theoretical potential yield and highest experimental yield. It represents the potential increase in biological efficiency (Dey *et al.,* 1996). In Bangladesh, insects, diseases, weeds and abiotic stresses like salinity, cold, heat and drought are the major technical constraints to higher yields. About 175 species of rice insect pests have been recorded in Bangladesh, out of which 20 to 30 species are important (Dey, *et al.,* 1996). Assessment trials on crop loss conducted in Bangladesh showed, from 1977-1979, major insect pests on average caused a yield loss of 13% in the boro season, 24% in the aus season and 18% in the transplanted aman season. An insect outbreak of brown planthopper or rice hispa can cause a loss range of 20 to 44% or 14 to 62%, respectively (Dey *et al.*, 1996).

The important rice diseases in Bangladesh are tungro, bacterial leaf blight, bacterial leaf streak, sheath blight, sheath rot, stem rot, blast, leaf scad, brown spot, bakanae, seedling blight, damping off, ufra and root knot. Yield loss for different diseases ranged from 6 to 98%. Devastating yield losses may be encountered from the attack of tungro virus (55%), ufra infection (50-90%) or seedling blight disease (98%) (Dey *et al*., 1996).

Rainfed aus, rainfed aman and irrigated boro accounted for 13, 30 and 23% of total rice area, respectively, and represent three distinct rice ecosystems (upland, rainfed lowland and irrigated). Dey *et al.* (1996) surveyed the effects of technical constraints on each of them. Their results showed that for irrigated boro, the technical constraints accounted for 60% of yield gap II. The same factors accounted for 66% in rainfed aus and 80% in rainfed aman areas. In irrigated areas, farmers normally have higher access to agricultural chemicals (fertilizers, pesticides) and irrigated water. They are more likely to be constrained by socioeconomic factors such as the availability of credit. Biotic factors affect farmers more in irrigated areas than in rainfed areas. In rainfed areas, abiotic factors have more significant impacts. Sometimes climatic factors alone contribute about 35% of total technical constraints reflecting the more uncontrolled environment (Dey *et al.*, 1996). Some technical constraints on aus, aman and boro are described below in detail.

- For rainfed aus the most prevalent and important contributing factors to yield loss are drought, submergence at anthesis stage, bacterial leaf blight disease and rice hispa. Drought at the seedling stage affects the quality of the seedlings, and drought at the vegetative stage causes a significant reduction in tiller numbers per plant. The area under rainfed aus rice is predominantly cropped with local varieties which are susceptible to bacterial leaf blight disease and rice hispa, an insect, which causes serious damage to the leaves of rice plants.

- For rainfed aman submergence and drought are the top two constraints in rainfed aman rice. Submergence at the vegetative stage is common in the aman season, and it sometimes causes total crop failure. Submergence at the seedling stage causes deterioration in the seedling quality resulting in a poor stand and causes substantial yield loss. Drought is also common during late September to early October when most of the aman varieties approach the reproductive stage. This hampers panicle emergence as well as the development of spikelets. Brown plant hopper, ufra, stem borer and rice hispa are important pests in rainfed aman in Bangladesh.

- Boro rice is mostly grown in an irrigated environment and the coverage of modern varieties is about 90% of the total boro cropped area. A negligible acreage is in a rainfed environment where the traditional boro is grown. In the top 20 constraints for irrigated boro rice, stem borer and plant hopper are the most important. The next most important constraints are drought and submergence at the anthesis stage.

The easy options for increasing rice yield have already been exploited. The dominant source of increase in yields so far has been the reallocation of rice land from the low-yielding traditional varieties to the high yielding modern varieties. The coverage of modern rice varieties has expanded to over three-fourths of the cultivated land in the dry season and one-half in the wet season. Further expansion of area for the dry season may not be feasible or desirable due to the over-exploitation of ground water for irrigation of boro rice. Rice is the only crop that can be grown during the wet season when most of the field remains submerged with water. But over 40 percent of the land in Bangladesh remains flooded at a depth of more than 50 cm where semi-dwarf modern varieties cannot be grown. Bangladesh also has a large coastal area subjected to tidal fluctuations causing frequent submergence and mild to medium salinity for which appropriate modern varieties have yet to be developed. Considering the above factors, further increase in yield in the aman season through replacement of traditional varieties by the modern ones is highly unlikely.

The level of yield for the modern varieties remained almost stagnant until the late 1990s for both the wet (aman) and the dry (boro) seasons. Only in the last few years has the yield for boro increased somewhat due to adoption of improved crop management practices, such as transplanting of young seedlings, reducing the number of seedlings per hills and wider spacing between hills. The yield is about a ton lower in the wet season compared to the dry season due to lower sunshine, submergence stresses during the vegetative stage, and drought stresses during the grain filling stage. Scientists have not been successful in developing a higher yielding variety for the aman season than those released during the initial years of the Green Revolution. BR11 introduced to farmers in 1981 has remained popular in spite of a large number of varieties released for the season since then. Attempts to increase yield through development and import of hybrid rice varieties have not been successful (Hossain, Janaiah and Husain, 2003).

Recent progress in modern biotechnology has the potential to shift the yield frontier and reduce yield gaps for sustaining the growth in rice production in Bangladesh. Some emerging opportunities are as follows.

- The gene for submergence tolerance has already been identified, which if incorporated into the popularly grown modern varieties, such as BR11 and Swarna (Indian variety grown widely in the border belt), can help increase the yield and reduce the cost of production on account of re-transplanting in the wet season.

- IRRI scientists have been collaborating with Dhaka University to develop high-yielding salt tolerant varieties using biotechnology tools, which if successful, can help expand areas under modern varieties in the coastal region.

- Cornell scientists are developing a drought and salt tolerant rice suitable for the rice environment in Bangladesh.

- *Bt* rice has been proven effective in controlling stem borers and chitinase genes for sheath blight disease and is now being considered for release in China and is being field tested in India. Resistance against these pests has been found difficult to incorporate in high yielding varieties through conventional breeding. If the *Bt* rice is widely adopted, farmers will be able to save substantial yield losses and at the same time reduce pesticide use, which will have a positive effect on human health and the environment.

2.2.4 Public attitude towards transgenic rice and its adoption potential

In Bangladesh information about biotechnology and transgenic crops are mainly spread through newspapers, electronic media, literature, teachers and NGOs. A survey was conducted among 232 professional people to understand their knowledge, perceptions and attitude on undertaking rice biotechnology research in Bangladesh in 2003 (Husain, Bose and Hossain, 2003). The respondents came from different civil society groups, representing policy makers and government officials, agriculturalists, university teachers, NGO officials, environmentalists and other civil society members. The survey showed that, in general, public knowledge within this group on biotechnology is high. Ninety five percent of the respondents reported that they have heard about biotechnology, while 59% reported that they have heard about genetically modified crops. Newspapers were the most important source of information. More than half of the respondents had some knowledge of negative effects of transgenic crops. Food safety, human health and environmental concerns were among the negative effects.

The rate for unconditional support of transgenic rice, however, is low. While only about 14% of the respondents expressed unconditional supports, 83% of respondents supported the research on transgenic rice, only under the conditions that health and environmental impacts were addressed first. Research conducted by the public sector usually can produce a product without IPR premium. This is particularly attractive to farmers and can gain more support for bio-products. The number of respondents in this group that are against biotechnology research is very low (3%). The major reason given by those who do not support rice biotechnology research was the concern about farmers' dependence on high priced seed by private companies. Ethical and environmental factors also contributed to their opposition to this research.

The survey also solicited the public attitude towards *Bt* rice. *Bt* rice is resistant to one of the major pests in Bangladesh – stem borers. The majority (52%) of respondents conditionally supported the import of *Bt* rice for testing its adaptation in Bangladesh. Prior assessment of health and environmental effects, including bio-diversity problems, economic benefits, observing bio-safety regulations and availability of skilled scientists, were mentioned for consideration before importing transgenic rice. Those opposing it mentioned health, environment and bio-diversity problems.

In the context of general support for transgenic rice, a quantitative analysis on the economic impact, as well as the nutritional impact of transgenic rice, should contribute to the formation of public opinion toward its adoption in Bangladesh.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter describes the conceptual framework that will be used to study the impacts of introducing transgenic rice on farmers' nutritional well-being. Both the static and dynamic dimensions of the nutritional well-being—represented by farmers' nutrient consumption, including calorie intake and protein intake—are investigated. In this research, the static dimension refers to farmers' current nutritional status, while the dynamic dimension examines farmers' nutritional vulnerability over a longer period. Towards that end, two models are proposed. First, based on a literature review, a farm household behavior model is constructed. The household model simulates farm households' production and consumption behavior and projects the profit effect of introducing transgenic rice. This profit effect is then integrated into farmers' consumption decisions. Second, based on the discussion of the concept of and various modeling techniques on nutritional vulnerability, a consumption forecasting model is constructed to predict each household' nutritional vulnerability.

3.2 A theoretic farm household model

3.2.1 Literature review

Currently, in most developing countries, the agricultural sector remains a crucial sector in generating income and creating employment opportunities for vast agricultural populations. Agricultural households are the basic form of economic organization. It is estimated that at least 25% of the world population belongs to agricultural households, and most of this population is in the less developed countries. Although agricultural households may vary in size, composition and other characteristics, they all have a common feature that distinguishes them from other economic agents. That is, they integrate production, consumption and labor supply decisions. These decisions can be made simultaneously—as in the case of subsistence agriculture, where households consume only what they produce by themselves —or they can be made sequentially. For example, the existence of markets and good market access enables households to sell their own produce and purchase from the market. In fact, even with well functioning markets, most farm households are semi-commercialized where they produce partly for sale and partly for their own consumption (Singh, Squire, and Strauss, 1986). The complexity in farm households' decision making means that any attempt to understand the implications of external economic interventions on farm households warrants a thorough understanding of economic behavior at the micro level. It is essential to know what factors determine the level of farm production, agricultural inputs, household consumption, and labor supply. It is also useful to know how the behavior of the household as a producing unit affects its behavior as a consuming unit and supplier of labor, and vice versa.

Farm household modeling has long been used in policy analysis. Early seminal contributions include studies by Chayanov (1966), Sen (1966) and Nakajima (1969). Starting from the mid 1970s, researchers at the Food Research Institute of Stanford

University and at the World Bank developed microeconomic models of farm households that combine producer, consumer, and labor supply decisions. The purpose of those models was to capture the relationship of producer, consumer and labor supplier in a theoretically consistent manner so that the results of the analysis can be used empirically to illuminate the consequences of various policy interventions (Singh, Squire, and Strauss, 1986). A number of studies used the farm household model to examine the impact of the adoption of new technologies. During this period, both theoretical research and case studies of agricultural farm household models made great progress. 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).

Depending on whether decision making is simultaneous or not, agricultural household models can be broadly classified as non-separable or separable. In a non-separable model, farm households' production and consumption decisions are made simultaneously. Simultaneity usually arises when market failure exists. In a separable model, farm households are assumed to have recursive characteristics in their decision making. That is, their production decisions are independent of their consumption decisions. On the other hand, their consumption decisions are affected by total profit, which has a direct connection with production choices. The existence of this recursive character relies on a number of assumptions. Perfectly competitive markets exist for all products and factors (including family labor), all prices are exogenous to the household and all products and factors are tradables with no transaction costs. Farm households are price takers for every commodity that is both produced and consumed by the household. As a price taker, a farm household's decision on the amount of output to produce is independent of the amount of product they need to consume, since the differences can always be met through selling and buying at a fixed price in a market. If these assumptions can be reasonably justified, compared with non-separable ones, separable models are simpler and require less sophisticated techniques to solve.

Many farm households in Asian countries, including Bangladesh, are semi-commercial producers. In many areas, it is common 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 the model in a separable fashion. Product and factor markets are further assumed to be perfectly competitive.

3.2.2 Basic model

A separable farm household model is employed to quantify a representative farm household's consumption and production responses to the adoption of new transgenic rice varieties, and to predict their effects on a farm household's nutritional status.

The basic model assumes that the representative farm household has a utility function. The household maximizes its utility by choosing consumption of agricultural products, manufactured goods and leisure. Under the assumption of a perfectly competitive market, a household's consumption of agricultural products can come from its own produce or from markets. A household allocates time among leisure and labor supply. In this research, leisure is broadly defined as the household consumption of home time, including family maintenance (cooking, cleaning), domestication (taking care of children), socialization, and leisure. The household consumption is subject to the available production technology, income constraint and time constraint. The representative farm household's problem can mathematically be expressed as follows.

$$\underset{q_a, x, l, c_a, c_m, c_l}{Max} \quad u\left(c_a, c_m, c_l; z^h\right) \tag{1}$$

Subject to:

$$f\left(q_a, x, l; z^q\right) = 0 \tag{2}$$

$$p_a{}' c_a + p_m{}' c_m + p_x{}' x + wl = p_a{}' q_a + wl^h \tag{3}$$

$$l^h + c_l = T \tag{4}$$

Where

- c_a a vector of the quality of consumed agricultural product
- c_m a vector of the quality of consumed manufactured goods
- c_l Leisure
- z^h household characteristics related to consumption
- q_a a vector of agricultural output
- x a vector of agricultural input
- l total labor input, including households' own labor supply(l^h) and hired labor
- l^h a household's own labor supply
- z^q fixed factors and household characteristics related to agricultural production
- p_a price vector of agricultural output

p_m price vector of manufactured goods
p_x price vector of agricultural input
w wage rate
T total time endowment available

The available production technology is represented by the implicit production function (equation (2)). Equations (3) and (4) are the cash constraint and time constraint, respectively.

The basic model further assumes that households' consumption of leisure has the same value as supplied labor—Becker's full income concept—and a household has a net income R from other sources. Define a farm household restricted profit π as $\pi = p_a' q_a - p_x' x - wl$, and E as household's full income. The cash constraint and time constraint ((3), (4)) can be combined into one full income constraint:

$$p_a' c_a + p_m' c_m + wc_l = p_a' q_a - p_x' x - wl + wT + R \tag{5}$$

or

$$p_a' c_a + p_m' c_m + wc_l = \pi + wT + R = E \tag{6}$$

Using (1), (2), and (5) to set up the Lagrangian equation:

$$L = u(c_a, c_m, c_l, z^h) + \lambda\left[p_a' q_a - p_x' x - wl + wT + R - \left(p_a' c_a + p_m' c_m + wc_l\right)\right] + \phi \cdot f(q_a, x, l, z^q) \tag{7}$$

First order conditions are:

$$\frac{\partial L}{\partial c_a} = \frac{\partial u}{\partial c_a} - \lambda p_a = 0 \tag{8}$$

$$\frac{\partial L}{\partial c_m} = \frac{\partial u}{\partial c_m} - \lambda p_m = 0 \tag{9}$$

$$\frac{\partial L}{\partial c_l} = \frac{\partial u}{\partial c_l} - \lambda w = 0 \tag{10}$$

$$\frac{\partial L}{\partial q_a} = \lambda p_a + \phi \frac{\partial f}{\partial q_a} = 0 \tag{11}$$

$$\frac{\partial L}{\partial x} = -\lambda p_x + \phi \frac{\partial f}{\partial x} = 0 \tag{12}$$

$$\frac{\partial L}{\partial l} = -\lambda w + \phi \frac{\partial f}{\partial l} = 0 \tag{13}$$

$$\frac{\partial L}{\partial \lambda} = p_a' q_a - p_x' x - wl + wT + R - \left(p_a' c_a + p_m' c_m + wc_l \right) = 0 \tag{14}$$

$$\frac{\partial L}{\partial \phi} = f\left(q_a, x, l, z^q\right) = 0 \tag{15}$$

By rearranging the above equations and eliminating the Lagrangian multipliers, the first order conditions are:

$$\frac{\partial u}{\partial c_a} \bigg/ \frac{\partial u}{\partial c_m} = p_a / p_m \tag{16}$$

$$\frac{\partial u}{\partial c_l} \bigg/ \frac{\partial u}{\partial c_m} = w / p_m \tag{17}$$

$$\frac{\partial f}{\partial q_a} \bigg/ \frac{\partial f}{\partial x} = - p_a / p_x \tag{18}$$

$$\frac{\partial f}{\partial l} \bigg/ \frac{\partial f}{\partial x} = w / p_x \tag{19}$$

Equations (16) and (17) express the traditional first-order condition of welfare economics: that is, the marginal rate of substitution in consumption must equal the marginal rate of transformation in production. The profit-maximizing conditions for allocating labor and other variables are expressed in equations (18) and (19). Assuming the second order conditions are satisfied, there are interior solutions for optimal demand, output supply and input demand.

Due to the recursive assumption, the farm household model can be solved in two steps. The production problem is solved first.

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

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. In this research, it is assumed that the adoption of transgenic rice varieties and its effects on household production are represented by the fixed 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 π^e (equation (20)), subject to production technology (equation (21)). 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. The production function $f(q_a, x, l; z^q) = 0$ assumes the usual neo-classical properties.

$$\underset{q_a, x, l}{Max}\, \pi^e = p_a^{e}{}' q_a - p_x{}' x - wl \qquad (20)$$

$$s.t.:\ f(q_a, x, l; z^q) = 0 \qquad (21)$$

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 expected profit (γ)with respect to the percentage of rice area in HYVs (z_r) (equation (22)).

$$\gamma = \frac{\partial \pi^e}{\pi^e} \frac{z_r}{\partial z_r} \qquad (22)$$

In the second step, given the level of profit π^*, the consumer problem is then solved. On the consumption side, farm households are assumed to choose among the consumption of agricultural product c_a, manufactured goods c_m, and leisure c_l to maximize their utility (equation (23)). Households are also assumed to satisfy the full income (Becker, 1965) constraint (equation (24)) and the time constraint (equation (25)).

$$\underset{c_a, c_m, c_l}{Max} \quad u(c_a, c_{m,} c_l; z^h) \tag{23}$$

Subject to:

$$p_a{}' c_a + p_m{}' c_m + wc_l = \pi^* + wT + R = E \tag{24}$$

$$c_l + l^h = T \tag{25}$$

where $E = \pi + wT + R$. T is the household's total time endowment. R is the total income from other sources. z^h is household characteristics that affect household consumption. l^h is households' own labor supply.

Households' food demand can be derived from the first order condition. The elasticity of quantity demanded for the *i*th commodity (q_i) with respect to total expenditure E can be expressed as

$$\eta_i = \frac{\partial q_i}{\partial E} \frac{E}{q_i} \tag{26}$$

3.2.3 Effects of transgenic rice on households' nutrient intake

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 can then be expressed as:

$$q_c = \sum_i a_i q_i \tag{27}$$

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

$$dq_c = \sum_i a_i dq_i \tag{28}$$

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

$$\frac{\partial q_c}{\partial E}\frac{E}{q_c} = \frac{\sum_i^n a_i \partial q_i}{\partial E}\frac{E}{q_c} = \frac{\sum_i^n a_i q_i}{q_c}\frac{\partial q_i}{q_i}\frac{E}{\partial E} = \sum_i^n c_i \eta_i \tag{29}$$

By integrating the production and consumption sides of the model, household's calorie (or protein) consumption elasticity E_c (or E_p) with respect to the change in the percentage of rice area in HYVs (z_r) can be computed as:

$$\begin{aligned} E_c = \frac{\partial q_c}{\partial z_r}\frac{z_r}{q_c}\bigg|_{\pi=\text{variable}} &= \frac{\partial q_c}{\partial z_r}\frac{z_r}{q_c}\bigg|_{\pi=\text{constant}} + \left(\frac{\partial q_c}{\partial E}\frac{E}{q_c}\right)\left(\frac{\partial E}{\partial \pi}\frac{\pi}{E}\right)\left(\frac{\partial \pi}{\partial z_r}\frac{z_r}{\pi}\right) \\ &= 0 \qquad\qquad\qquad\quad + \left(\frac{\partial q_c}{\partial E}\frac{E}{q_c}\right)\left(\frac{\pi}{E}\right)\left(\frac{\partial \pi}{\partial z_r}\frac{z_r}{\pi}\right) \end{aligned} \qquad (30)$$

In equation (30), the first term represents, when profit is held constant, how household total calorie (protein) intake changes in response to the adoption of transgenic rice. Since the fixed factor (the percentage of rice area in HYVs) does not enter the household's consumption function, no direct effect exists. Therefore, this term becomes zero. The second term shows the case when profit is allowed to vary in the household's consumption decision. Other things held constant, transgenic rice can have an impact on household consumption (and ultimately on nutritional status) only through the profit effect.

Substituting equations (22) and (29) for the terms in equation (30), E_c becomes $E_c = \sum_i^n c_i \eta_i \left(\frac{\pi}{E}\right)\gamma$. This formula is used to calculate the value of calorie (protein) consumption elasticity.

3.3 Nutritional vulnerability and its measurement

3.3.1 Definition of nutritional vulnerability

In determining farm households'—especially marginalized households'—well-being, as well as the effects of policy interventions on welfare, both welfare indicators and appropriate measurement of the indicators are needed. In empirical studies, a number of poverty indicators such as poverty incidence, poverty depth and severity are widely used. These indicators, however, only capture the static aspects of the farm households' welfare situation at a point in time and ignore the dynamic aspect of poverty. Farm households' consumption (ultimately their well-being) is affected by various risk factors from one period to the next. For instance, when new technologies, represented by transgenic rice varieties which have potential to address drought, insect, disease and other constraints to rice production, are introduced into farm households' production in the current period, farm households may expect higher income from agricultural production. Higher income may affect farmers' future consumption. In a changing environment, static poverty indicators will not be able to clearly predict a poor farm household's future consumption changes. A dynamic measurement of poverty is needed.

Vulnerability is a forward-looking measure. In a broad sense, when people's welfare declines in the future, they can be regarded as becoming more vulnerable. For instance, a farmer is said to be vulnerable if his/her future food consumption (as a proxy for the overall welfare) is most likely to decline due to the implementation of a new government policy or unperceivable production risks (Glewwe and Hall, 1998; Jalan and Ravallion, 1999). More precisely, in a number of recent studies vulnerability was defined as the possibility now that individuals' future consumption will fall below a socially accepted standard (Christiaensen and Boisvert, 2000; Dercon, 2001). By this definition, vulnerability is a probabilistic concept which considers the failure to attain a certain threshold of well-being in the future.

A number of steps are usually followed to construct a measure of vulnerability (Christiaensen and Subbarao, 2001): first, a time horizon over which the potential of future shortfalls is assessed needs to be specified. Usually, it is specified as one period ahead. Second, an indicator of well-being must be chosen. Such indicators include food consumption, nutrition, income, education achievements, health outcomes, and so forth. Third, an ex ante probability distribution ($f(\cdot)$) of ex post outcomes regarding the well-being indicator need to be estimated. Furthermore, two thresholds must be defined. One threshold is for well-being (z). When consumption is used as the well-being indicator, the consumption poverty line is commonly used as the threshold. The other one is the probability threshold (θ). A person or household will be considered vulnerable if its probability of shortfall exceeds θ, which is usually set at the 0.5 level.

According to Christiaensen and Boisvert (2000), vulnerability of a person or household i now (at t) with respect to its future consumption (c_{t+1}) can then be expressed as:

$$V_{i,t,\gamma} = F(z)\int_{\underline{c}_{t+1}}^{z} (z - c_{t+1})^{\gamma} \frac{f(c_{i,t+1})}{F(z)} dc_{t+1} \tag{31}$$

Where $\underline{c}_{t+1}$ is the lower bound of future consumption c_{t+1}, $f(\cdot)$ is the ex ante probability distribution of ex post outcomes regarding the well-being indicator and $F(\cdot)$ is the cumulative distribution function associated with $f(\cdot)$. A household's vulnerability is thus measured as the current probability of becoming poor (F(z)), multiplied by a conditional probability weighted function of shortfall below the poverty line.

In this definition, depending on the value of γ, different aspects of shortfall can be measured. This research examines the case when $\gamma = 0$. When $\gamma = 0$, vulnerability is measured as the probability of consumption shortfall, and the formula becomes:

$$V_{i,t,0} = F(z) = \int_{\underline{c}_{t+1}}^{z} f(c_{i,t+1}) dc_{t+1} \tag{32}$$

When $\gamma = 1$, vulnerability is measured as the product of the probability of consumption shortfall and the conditional expected gap. It accounts for the average depth of shortfall. When $\gamma > 1$, given the same conditional probability of shortfall occurrence, larger shortfall is given more weight and means greater vulnerability. It accounts for the spread of the distribution of shortfalls.

The definition of vulnerability indicates that the key issue in vulnerability measurement is to estimate the ex ante probability distribution of future consumption. In empirical studies, this issue becomes how to predict future consumption. In principle, if the future consumption as well as its probability distribution are known, the number of people, whose probability of future consumption falling below the poverty line is higher than a predetermined level, can be counted. A number of consumption forecasting models have been constructed for this purpose (Chaudhuri, Jalan and Suryahadi, 2001; Christiaensen and Boisvert 2000). The section below first reviews the literature with respect to the models used to measure vulnerability, and then describes the consumption forecasting model in this research.

3.3.2 A consumption forecasting model

Farm households in developing countries constantly face various risks—uncertain events—from agricultural production and other social economic environments. Natural disasters (i.e. drought, widespread pests, flood), large price fluctuation, or job losses at the individual level can all destitute a group of farmers in developing countries. Farm households' consumption is likely to be affected by risk factors from one period to the next. A review of literature shows that depending on how risk factors are modeled, farm household consumption forecasting models can be classified into three groups: risk factors are modeled explicitly, implicitly, or combined.

Three types of risks are usually considered: idiosyncratic shocks, such as pest damage to crops, or illness of household members; common shocks that affect a number of households within a vicinity, such as rainfall or drought; and seasonality fluctuations such as labor requirements linked to crop cycles, or food price variance across production cycles (Dercon, 2001). Since seasonality in general will affect a wide range of farm households, it can be regarded as a covariate risk factor. If information about risks is available, risks can be modeled explicitly. For instance, Amin, Rai and Topa (1999), and Dercon and Krishnan (2000) modeled shocks and households' ability to cope explicitly in their studies of Bangladesh and Ethiopia. In their models they assumed that each household has a permanent or time-invariant underlying level of consumption, and actual outcomes are the results of shocks and fluctuations and its ability to cope with these shocks. The advantage of modeling risk explicitly is that it will make it possible to identify different sources that have caused the vulnerability.

A number of studies also modeled risk implicitly, especially when risk information is not available (Christiaensen and Boisvert, 2000; Chaudhuri, Jalan and Suryahadi, 2001). When risks are modeled implicitly, the model assumes that farm households adjust their consumption behavior to cope with the effects of risk factors. That is, the observed consumption is assumed to have embodied the effects of risks. In principle, risk factors affect both the ex ante mean and variance of a future consumption distribution. Explicit and implicit risk modeling techniques can also be combined (Christiaensen and Subbaro, 2001).

The consumption forecasting model in this research will in general follow the ones developed by Christiaensen and Boisvert (2000), and Chaudhuri, Jalan and Suryahadi (2001). A household's ex ante consumption is expressed as follows.

$$C_{i,t+1} = f\left(X_{i,t};\alpha\right) + \mu_{i,t+1} = f\left(X_{i,t};\alpha\right) + h^{\frac{1}{2}}\left(X_{i,t};\beta\right)\cdot e_{i,t+1} \tag{33}$$

where $C_{i,t+1}$ is person or household i 's future consumption at time $t+1$. $X_{i,t}$ is household characteristics. For the error term, it is assumed that $E\left(e_{i,t+1}\right)=0$, $E\left(e_{i,t+1}, e_{k,t+1}\right)=0$ and $V\left(e_{i,t+1}\right)=\sigma^2$

This stochastic model assumes that the ex ante mean and the ex ante variance of household future consumption are both functions of the household's ex ante characteristics $X_{i,t}$ and its environment. Different from the traditional functional specification of the consumption function where the disturbance term is usually appended in an additive manner, this model allows the conditional variance of consumption to be heteroskedastic. The heteroskedastic specification allows the household characteristics $X_{i,t}$ to affect both the ex ante mean and variance of future consumption in different directions.

Similar to what Chaudhuri, *et al.* used, Christiaensen and Boisvert used a linear model and specified h ($X_{i,t}$; β) as an exponential function.

$$C_{i,t+1} = X'_{i,t}\alpha + \mu_{i,t+1} \tag{34}$$

Where:

$$E\left(\mu_{i,t+1} \middle| X_{i,t}\right)=0,\ E\left(\mu_{i,t+1}, \mu_{k,t+1} \middle| X_{i,t}\right)=0$$

$$V\left(\mu_{i,t+1} \middle| X_{i,t}\right)=\sigma_i^2 = \sigma_e^2 \cdot \exp\left(X_{i,t}{}'\beta\right)$$

The econometric model reflects multiplicative heteroskedasticity, where α and β can be estimated by a three-step heteroskedastic correction procedure.

3.3.3 Effects of transgenic rice on households' nutritional vulnerability

When facing a variety of risks—the uncertain events that damage their well-being—farm households engage in both ex ante and ex post coping strategies. Aware of the risks they face, households can reduce their exposure to risk by smoothing their income ex ante, before it is realized (Christiaensen and Subbarao, 2001). Such measures include income diversification or engaging in less risky activities. After income is realized, farm households can adopt ex post consumption smoothing behavior. For instance, households can smooth consumption through asset depletion (Fafchamps, Udry and Czukas, 1998), borrowing (Udry, 1995), participation in government supported public work programs (Ravallion, 1991), activation of informal insurance networks (Grimard, 1997), reallocation of the labor supply to the labor market (Kochar,1995), temporal geographical reallocation of the household's labor supply, reconfiguration of spending patterns away from investment in human capital (Jacoby and Skoufias, 1997), or a combination of two or more of the above.

In general, farm households vary in their exposure to risk and their abilities to cope with risk. The bundle of income and consumption smoothing strategies employed by each household depends on its environment, its endowments and the functioning of the credit and insurance markets. The interaction between the risk factors of a household's environment and its behavior determine the ex ante distribution of its future consumption. At the household level, vulnerability reflects not only a household's risk exposure, but also the lack of capacity to cope with it. It concerns the ex ante potential of a decline in well-being in the future and is a function of the risk factors of a person's environment—the nature, frequency and severity of the shocks he is exposed to, its exposure to these risks, as well as his ability to cope with it when the shock materializes. Farmers' coping abilities are often determined by their asset endowments and the ability to insure themselves formally or informally.

In this research, when transgenic rice is introduced, farm households expect high profit. With this expected shock, farm households are assumed to adjust their consumption behavior in the future. The effect of transgenic rice on households' nutritional vulnerability is therefore investigated through how the induced income increase will affect households' future nutritional consumption. This is realized by the consumption forecasting function proposed in this chapter.

CHAPTER 4: EMPIRICAL SPECIFICATION

4.1 Introduction

To investigate the effects of introducing transgenic rice on farm households' nutritional vulnerability, a farm household model and a consumption forecasting model are proposed in Chapter Three. This chapter discusses the econometric specification of these two models. For the farm household model, the production and consumption behaviors of a household are estimated separately. On the production side, a trans-log profit function is specified to estimate an output supply and factor demand system. On the consumption side, an almost ideal demand system (ALIDs) is specified to estimate the food consumption. Statistical issues in estimation are also discussed. For the consumption forecasting model, a multivariate heteroskedastic regression function is specified to estimate the determinants of the ex ante mean and variance of farmers' future consumption. The statistical estimation procedure is discussed in the last section.

4.2 Flexible functional form

Once the goal of the research has been set, the first step in empirical analysis usually is to choose an appropriate functional form. Since different functional forms by nature represent different production technologies or consumption behaviors, it is normally desirable to represent a technology in a general way. That is, "within the context of the problem, the form should be as general as possible and should restrict the ultimate outcome as little as possible" (Chambers, 1988). Flexible functional forms—defined by Chambers (1988) as forms that can be either a second-order Taylor series approximation or a second-order differential approximation to any arbitrary function—were developed for such purposes.

Economically relevant information measured by econometric analysis to characterize the behavior of economic agents normally includes the functional value, the gradient of the function, and the Hessian matrix. For a twice differential function with n dimensions, there are a total number of $\frac{1}{2}(n+1)(n+2)$ independent effects, which are one function value, n marginal value (the gradient of the function), and $\frac{1}{2}n(n+1)$Hessian elements. A flexible functional form should be able to have enough parameters to portray all of these effects independently without imposing *a priori* constraints on preferences or technology. Chambers (1988) proved that the widely used general linear model (GLM) can be regarded as a flexible functional form.

The general linear model can be expressed as:

$$h(z) = \sum_{j=1}^{k} \alpha_j b_j(z)$$

Where each $b_j(z)$ is a known, twice-continuously differentiable, numeric function of z, and each α is a parameter to be estimated. GLM has k parameters and, therefore, it can depict k distinct economic effects. It is linear in the parameters. It does not need to be linear in z. It can approximate any arbitrary twice-continuously differentiable function in the sense that the parameter values can be chosen such that the functional value, gradient, and the Hessian equal the corresponding values for any arbitrary $h^*(z)$ at a point z^0.

If the $b_j(z)$ in the GLM transforms z in an appropriate manner, then the GLM may also be interpreted as a Taylor series expansion. The proof is shown as follows.

Assume that the true functional form can be expressed as:

$f^*(x_1, x_2 ..., x_n) = f(h_1(x_1), ..., h_n(x_n))$.

Express the right-hand-side as a second-order Taylor series expansion about the point:

$$f^*(x) = f(h_1(\bar{x}_1), ..., h_n(\bar{x}_n)) + \sum_{i=1}^{n} \frac{\partial f(\cdot)}{\partial h(x_i)} [h_i(x_i) - h_i(\bar{x}_i)] + ½ \sum_{i=1}^{n} \sum_{j=1}^{n} \frac{\partial^2 f(\cdot)}{\partial h(x_i) \partial h(x_j)} [h_i(x_i) - h_i(\bar{x}_i)][h_j(x_j) - h_j(\bar{x}_j)] + R^2$$

Define:

$$\bar{\alpha}_0 = f(h_1(\bar{x}_1), ..., h_n(\bar{x}_n)), \qquad \bar{\alpha}_i = \frac{\partial f(\cdot)}{\partial h(x_i)}, \qquad \bar{\beta}_{ij} = \frac{\partial^2 f(\cdot)}{\partial h(x_i) \partial h(x_j)}$$

Drop the higher order term to get:

$$f^*(x) = \bar{\alpha}_0 + \sum_{i=1}^{n} \bar{\alpha}_i [h_i(x_i) - h_i(\bar{x}_i)] + ½ \sum_{i=1}^{n} \sum_{j=1}^{n} \bar{\beta}_{ij} [h_i(x_i) - h_i(\bar{x}_i)][h_j(x_j) - h_j(\bar{x}_j)]$$

Next, make the following substitutions:

$$\alpha_0 = \bar{\alpha}_0 - \sum_{i=1}^{n} \bar{\alpha}_i h_i(\bar{x}_i) + ½ \sum_{i=1}^{n} \sum_{j=1}^{n} \bar{\beta}_{ij} h_i(\bar{x}_i) h_j(\bar{x}_j), \qquad \alpha_i = \bar{\alpha}_i - \sum_{j=1}^{n} \bar{\beta}_{ij} h_j(\bar{x}_j), \quad \beta_{ij} = \bar{\beta}_{ij}$$

Then:

$$f^*(x) = \alpha_0 + \sum_{i=1}^{n} \alpha_i h_i(x_i) + \tfrac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \beta_{ij} h_i(x_i) h_j(x_j)$$

Using different $h_j(x_j)$ functions, different Taylor-Series approximations can be generated. If $f^*(x) = \log y$ and $h_j(x_j) = \log x_j$, the trans-log function then can be derived.

The advantages of using Taylor-Series approximations include that, in a neighborhood of the point of approximation, the error of the approximation is bounded and the approximation converges to the unknown function as higher-order terms are added. Also in this neighborhood, the derivatives of the approximation converge to the derivatives of the unknown functions as higher-order terms are added. The limitations of flexible functional forms are that second-order functional forms turn out to be "inflexible" in representing separable technologies, and the notion of an approximation implies that any results may only hold locally, not globally.

4.3 Specification of a trans-log profit function

A trans-log profit function is specified to estimate an output supply and factor demand system. The trans-log functional form is widely used in empirical analysis. Other typical functions, including Cobb-Douglas, Leontief, and quadratic function, all have certain restrictions. For instance, the Cobb-Douglas function gives the first-order linear approximation to any function. The cross-price elasticities of the different input demands with respect to the price of one of them are constant and all equal. In comparison, the trans-log profit function is a second-degree function in prices and fixed factors and can be considered as a second-order approximation of any function. It is a flexible model with variable elasticities, and it does not suffer from the very restrictive characteristics of the Cobb-Douglas and other functions. In this research, the trans-log profit function is specified as:

$$\log\pi = \alpha_0 + \sum_i \alpha_i \ln p_i + \sum_m \beta_m \ln z_m + \frac{1}{2}\sum_i \sum_j \beta_{ij} \ln p_i \ln p_j + \frac{1}{2}\sum_m \sum_n \gamma_{mn} \ln z_m \ln z_n + \sum_i \sum_m \delta_{im} \ln p_i \ln z_m$$

By the Shephard lemma, there is $\frac{\partial\pi}{\partial p_i} = q_i$, in which the terms can be rearranged as follows.

$$\frac{\partial\pi}{\partial\ln\pi}\frac{\partial\ln\pi}{\partial\ln p_i}\frac{\partial\ln p_i}{\partial p_i} = q_i \Rightarrow \frac{\partial\ln\pi}{\partial\ln p_i}\frac{\pi}{p_i} = q_i \Rightarrow \frac{\partial\ln\pi}{\partial\ln p_i} = \frac{p_i q_i}{\pi} = s_i$$

Where $s_i = p_i q_i / \pi$ is the share of output sale (a positive number) or an input purchase (a negative number) in the profit. Since

$$\frac{\partial\ln\pi}{\partial\ln p_i} = \alpha_i + \sum_j \beta_{ij} \ln p_j + \sum_m \delta_{im} \ln z_m$$

the output supply and input demand system can be estimated in terms of share equations:

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

As the sum of the shares is equal to one, the system is not linearly independent, and one equation has to be eliminated. The coefficients of the eliminated equation are identifiable from the restrictions. Other economic theoretical constraints also need to be imposed. In principle, for a function to be admissible as a profit function, it must be nonnegative, monotonically increasing in prices of outputs, decreasing in prices of inputs, convex, homogenous of degree zero in all prices, and, if the production function displays constant return to scale, homogenous of degree one in all fixed factors. In this research, the system was estimated with imposition of the symmetry and homogeneity constraints.

- Symmetry restrictions:

$$\beta_{ij} = \beta_{ji} \qquad \gamma_{mn} = \gamma_{nm}$$

- Homogeneity restrictions with respect to both prices and fixed factors:

$$\sum_i \alpha_1 = 1 \qquad \sum_m \beta_m = 1$$

$$\sum_i \beta_{ij} = 0 \qquad \sum_m \gamma_{mn} = 0$$

$$\sum_i \delta_{im} = \sum_m \delta_{im} = 0$$

The derived factor demand and output supply functions are:

$$q_i = \frac{\pi}{p_i}\left[\alpha_i + \sum_j \beta_{ij} \ln p_j + \sum_m \delta_{im} \ln z_m\right]$$

Both direct/cross-price elasticities and profit elasticity with respect to introducing transgenic rice—represented by the percentage of rice area in HYVs—can be computed according to the formula below. The derivations of formula are presented in Appendix A.

Direct-price elasticities, i=1,…n:	$\varepsilon_{ii} = -1 + s_i + \beta_{ii}/s_i$
Cross-price elasticities, i=1,…n:	$\varepsilon_{ij} = s_j + \beta_{ij}/s_i$
Elasticities of input demand and output supply with respect to fixed factors:	$\varepsilon_{im} = \beta_r + \sum_i \delta_{ir} \ln p_i + \delta_{im}/s_i$
Profit elasticity with respect to the percentage of rice area in HYVs:	$\gamma = \frac{\partial \ln \pi}{\partial \ln z_r} = \beta_r + \sum_i \delta_{ir} \ln p_i$

4.4 Specification of an almost ideal demand system

Estimation of a single demand function either from time series data or from price variations across clusters in the household survey may give rise to an inconsistency in economic theory. For instance, quantity projections obtained may not satisfy the requirements of demand theory, particularly the budget constraint. Such predictions are consequently inadequate for use in complete models such as multi-markets. For this reason, complete systems of demand equations, which take into account consistently the mutual inter-dependence of large numbers of commodities in the choice made by consumers, is desirable. In the past, three demand systems received considerable attention because of their relative empirical expediency. They are the Linear Expenditure System (LES) developed by Stone (1953), the Almost Ideal Demand System (ALIDS) developed by Deaton and Muellbauer (1980), and the combination of these two systems into a Generalized Almost Ideal Demand System (GAIDS) proposed by Bollino (1990). Other complete demand systems found in the literature, but not widely used, include the Rotterdam model of Barnett (1979) and the translog model of Christensen, Jorgenson, and Lau (1975).

The almost ideal demand system model (ALIDS) proposed by Deaton and Muellbauer (1980) is used for the empirical estimation of the farm household food demand system in Bangladesh. The econometric specification is expressed as follows.

$$s_i = \alpha_i + \sum_{j=1}^{n} \delta_{ij} \ln p_k + \beta_i \left(\ln x - \sum_{k=1}^{n} \alpha_k \ln p_k - (1/2) \sum_{i=1}^{n} \sum_{k=1}^{n} \delta_{ik} \ln p_i \ln p_k \right)$$

where $p=(p_1,\ldots,p_N)'$ is a $(N\times 1)$ vector of prices for each food group i, $i=1,\ldots,8$, x is the total expenditure. s_i is the budget share for the ith goods consumed.

Since demographic variables such as family size and age composition are major determinants of farm households' consumption patterns, they have traditionally played a major role in household demand analysis (Pollak and Wales, 1992). Family size and composition, race, religion, age and education of household members have all been used as demographic variables in demand studies. In general, there are two ways to investigate the effects of demographic variables. Given enough data, one could estimate separate demand systems for each subgroup of households with identical demographic profiles. This approach allows all of the parameters of the demand system to depend on the demographic profile and does not require one to give an explicit specification for the relationship between the parameters and the demographic variables (Pollak and Wales, 1992). However, limitations in data often prevent the use of the identical demographic profile approach. Alternatively, specifications that relate the behavior of households with different demographic profiles can be introduced. The demographic translating method (Pollak and Wales, 1992) is adopted in this research. The basic ALIDS model is thus expanded to incorporate the effects of socio-demographic variables on farm households' consumption behavior. Under the demographic translating approach, the intercept α_i is assumed to take the following form:

$$\alpha_i = \alpha_{0i} + \sum_{k=1}^{K} \lambda_{ik} Z_k$$

where α_{0i} represents the fixed effect for each analytical food group., and Z_k denotes the demographic variables. In this research, the demographic variables initially considered include household size, household head age, sex, education, and district dummy. In the final specification of the model, the district dummy variable is dropped due to the statistical insignificance in the test runs of the model.

The final ALIDS specification for the present analysis is

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

It is also assumed that there is no interaction between demographic variables and prices. Symmetry and homogeneity restrictions are imposed in the estimation.

- Symmetry restrictions:

  $\delta_{ij} = \delta_{ji}$ for all $i \neq j$

- Homogeneity restrictions:

  $\sum_{i=1}^{7} \alpha_{0i} = 1$ $\sum_{i=1}^{7} \lambda_{ik} = 0, \forall k$

  $\sum_{i=1}^{7} \delta_{ij} = 0, \forall j$ $\sum_{i=1}^{7} \beta_i = 0$

The price and income elasticities can be computed from the parameter estimates.

Own price elasticity: $\varepsilon_{ii} = -1 - \beta_i + \delta_{ii} / s_i$

Cross-price elasticity: $\varepsilon_{ij} = -1 - \beta_i + \delta_{ij} / s_i$

Income elasticity: $\eta_i = 1 + \delta_i / s_i$

In the estimation an error term is added to each equation to make the econometric model a statistical model. The disturbance term is used to capture the influence of innumerable chance events, measurement error or human indeterminancy. Demand equations appear to be unrelated, since none of the endogenous quantities or budget shares appear on the right-hand side of the equations. This is not the case, however, since error terms across equations are correlated by the fact that the dependent variables need to satisfy the budget constraint (e.g., the budget shares in ALIDS and GAIDS sum to one). While an OLS estimate of these equations would be consistent and unbiased, the estimation method developed by Zellner (1962) for Seemingly Unrelated Regressions (SUR) provides estimates that are more efficient. In a first stage, OLS is used to estimate the variance-covariance matrix among residuals; in a second stage this estimated matrix is used in a generalized least squares estimation. Since the covariance matrix among residuals is singular because the residuals satisfy the budget constraint, the typical procedure consists of deleting one of the equations of the demand system. The parameters from the deleted equation can be calculated from the parameters of the other equations through the restrictions on parameters. As an improvement of SUR, the Iterated Seemingly Unrelated Regression (ITSUR) routine (Barten, 1969) produces results that are invariant to the equation deleted. In this research, ITSUR is used.

4.5 Specification of a multivariate regression function

To estimate a household's ex ante distribution of future nutrient consumption, it is first assumed that household future nutrient consumption (daily per household resident calorie intake) is log-normally distributed. By definition, a log-normal distribution is the probability distribution of any random variable X whose logarithm is normally distributed. The base of the logarithmic function is immaterial in that $\log_a X$ is normally distributed if and only if $\log_b X$ is normally distributed. The lognormal distribution for a random variable X can be specified either with its mean μ and variance σ^2, or with the mean m and variance s^2 of the normally distributed *log*(X). Its probability density function (PDF) expressed in terms of m and s is:

$$\phi(x) = \begin{cases} \dfrac{\exp\left(-\frac{1}{2}\left(\dfrac{\log(x)-m}{s}\right)^2\right)}{xs\sqrt{2\pi}} & \text{x>0} \\ 0 & \text{otherwise} \end{cases}$$

As with the normal distribution, the cumulative distribution function (CDF) of a lognormal distribution exists but cannot be expressed in terms of standard functions. Values can be inferred from appropriate values of the standard normal CDF.

Since lognormal distribution is completely determined by its mean and variance, it is sufficient to estimate the conditional mean and variance of a household's future consumption to obtain an estimate of its ex ante distribution. A household's nutrient consumption function is specified as follows:

$$\ln c_{it+1} = f(X_{it};\alpha) + \mu_{it+1} = f(X_{it};\alpha) + h^{1/2}(X_{it};\beta) * e_{it+1}$$

where X_{it} is the ex ante household characteristics, and α , β are the regression parameters of the mean and variance equations, respectively.

In the above equation, it is assumed

$$E(e_{it+1}) = 0\,, E(e_{it+1}, e_{kt+1}) = 0 \qquad \text{with } i \neq k$$
$$V(e_{i,t+1}) = \sigma_e^2$$

Then the conditional mean and variance are:

$$E(\ln c_{it+1} | X_{it}) = f(X_{it};\alpha)$$
$$V(\ln c_{it+1} | X_{it}) = h(X_{it};\beta) * \sigma_e^2$$

The first derivatives with respect to a particular characteristic X_{itc} (c=1…k, where k is the number of household characteristics) can then be expressed as:

$$\partial E(\ln c_{it+1} | X_{it}) / \partial X_{itc} = \partial f(X_{it};\alpha) / \partial X_{itc}$$
$$\partial V(\ln c_{it+1} | X_{it}) / \partial X_{itc} = (\partial h(X_{it};\beta) / \partial X_{itc}) * \sigma_e^2$$

In contrast with the traditional demand specifications where the error term is specified in an additive or multiplicative manner, the multiplicative heteroskedastic specification in this research (as shown by the first derivatives above) allows the marginal effects of the regressors on the ex ante mean and variance of future consumption to differ in sign. The different impact on mean and variance is of particular interest in studies like this one when the effects of possession of assets on farmers' consumption smoothing ability are examined. For instance, it is possible that having more assets today decreases a household's ex ante variance of future consumption and increases its ex ante mean at the same time.

Following Mullahy and Sindelar (1995), Christiaensen and Subbarao (2001), $f\left(X_{i,t,};\alpha\right)$ is specified as a linear function and $h\left(X_{i,t,};\beta\right)$ is specified as an exponential function as follows:

$$\ln c_{it+1} = X'_{it}\alpha_X + \mu_{it+1} = X'_{it}\alpha_X + \left[\exp\left(X'_{it}\beta_X\right)\right]^{1/2} e_{it+1}$$

Where

$$E\left(\mu_{it+1}\middle|X_{it}\right) = 0\,, E\left(\mu_{it+1,}\mu_{kt+1}\middle|X_{it}\right) = 0 \qquad\qquad i \neq k$$
$$V\left(\mu_{it+1}\middle|X_{it}\right) = \sigma^2_{it+1} = \sigma^2_e * \exp\left(X'_{it}\beta_X\right)$$

α and β can be estimated by a three-step heteroskedastic correction procedure (Judge *et al.*, 1988).

First, perform an OLS regression of $\ln c_{it+1}$ on X_{it} to obtain consistent estimates $\hat{\alpha}$ of α, and the estimated error terms $\hat{\mu}_{it+1} = \ln c_{it+1} - X'_{it}\hat{\alpha}_X$. Square $\hat{\mu}_{it+1}$ and obtain an estimate of the variance σ^2_{it+1}. Denote $\hat{\sigma}^2_{it+1} = \hat{\mu}^2_{it+1}$.

Second, regress $\ln \hat{\mu}^2_{it+1}$ on X_{it}, and obtain consistent estimates $\hat{\beta}$ of β.

Third, apply a weighted least squares regression of $\ln c_{it+1} * \left[\exp\left(X'_{it}\hat{\beta}_X\right)\right]^{-1/2}$ on $X_{it} * \left[\exp\left(X'_{it}\hat{\beta}_X\right)\right]^{-1/2}$ and obtain efficient estimates of α.

Following the three steps, each household's ex ante mean and variance of future (logarithmic) nutrient consumption can be predicted by substituting the individual household and community characteristics into the estimated regressions, based on its current socio-economic characteristics as well as actual shocks which occurred during that period. Given the log-normality assumption and the determination of a poverty line, each household's vulnerability V_{ijt} can be determined and vulnerability profiles constructed.

CHAPTER 5: DATA

5.1 Description of original data

5.1.1 Survey design

The original data used in this research were provided by the International Food Policy Research Institute (IFPRI)'s Food Management and Research Support Project (IFPRI-FMRSP) Household Survey 1998. The data were initially collected in the context of the 1998 Bangladesh flood with a focus on food security of the rural households and non-availability of job opportunities during the flood of 1998 and in the period following the flood. It aimed to provide policy suggestions to improve household food security in a sustainable way (Del Ninno, 2001). IFPRI has made the data available for public access. This research benefits directly from the information on household composition, education, agricultural activity, fishing and livestock activity, allocation of family labor, social assistance, household assets, credit, housing and sanitation, non-food spending, and food expenditure and consumption.

A total of 757 households in seven flood-affected thanas were included in the IFPRI survey. According to IFPRI, three main criteria were used to select those seven thanas in order to give a fair representation of the parts of the country affected by flood (Del Ninno, 2001). First, the Bangladesh Water Board's definition of flood severity and its corresponding classifications of thanas--not affected, moderately affected and severely affected--were used. Second, the percentage of poor people in the district in which the thana is located was used. Thanas with more than 70 percent of the population below the poverty line were classified as poor. Third, among the thanas included in each of the categories, those thanas that have been included in other studies and that would give a good regional and geographical balance throughout the six administrative divisions of the country were selected. In total, in terms of poverty status, three nonpoor thanas and four poor thanas were selected. In terms of flood severity, four severely affected thanas and three moderately affected thanas were selected. Table 5.1 lists the names of selected thanas. A map of Bangladesh included in Appendix B further illustrates the location of the flood affected areas as of September 9, 1998, and the selected thanas in the sample.

Table 5.1 List of *thanas* in the sample

	Nonpoor *thanas*	Poor *thanas*	Total
Severely affected	Muladi, Barisal District (Barisal) Shibpur, Narsingdi District (Dhaka)[BINP]	Mohammadpur, Magura District (Khulna)[BINP] Saturia, Manikganj District (Dhaka)[Micro]	4
Moderately affected	Shahrasti, Chandpur District (Chittagong)[BINP]	Madaripur, Madaripur District (Dhaka)[BINP] Derai, Sunamganj District (Sylhet)[HKI]	3
Total	3	4	7

Notes: "BINP" superscript denotes *thanas* with Bangladesh Integrated Nutrition Project; "Micro" superscript denotes *thanas* where the IFPRI micro-nutrients survey took place; "HKI" superscript denotes *thanas* used in the Helen Keller International Nutritional Surveillance Survey.
Source: Del Ninno, 2001

Except for one thana, a multiple stages probability sampling technique was used to randomly select sample households. In the Saturia thana, the sample was the same as those in another IFPRI study. In the first stage, three unions in each thana were randomly selected. In the second stage, six villages were first randomly selected from each union with probability proportional to the population in each village. Then, in each village two clusters (paras) were randomly selected using pre-assigned random numbers. Finally, three households were randomly selected in each cluster from a complete list of all households in the cluster (paras). As a result, approximately six households per village, 36 per Union, 108 per thana were selected. The final sample size of 757 households in 126 villages was chosen (Del Ninno, 2001).

The IFPRI household survey was conducted at three points in time over the period from November 1998 to December 1999. The first round of data collection took place between the 3rd week of November to the 3rd week of December 1998. The second round for the data collection was carried out between April and May 1999. Finally the third round of data collection took place in November 1999, exactly a year after the first round (Del Ninno, 2001).

The original sample was drawn without replacement. When the interviews were conducted, if the household was not found or refused to participate in the research, no replacement took place. In the first round 757 households participated in the research. In the second round, 7 households either refused to be interviewed or were absent at the time of interview. And in the third round of the survey, 23 households refused to be interviewed or were absent at the time of the survey (Del Ninno, 2001).

Both household level and community level surveys were conducted in each round. A household questionnaire was designed and used to collect detailed information on the pattern of household expenditure, land use, the participation to the rural labor market, the ownership and loss of assets, borrowing strategy and anthropometry. Retrospective questions on the situation during and before the flood were also asked. In addition to the household questionnaire, a community level questionnaire was used to collect information on the local labor market, agricultural production, and other economic conditions at the union level and at the village level during and after the flood. Original data were organized in main sections and several subsections. Appendices C and D give a brief description of the sections of the household questionnaire and the community level questionnaire, respectively.

In general, the contents and quality of the original data have enabled this research to carry out most proposed empirical modeling and estimations. Missing values particular to the goal of this research were obtained from other sources.

5.1.2 Rice farm households

Except for a few non-agricultural households, most surveyed households are agricultural households with a wide range of agricultural activities. Rice farm households account for a large proportion of all households (Table 5.2). In 1998, of 757 households, approximately 57% (434 households) and 50% (375 households) planted and harvested rice, respectively. The difference in the numbers of households that planted and harvested rice may be caused by 1998 flood or other reasons. After the flood, the number of rice farm households increased in 1999. Only rice farm households are studied in this research. Since the first round survey was conducted at the end of 1998 and the second and third ones were in 1999, the data actually covered rice production in two consecutive years. To be consistent with the annual rice production cycle, farm households' decision cycle is assumed to be one year.

Table 5.2 The number and percentage of rice farm households

Survey year	Total HHLD	No. of HHLD planting rice (%)	No. of HHLD harvesting rice (%)
1998			
Round 1	757	434(57.33)	375(49.54)
1999			
Round 2	753	255(34.00)	244(32.53)
Round 3	734	376(51.23)	268(36.51)
Round 2,3 combined	733	446(60.85)	407(55.53)

Among rice farm households, households are diversified in the individual items they produce and consume. In rice production, depending on seasons, broadcast aman, transplant aman, broadcast aus, transplant aus, and boro were planted and harvested. Boro rice is the dominant variety. Although both local and high yield boro rice varieties were used in production, the percentage of households that used high yield varieties were much higher than those using local varieties. For instance, approximately 52% and 74% of households harvested high yield boro rice in 1998 and 1999, respectively, compared with 13% and 14% of households with local varieties in 1998 and 1999, respectively (Table 5.3).

In addition to rice, rice farm households also produced various other crops and livestock. A few households participated in fishing activities. In most cases outputs from other production activities were small. To produce products other than rice, however, presents an important part in households' decision making with regard to labor allocation and input cost.

Table 5.3 The number and percentage of households with different rice varieties

Year	1998		1999	
Total households	375		407	
Varieties	Number	Share (%)	Number	Share (%)
Broadcast amam (Local variety)	32	8.53	51	12.53
Broadcast aman (Mixed variety)	28	7.47	28	6.88
Transplant aman (Local variety)	53	14.13	22	5.41
Transplant aman (HYVs)	56	14.93	40	9.83
Broadcast aus (Local variety)	61	16.27	70	17.20
Broadcast aus (Mixed variety)	35	9.33	55	13.51
Transplant aus (Local variety)	1	0.27	6	1.47
Transplant aus(HYVs)	1	0.27	1	0.25
Boro (Local variety)	49	13.07	57	14.00
Boro (HYVs)	195	52.00	300	73.71

Information gathered from two sections of the original survey—regular and occasional non-food spending, and food expenditure and consumption—indicates rice households consumed a wide range of items. Food items consumed by households in the second round survey were categorized into broad groups in Table 5.4. Among all food group rice and vegetables were the two basic foods that all rice farm households consumed. Next to rice and vegetables, more than 95% households consumed pulses and oil, fish, spices, and snacks. Households' food consumption pattern is analyzed further in terms of expenditure in chapter 6.

Table 5.4 Rice households' food consumption pattern in survey round 2

Analytic food group	Number of households	Share of total households (%)
Rice	244	100.00
Wheat	159	65.16
Bread/other cereals	104	42.62
Pulses	237	97.13
Oil	242	99.18
Vegetables	244	100.00
Meat	135	55.33
Egg	197	80.74
Milk	179	73.36
Fruits	231	94.67
Fish	239	97.95
Spices	243	99.59
Snack/etc	238	97.54
Tea/beverage	214	87.70
Prepared food	74	30.33

Source: computed by the author based on the second round survey data of IFPRI

5.1.3 Aggregated commodities

Diversity in rice farm households' decision making increases the difficulty in including all individual output/input and consumption items into the analysis. Therefore, it is both theoretically and empirically desirable to aggregate individual items at a reasonable level. In principle, consistent aggregation of product categories requires separability. In practice, subgroups are usually obtained by satisfying separability assumption at least in an intuitive sense. In this research, outputs were first tentatively aggregated into seven subgroups (Table 5.5), including rice, other major cereals, pulses and oil seeds, fiber and other crops, vegetables and fruits (including spices), animal product, and fish. When the household model was subsequently estimated, it was found that data on small crops, such as wheat and fiber, were not available for all households. Limited by the chosen estimation techniques, all products were aggregated into three output groups of rice, all other crops, and animal and fish in the estimation.

Table 5.5 Components of 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(HYVs),*
Other Major Cereals	*bojra(Pearl millet), kawn (Italian millet), joar(Great millet), maize,wheat(L),wheat(hy),Others,*
Pulses and Oil Seeds	*GrKali (soybean), MsKali(black gram), chickpea, keshari (chickling vetch), mashur(lentil), motor(field pea), mung* *Mustard, sesame, tishi(linseed), other seeds,*
Fiber and Other Crops	*Jute, bamboo, Tobacco, Sugar cane*
Vegetables and Fruits (including spices)	*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)* *chilli, dhania, garlic, onion* *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),*
Animal Product	*Egg, Milk*
Fish	*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*

Source: organized by the author from IFPRI survey round 1

When food consumption items were aggregated, more subgroups were able to be constructed. Table 5.6 shows the components of each aggregated consumption subgroup. The subgroups included in this research are rice, wheat and other cereals, pulses, oil, vegetables and fruits, meat/egg/milk, fish, spices, and all other food (snack and others, tea/ beverage, and prepared food). Similar to the large number of individual food items, the non-food consumption in rice farm households includes a wide range of different items. For the convenience of analysis, all non-food items are aggregated into one group.

5.1.4 Tornqvist-Theil price index

As shown above, rice farm households' production and consumption decisions involve a large number of items. In the farm household model, commodities are modeled in the form of aggregated commodities. A quantity index or a price index is usually constructed to measure the quantity and price of aggregated commodities. In this research, since the estimation of a household model involves only product price and total product value, a price index for each aggregated commodity group was computed with quantity used as weights. The quantity of an aggregated commodity can also be obtained by dividing total product value by the price index. With the price and quantity index an aggregated commodity is assumed to be a homogeneous product with its price and quantity represented by the price index and quantity.

Table 5.6 Components of consumption goods

Commodity subgroup	Components
Rice	Rice CP, Rice CN, Rice Med, RiceFine
Wheat/other cereals	Wheat, Atta, Atta Rice, Moida, Noodle, Chatu, Chira, Muri Khoi, Shuji, Barley, Shagu, Moa
Pulses	Lentil, Chick Pea, Black Gram, Khesari, Mugg, Mator, Sheem Bich
Oil	SoyaOil, Mustard, Dalda, Ghee, Tiler Tel, Snflowr Oil
Vegetables and fruits	Potol, B Gourd, Okra, Egg Plant, Tomato, Pumpkin, S Gourd, A Gourd, W Gourd, Barbati, Carrot, Radish, kach kala, Papaya, Green Chili, Cucumber, Arum, Data, Potato(Hmad), Sweet Potato, Green Mango, Onion, Garlic, Dhundul, Kachur lati, Jhinga, Dumur, Sweet gourd, Mocha, Sazna, Kacha kathal, Pui, Lal Shak, Bathua, Danta Shak, Helencha, Kalmi Shak, Arum leaf, Lau Shak, Pat Shak, Dheki Shak, Spinach, Matar Shak, Sajna Shak, Alu Shak, Pchmishli shak, Onion Leaf, Sechi Shak, Mustar Flower, Pumpkin leaf, Batjua Mango, Banana, Papaya, Orange, Apple, Coconut, Jackfruit, Lichis, Blackberry, Wood apple, Grapes, Amra, Bilimbi, Guava, Jujube, Tamarind, Dalim, Lemon, Dates, Sugar cane, G coconut, Custrd Apple, Water Melon, Melon, Rose Apple, Palm, Zilipy fruit, Sugar cane juice
Meat/egg/milk	Beef, Mutton, Liver, Chicken, Duck, Pigeon, Tortoise, Vuree, Egg, Milk
Fish	Rui, Mrigel, Katla, Magur, Singi, Boal, Taki, Hilsa, Telapia, Swarputi, Kalibaus, SilverCarp, Koi, Mani, Aair, Shoul, Driedfish, Karfu, Ritha, Aire, Chital, SeaFish, Shrimp, Baim, Pangash, Brigade, Puti, Tengra, Moa, Kachki, Chanda, Chapila, Dhela, Khalisa, Pabda, Kajari, S Shrimp, S Baim, Khoera, Bele, Cheua, Poa, Foli, MxdFish, Kekla, Tatkini, Boicha, Gaira, Gutum, Bacha
Spices	Green Chili, Turmeric, D Turmeric, Cumin seed, Cardamom, Cinamon, Salt, Panch Phoron, Coriander, Ginger, Garam masala
All other foods	Sugar, gur, Sweets, Cookies, Tea leaves, Betel leaves, BetelNut, IceCream, Horlics, Chocolate, Ghee, Cake, Patties, MilkPowder, Sugar candy, Chanachur, Chips, Goja, Khili Pan, Nut Prepared tea, Soft Drink Rice, Khichuri, PntaBhat, Ruti, Parota, Bhaji, Curry, Dal, OutSweets, Curd, Biriani, Salad, AlurChop, Singara, Puri, Sandesh, Bread, Halua

In principle, an appropriate method of constructing an index number should be consistent with economic theory and be able to accommodate the optimizing responses of economic agents (Alston, Norton, Pardey, 1995). The widely used Divisia index is the one with such properties (Richter, 1966; Hulten, 1973). Both a quantity and price Divisia indices can be constructed.

When weighted by individual price, the Divisia index for an aggregate quantity can be expressed as

$$XI_t^D = XI_b^D \exp \int_b^t \frac{W_s' \Delta X_s}{W_s' X_s} ds$$

where XI_b^D is the index value of the quantity in base period b, XI_t^D is the index value of the quantity in period t, X_s is a vector of input/output quantities of each individual, W_s is a vector of input/output prices of each individual, and ΔX denotes changes in quantity.

When weighted by individual quantity, the Divisia index for an aggregate price can be expressed as

$$PI_t^D = PI_b^D \exp \int_b^t \frac{W_s' \Delta P_s}{W_s' P_s} ds$$

where PI_b^D is the index value of the price in base period b, PI_t^D is the index value of the price in period t, P_s is a vector of price of each individual , W_s is a vector of quantities of each individual , and ΔP denotes changes in prices.

In the above formulae, both quantity and price are measured continuously. In practice, instead of continuous measurement, discrete measurement of quantity and price are usually used. A discrete approximation to a Divisia index is therefore needed. A number of such approximations are available. For instance, the Laspeyres index, Paasche index, Fisher ideal index, and Tornqvist-theil index are all popular in empirical studies. Diewert (1976)'s theoretical work on superlative index numbers in the 1970s provided theoretical justification for these approximations of a Divisia index. That is, these approximations are exact for specific aggregator functions. For instance, if inputs are aggregated with linear functions, the Laspeyres and Paasche approximations of the Divisia offer exact measures of real quantity changes. Similarly, the Fisher approximation is exact for quadratic aggregator functions. The Tornqvist-Theil Divisia index is exact for the more general class of trans-log aggregator functions. Tornqvist-Theil approximation to the Divisia index is chosen in this research to be consistent with the proposed trans-log profit function and almost ideal demand systems.

Another issue associated with the above formula is that the Divisia index is defined on time series data while in empirical studies, including this research, cross-sectional data are frequently used. When cross-sectional data are used, the base period in the above formula does not exist. To address this issue the average product price/quantity of all households is used as the base in this research. An individual household can compare its price and quantity with the base. The formula is thus modified as follows.

Define

p_i^0 :	the price of i th product faced by the base household, which equals to the average price of i th product among all households
p_i^1 :	the price of i th product faced by an individual household
q_i^0 :	the quantity of i th product faced by the base household, which equals to the average quantity of i th product among all households
q_i^1 :	the quantity of i th product faced by an individual household
Superscript 1:	individual households
Superscript 0:	the base household, or all household average value

The Tornqvist-Theil price index is given by

$$P_t^{TT}(p^1, p^0) = P_0^{TT} \prod_{i=1}^{n} \left(\frac{p_i^1}{p_i^0} \right)^{\frac{(w_i^1 + w_i^0)}{2}}$$

Where

$w_i^1 \equiv \dfrac{p_i^1 q_i^1}{\sum_i^n p_i^1 q_i^1}$: the i th product value share in total product value of each individual household

$w_i^0 \equiv \dfrac{p_i^0 q_i^0}{\sum_i^n p_i^0 q_i^0}$: the i th average product value share of total average product value of all households

When the price index is expressed in logarithmic form as

$$\ln\left(\frac{P_t^{DT}}{P_0^{DT}} \right) = \sum_i \frac{(w_i^1 + w_i^0)}{2} \ln\left(\frac{p_i^1}{p_i^0} \right)$$

$\ln\left(P_t^{DT} \,/\, P_0^{DT}\right)$ represents the rate of change in the Tornqvist-Theil price index from period t to base period, or from individual household to all households' average as in this research. In practice, the base period (or all household average) price is usually set at 1, that is, $P_0^{TT} = 1$. All other periods or an individual household's price index then can be measured forward or backward according to the formula.

5.2 Definition and measurement of variables

The following sections describe how the variables in the empirical models in this research are defined and measured for the estimation purpose.

5.2.1 Profit function variables

The restricted profit function specified in chapter 4 is:

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

When this function was estimated, depending on the availability of data, three aggregate outputs, two aggregate inputs, and three fixed factors were included as variables. These variables are rice, all other crops, and animal product as outputs, labor and fertilizer as inputs, and total land, the percentage of rice area in high yield varieties, and standard animal units as fixed factors. The components of aggregated outputs are given in section 5.1.3. Consequently, the profit function thus can be expanded in full notation.

$$\begin{aligned}\ln\pi &= \alpha_0 + \alpha_1 \mathrm{lnp}_1 + \alpha_2 \mathrm{lnp}_2 + \alpha_3 \mathrm{lnp}_3 + \alpha_4 \mathrm{lnp}_4 + \alpha_5 \mathrm{lnp}_5 + \beta_1 \mathrm{lnz}_1 + \beta_2 \mathrm{lnz}_2 + \beta_3 \mathrm{lnz}_3 + \tfrac{1}{2}(\beta_{11}\mathrm{lnp}_1\mathrm{lnp}_1 \\ &+ \beta_{22}\mathrm{lnp}_2\mathrm{lnp}_2 + \beta_{33}\mathrm{lnp}_3\mathrm{lnp}_3 + \beta_{44}\mathrm{lnp}_4\mathrm{lnp}_4 + \beta_{55}\mathrm{lnp}_5\mathrm{lnp}_5) + \beta_{12}\mathrm{lnp}_1\mathrm{lnp}_2 + \beta_{13}\mathrm{lnp}_1\mathrm{lnp}_3 + \beta_{14}\mathrm{lnp}_1\mathrm{lnp}_4 \\ &+ \beta_{15}\mathrm{lnp}_1\mathrm{lnp}_5 + \beta_{23}\mathrm{lnp}_2\mathrm{lnp}_3 + \beta_{24}\mathrm{lnp}_2\mathrm{lnp}_4 + \beta_{25}\mathrm{lnp}_2\mathrm{lnp}_5 + \beta_{34}\mathrm{lnp}_3\mathrm{lnp}_4 + \beta_{35}\mathrm{lnp}_3\mathrm{lnp}_5 + \beta_{45}\mathrm{lnp}_4\mathrm{lnp}_5 \\ &+ \tfrac{1}{2}(\gamma_{11}\mathrm{lnz}_1\mathrm{lnz}_1 + \gamma_{22}\mathrm{lnz}_2\mathrm{lnz}_2 + \gamma_{33}\mathrm{lnz}_3\mathrm{lnz}_3) + \gamma_{12}\mathrm{lnz}_1\mathrm{lnz}_2 + \gamma_{13}\mathrm{lnz}_1\mathrm{lnz}_3 + \gamma_{23}\mathrm{lnz}_2\mathrm{lnz}_3 + \delta_{11}\mathrm{lnp}_1\mathrm{lnz}_1 \\ &+ \delta_{12}\mathrm{lnp}_1\mathrm{lnz}_2 + \delta_{13}\mathrm{lnp}_1\mathrm{lnz}_3 + \delta_{21}\mathrm{lnp}_2\mathrm{lnz}_1 + \delta_{22}\mathrm{lnp}_2\mathrm{lnz}_2 + \delta_{23}\mathrm{lnp}_2\mathrm{lnz}_3 + \delta_{31}\mathrm{lnp}_3\mathrm{lnz}_1 + \delta_{32}\mathrm{lnp}_3\mathrm{lnz}_2 \\ &+ \delta_{33}\mathrm{lnp}_3\mathrm{lnz}_3 + \delta_{41}\mathrm{lnp}_4\mathrm{lnz}_1 + \delta_{42}\mathrm{lnp}_4\mathrm{lnz}_2 + \delta_{43}\mathrm{lnp}_4\mathrm{lnz}_3 + \delta_{51}\mathrm{lnp}_5\mathrm{lnz}_1 + \delta_{52}\mathrm{lnp}_5\mathrm{lnz}_2 + \delta_{53}\mathrm{lnp}_5\mathrm{lnz}_3\end{aligned}$$

The corresponding share equations are

$$\begin{aligned}
s1 &= \alpha_1 + \beta_{11}\mathrm{lnp}_1 + \beta_{12}\mathrm{lnp}_2 + \beta_{13}\mathrm{lnp}_3 + \beta_{14}\mathrm{lnp}_4 + \beta_{15}\mathrm{lnp}_5 + \delta_{11}\mathrm{lnz}_1 + \delta_{12}\mathrm{lnz}_2 + \delta_{13}\mathrm{lnz}_3 \\
s2 &= \alpha_2 + \beta_{12}\mathrm{lnp}_1 + \beta_{22}\mathrm{lnp}_2 + \beta_{23}\mathrm{lnp}_3 + \beta_{24}\mathrm{lnp}_4 + \beta_{25}\mathrm{lnp}_5 + \delta_{21}\mathrm{lnz}_1 + \delta_{22}\mathrm{lnz}_2 + \delta_{23}\mathrm{lnz}_3 \\
s3 &= \alpha_3 + \beta_{13}\mathrm{lnp}_1 + \beta_{23}\mathrm{lnp}_2 + \beta_{33}\mathrm{lnp}_3 + \beta_{34}\mathrm{lnp}_4 + \beta_{35}\mathrm{lnp}_5 + \delta_{31}\mathrm{lnz}_1 + \delta_{32}\mathrm{lnz}_2 + \delta_{33}\mathrm{lnz}_3 \\
s4 &= \alpha_4 + \beta_{14}\mathrm{lnp}_1 + \beta_{24}\mathrm{lnp}_2 + \beta_{34}\mathrm{lnp}_3 + \beta_{44}\mathrm{lnp}_4 + \beta_{45}\mathrm{lnp}_5 + \delta_{41}\mathrm{lnz}_1 + \delta_{42}\mathrm{lnz}_2 + \delta_{43}\mathrm{lnz}_3 \\
s5 &= \alpha_5 + \beta_{15}\mathrm{lnp}_1 + \beta_{25}\mathrm{lnp}_2 + \beta_{35}\mathrm{lnp}_3 + \beta_{45}\mathrm{lnp}_4 + \beta_{55}\mathrm{lnp}_5 + \delta_{51}\mathrm{lnz}_1 + \delta_{52}\mathrm{lnz}_2 + \delta_{53}\mathrm{lnz}_3
\end{aligned}$$

The variables in these equations are defined as follows.

p_1, p_2, p_3 are the Tornquist-Theil price indices for rice, all other crops (including cereal, pulses, fiber and vegetables and fruits), and egg/milk/fish product, respectively. Both the price and quantity of individual items are needed for the computation of the Tornquist-Theil price index. For all products, quantity is measured by kilogram and price is measured by Taka per kilogram. Output quantities are defined as the total amount of product harvested by individual households. They were obtained directly from the original data. The output price sources vary by households. According to the original survey, outputs were used for various purposes after harvesting. Some outputs were consumed directly by households, which occurred in almost all households. Some were given to land owners as rent, or to laborers as in-kind wage, or to others as gifts. Some were sold on market. If a household sold part of its product, the farm gate product price is then used as the output price for the total amount of product that the household had harvested. If no output was sold by an individual household, the output price was chosen as follows:

1. If within a village, farm gate price for the same product is available for some households, a village level average price is computed and used as the product price for those households with missing price values.
2. If the village level average price is not available, the thana level average price is computed and used.
3. If the thana level average price is not available, then the district level average price is computed and used.

p_4 is the Tornquist-Theil price index for labor. By definition, labor includes both family labor and hired labor. Male and female labor is weighted equally. The labor of household members under 10 years of age is not included because no such information was collected in the original survey. Labor is measured in standard days (1 day = 8 hours). Labor wage is measured by Taka per day. If a household hired labor from outside, market price for hired labor is used as the wage rate for family labor. If there is no hired labor, the wage rate was computed in a way similar to the derived output price.

p_5 is the Tornquist-Theil price index for fertilizer. As an input variable, fertilizer is an aggregate of two types of commonly used fertilizers by households: Urea and Triple Superphosphate. The quantities of individual households' usage of fertilizers were available from the original data. No information on fertilizer prices, however, was collected at the household level. In the estimation, the village level fertilizer price, measured by taka per kilogram, was given to all households within the same village.

z_1, z_2, z_3 represent the production characteristics of individual households. By including these variables into the profit function, households with different capital assets and production technologies (new varieties) are assumed to make different production decisions with regard to outputs and inputs. z_1 is the total land area of each household, measured by decimal (247 decimal = 1 hectare). z_2 is the percentage of rice area in high yield varieties. z_3 is the total number of standard animal units in each household. The standard animal number is derived by converting various domestic animals into standard animal units (Table 5.7).

Table 5.7 The conversion table for standard animal unit

Animal name	Unit	Standard unit
0-6 months cattle	1	0.4
Young cattle(6-12 months)	1	0.6
Cattle	1	1
Dairy cow	1	1
Bullock	1	1.1
Baby goat/sheep	1	0.05
Adult goat	1	0.1
Sheep	1	0.1
Young chick (<2 months)	1	0.01
Chicken	1	0.01
Young duck(<2 months)	1	0.01
Adult duck	1	0.01
Pigeon	1	0.01
Horse	1	1.1

s is the total restricted profit and is measured by Taka. It is computed by subtracting total input value from total product value. s_1, s_2, s_3 denote the rice, all other crops, and egg/milk/fish's output share in total profit, respectively. s_4 and s_5 denote labor and fertilizer's input share in total profit, respectively. In the estimation, all prices are positive. All output shares are positive and input shares are negative.

5.2.2 ALIDs system variables

The share equation used to estimate the ALIDs system is reproduced here:

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

In the equations the variables are defined as:

x The total expenditure, which includes the expenditure on food, non-food and leisure, measured in taka
p_1 Tornquist-Theil price index for rice
p_2 Tornquist-Theil price index for wheat and other food
p_3 Tornquist-Theil price index for pulses
p_4 Tornquist-Theil price index for oil
p_5 Tornquist-Theil price index for vegetables and fruits
p_6 Tornquist-Theil price index for meat, egg and milk
p_7 Tornquist-Theil price index for fish
p_8 Tornquist-Theil price index for spices
p_9 Tornquist-Theil price index for non-food items
p_{10} Tornquist-Theil price index for wage

All price/quantity data for individual items were obtained directly from the original household survey.

Several variables were chosen to represent farm households' demographic characteristics. They are:

adulteq	The computed adult equivalent in the surveyed household
hhsizea	The household size, defined as the total number of residents of each household
sex	The sex of the household head with 1 denoting male and 2 denoting female
marriage	The marital status of the household head, 1 denotes married, 2 denotes unmarried, 3 denotes widow/widower, 4 denotes separated, and 5 denotes divorced
edu	The education level of the household head, defined as the maximum class passed

s_1 Rice expenditure share in total expenditure

s_2 Wheat and other food expenditure share in total expenditure

s_3 Pulses expenditure share in total expenditure

s_4 Oil expenditure share in total expenditure

s_5 Vegetables and fruits expenditure share in total expenditure

s_6 Meat, egg and milk expenditure share in total expenditure

s_7 Fish expenditure share in total expenditure

s_8 Spices expenditure share in total expenditure

s_9 Non-food expenditure share in total expenditure

s_{10} Leisure expenditure share in total expenditure

In the original survey, households' expenditure information was collected only for the month before each round of survey. To be consistent with the one-year decision cycle in this research, each household's one month expenditure was multiplied by 12 and was converted into 12 months expenditure.

The total nutrient intake of a household was derived by using the following nutrient content table (Table 5.8).

Table 5.8 Average value of calorie/protein contents of each food group

Food Group	Average calorie content (kcal/100g)	Average protein content (g/100g)
Rice	352.00	6.77
Wheat and other food	357.32	11.43
Pulses	342.29	25.93
Oil	900.00	7.88
Vegetables and fruits	64.92	2.35
Meat/egg/milk	141.42	19.73
Fish	114.11	19.26
Spices	275.34	63.28

5.2.3 Consumption regression function variables

The two periods considered in this research are the hunger season (t+1) in April 1999 and the preceding post harvest season in December 1998 (t). These two periods were chosen based on the fact that farm households are usually more vulnerable in hunger season than in post harvest season. In the regression function, the dependent variable is the logarithm of daily caloric intake per resident household member during the hunger season (t+1). It was obtained by converting total reported household food consumption over the 30 days prior to the interview into kilo calories per resident household member. Total food consumption was based on a list of 232 regularly consumed local food items.

Independent variables include variables that represent a household's income, assets, education, and demographic characteristics. They are:

agri. income	A household's agricultural income at time t, measured in taka
other income	A household's income from other sources at time t, measured in taka
flood depth	The usual flood depth in feet
production assets	Value(taka) of agricultural equipment, large trees, fishing tools at t
consumer durables	Value (taka) of consumer durables at t
gain stock	Quantity (kilogram) of grain stock (rice, paddy, wheat)at t
cattle	The number of cattle(calves, dairy cow, bullock)at t
goat	The number of goad/sheep at time t
chicken	The number of poultry, such as chicken, duck at time t
education	At least one household member completed primary school at t, which is a binary variable, yes=1, no=0
adult male	The number of male household members that are between the age of 16 and 65 at time t
adult female	The number of female household members that are between the age of 16 and 65 at time t
children	The number of household members that are less than or equal to 15 year old at time t
elderly	The number of household members that are over 65 years old at time t
head age	The age of the household head at time t

CHAPTER 6: RESULTS AND DISCUSSION

6.1 Introduction

This chapter presents the empirical results from the farm household model and the consumption forecasting model. Based on the results, the effects of introducing transgenic rice on farm households' nutrition status and on their nutritional vulnerability are discussed.

6.2 Results of farm household model

6.2.1 Output supply/input demand price elasticities and profit effect

Four share equations (rice, other crops, animal product and labor) and the profit function were estimated as a system. Symmetry and homogeneity restrictions were imposed in the estimation. Table 6.1 presents the parameter estimates.

Based on the parameter estimates in Table 6.1, estimates of the elasticities of the output supply and input demand with respect to output/input prices and fixed inputs are computed (Table 6.2). As indicated by the formulas in Chapter Four, in addition to the parameter estimates, these elasticities are functions of variable ratios, variable input prices, and level of fixed inputs. These elasticities are evaluated at arithmetic average of input/output shares, average prices, and average level of fixed inputs. To interpret these results, the household should be regarded as an average household or a representative household of surveyed households.

Table 6.1 Restricted parameter estimates of the trans-log profit function

		Price of rice	Price of other crops	Price of animal product	Price of labor	Price of fertilizer	Land area	Percentage of rice area in HYVs	Animal asset in standard unit
	Intercept	$\ln p_1$	$\ln p_2$	$\ln p_3$	$\ln p_4$	$\ln p_5$	$\ln z_1$	$\ln z_2$	$\ln z_3$
Rice ratio to profit	-0.0138	1.2327	0.9737	-0.8677	-0.2853	-1.0535	0.1060	0.0231	-0.1291
	(0.3693)	(0.5247)	(0.3041)	(0.4001)	(0.2910)	(0.3962)	(0.0842)	(0.0532)	(0.0652)
Other crops ratio to profit	0.04733	0.9737	-0.1604	-0.8108	-0.2924	0.2898	0.0517	-0.0830	0.0312
	(0.3364)	(0.3041)	(0.3153)	(0.2647)	(0.2315)	(0.3853)	(0.0766)	(0.0483)	(0.0599)
Animal product ratio to profit	0.5124	-0.8677	-0.8108	0.6771	0.5609	0.4404	-0.0206	0.0187	0.0020
	(0.2901)	(0.4001)	(0.2647)	(0.4547)	(0.2672)	(0.3028)	(0.0676)	(0.0421)	(0.0543)
Labor ratio to profit	0.1883	-0.2853	-0.2924	0.5609	-0.5892	0.6060	-0.0617	0.0376	0.0241
	(0.2304)	(0.2910)	(0.2315)	(0.2672)	(0.3177)	(0.2603)	(0.0541)	(0.0340)	(0.0419)
Fertilizer ratio to profit	0.2657	-1.0535	0.2898	0.4404	0.6060	-0.2827	-0.0754	0.0036	0.0718
	(0.4998)	(0.3962)	(0.3853)	(0.3028)	(0.2603)	(0.5769)	(0.1082)	(0.0666)	(0.0848)
	5.6727	-0.0138	0.04733	0.5124	0.1883	0.2657	0.3729	0.0812	0.5459
Profit Function	(0.4093)	(0.3693)	(0.3364)	(0.2901)	(0.2304)	(0.4998)	(0.1464)	(0.0762)	(0.1461)
	$(\ln p_1 * \ln p_1)/2$	$(\ln p_2 * \ln p_2)/2$	$(\ln p_3 * \ln p_3)/2$	$(\ln p_4 * \ln p_4)/2$	$(\ln p_5 * \ln p_5)/2$	$\ln p_1 * \ln p_2$	$\ln p_1 * \ln p_3$	$\ln p_1 * \ln p_4$	$\ln p_1 * \ln p_5$
	1.2327	-0.1604	0.6771	-0.5892	-0.2827	0.9737	-0.8677	-0.2853	-1.0535
	(0.5247)	(0.3153)	(0.4547)	(0.3177)	(0.5769)	(0.3041)	(0.4001)	(0.2910)	(0.3962)
	$\ln p_2 * \ln p_3$	$\ln p_2 * \ln p_4$	$\ln p_2 * \ln p_5$	$\ln p_3 * \ln p_4$	$\ln p_3 * \ln p_5$	$\ln p_4 * \ln p_5$	$(\ln z_1 * \ln z_1)/2$	$(\ln z_2 * \ln z_2)/2$	$(\ln z_3 * \ln z_3)/2$
	-0.8108	-0.2924	0.2898	0.5609	0.4404	0.6060	0.0644	0.0541	0.0710
	(0.2647)	(0.2315)	(0.3853)	(0.2672)	(0.3028)	(0.2603)	(0.0318)	(0.0189)	(0.0262)
	$\ln z_1 * \ln z_2$	$\ln z_1 * \ln z_3$	$\ln z_2 * \ln z_3$	$\ln p_1 * \ln z_1$	$\ln p_1 * \ln z_2$	$\ln p_1 * \ln z_3$	$\ln p_2 * \ln z_1$	$\ln p_2 * \ln z_2$	$\ln p_2 * \ln z_3$
	-0.0237	-0.0406	-0.0304	0.1060	0.0231	-0.1291	0.0517	-0.0830	0.0312
	(0.0207)	(0.0257)	(0.0138)	(0.0842)	(0.0532)	(0.0652)	(0.0766)	(0.0483)	(0.0599)
	$\ln p_3 * \ln z_1$	$\ln p_3 * \ln z_2$	$\ln p_3 * \ln z_3$	$\ln p_4 * \ln z_1$	$\ln p_4 * \ln z_2$	$\ln p_4 * \ln z_3$	$\ln p_5 * \ln z_1$	$\ln p_5 * \ln z_2$	$\ln p_5 * \ln z_3$
	-0.0206	0.0187	0.0020	-0.0617	0.0376	0.0241	-0.0754	0.0036	0.0718
	(0.0676)	(0.0421)	(0.0543)	(0.0541)	(0.0340)	(0.0419)	(0.1082)	(0.0666)	(0.0848)
	r_1	r_2	r_3	r_4	r_5	r_6			
	-0.2374	-0.0923	0.3492	0.3588	-0.0542	0.3975			
	(0.1431)	(0.1940)	(0.1603)	(0.1497)	(0.1704)	(0.1912)			

Note: Numbers in parentheses are asymptotic standard errors.

Table 6.2 shows that among outputs, rice has the largest own price elasticity. If rice price increases or decreases by 1%, the supply of rice will increase or decrease by 1.59%. Prices of labor and fertilizer also have significant effects on farm households' production decisions. The results indicate that if the wage rate of labor increases by 1%, labor demand will decrease by 2.33%. If the price of fertilizer increases by 1%, the demand for fertilizer will decrease by 1.62%.

Table 6.2 Derived elasticity estimates for output supply and variable input demand

	Price of					Land area	Percentage of rice area in HYVs	Animal asset in standard unit
	Rice	Other crops	Animal product	Labor	Fertilizer			
Rice	1.5948 (0.2665)	1.4384 (0.1545)	0.2586 (0.2032)	-1.8290 (0.1478)	-1.4630 (0.2013)	0.4476 (0.1450)	0.0939 (0.0795)	0.4585 (0.1447)
Other crops	3.0004 (0.3222)	-0.2262 (0.3341)	-0.1596 (0.2805)	-1.9938 (0.2453)	-0.6208 (0.4083)	0.4486 (0.1447)	-0.0057 (0.0953)	0.5571 (0.1542)
Animal product	0.7281 (0.5720)	-0.2154 (0.3784)	0.6675 (0.6501)	-0.8821 (0.3820)	-0.2982 (0.4329)	0.3643 (0.1647)	0.1089 (0.0935)	0.5268 (0.1607)
Labor	2.1380 (0.1728)	1.1174 (0.1375)	0.3664 (0.1586)	-2.3341 (0.1886)	-1.5810 (0.2806)	0.4304 (0.1436)	0.0599 (0.0774)	0.5097 (0.1429)
Fertilizer	3.104 (0.4270)	0.6315 (0.4153)	0.2248 (0.3263)	-2.3372 (0.2806)	-1.6231 (0.6218)	0.4750 (0.1771)	0.0783 (0.1060)	0.4466 (0.1655)

Note: Numbers in parentheses are asymptotic standard errors.

The results also show how factors like the total land area, the percentage of rice area in HYVs, and total number of animals will affect farm households' production decisions. For instance, the elasticity of rice supply with respect to the percentage of rice area in HYVs is 0.09. This means that if the percentage of rice area in HYVs increases by 1%, rice supply will increase by 0.09%.

Changes in fixed factors will have different impacts on farm households' total profit. Estimated profit elasticities with respect to these factors are presented in Table 6.3. The results show how the changes in these fixed factors will all affect farm households' total profit. According to the model, the animal asset—the total number of animals—has the largest impact on a household's profit: a one percent increase in the total animal number will increase the profit by 0.52%. The total land area has the second largest impact on profit. If a farm household's total land area increases by 1%, its profit will increase by 0.39%.

The result clearly indicates that transgenic rice—assumed to be similar to the adoption to other high yield rice varieties—will have a positive effect on a farm household's profit. That is, if the percentage of rice area in HYVs increases by 1%, the total profit will increase by 0.08%.

Table 6.3 Estimated profit elasticity with respect to fixed factors

	Land area	Percentage of rice area in HYVs	Animal asset in standard units
Profit	0.3938 (0.1418)	0.0822 (0.0750)	0.5240 (0.1433)

Note: Numbers in parentheses are asymptotic standard errors.

6.2.2 Poverty prevalence among rice farm households

In this research, a farm household's poverty status was first investigated before its consumption demand was estimated. Households' total expenditures on food and non-food consumption rather than income was used to measure households' poverty. Using consumption rather than income is based on a number of considerations: first, income may underestimate or overestimate the level of living. For instance, when household members share with each other, a household may have a higher living standard than its income permits. On the other hand, when money can not purchase certain consumption goods, income tends to overestimate the level of living of a household (Atkinson, 1991). Second, in developing countries, while households can smooth their consumption over a period, income, especially agricultural income varies from time to time. In particular, income in a short time period – like in one month—is a poor indicator of living standard in that period. Annual income data is usually required (Deaton, 1997). Therefore, poverty measures based on consumption, not income, are preferred in the context of measuring welfare in developing countries (Deaton, 1997). Finally, convenience in collecting relevant data is also a factor. For instance, at the practical level, the difficulties of measuring income are much more severe than those of measuring consumption, especially for rural households whose income comes largely from self employment in agriculture. Given also that annual income is required for a satisfactory estimate of living standards, an income-based measure requires multiple visits or the use of recall data, whereas a consumption measure can rely on consumption over the previous few weeks (Deaton, 1997). Additionally, people tend to be more sensitive about reporting their incomes in many cases. Thus they may be more likely to report biased figures.

To make different households comparable in their consumption, per capita consumption is usually used to adjust household consumption or income according to the number of people in the household. Since per capita measurement ignores economies of scale in household consumption related to size and other differences in needs among household members, particularly ages of adults and children, equivalence scales are used to make further adjustment of the effects of households' demographic characteristics (Buhmann *et al.*, 1988). Although it seems likely that household members do not all require the same share of the household’s total resources, and that household resources are not allocated equally across all household members, there is no widely accepted alternative to the simple per capita convention (Lanjouw, 1997). The adult equivalence scale used in this research, as shown in Table 6.4, considers Lanjouw (1997)’s scale and Buhmann *et al.* (1988)’s rule of thumb. In terms of consumption, the first adult in the household is given a weight of 1 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. All members in each household were converted into the adult equivalent number.

Table 6.4 Adult equivalence scale used in computing poverty prevalence

Description	Age category	Adult equivalence scale
Infants	Less than 5	0.3
Children	>=5 & <16	0.5
Adults	>=16 & <=65	first adult: 1; additional adults: 0.7
Elderly	over 65	0.5

Based on the situation in Bangladesh, the poverty line in this research 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 were computed (Table 6.5). Among a total of 347 households, 232 are poor and 115 are non-poor, which accounts for 66.86% and 33.14%, respectively. The high percentage of poor households illustrates the existence of poverty in Bangladesh.

Table 6.5 Prevalence of poverty among rice farm households

	Number	Percentage
Poor	232	66.86%
Non-poor	115	33.14%
Total households	347	100%

6.2.3 Demand and income elasticities

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. The 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 (Table 6.6). 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 6.6 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%

The estimates of demand and income elasticities of both poor and non-poor farm households' food consumption are presented in Table 6.7. The results show for both households 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 a larger impact on poor households in rice.

Table 6.7 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 (0.1014)	0.0744 (0.0640)	0.0149 (0.0234)	-0.0362 (0.0139)	-0.3372 (0.0599)	-0.0232 (0.0416)	-0.0736 (0.0363)	-0.0156 (0.0189)	0.8777 (0.0638)
	Non-poor	-0.2403 (0.1831)	0.0771 (0.1140)	0.0620 (0.0380)	0.0234 (0.400)	-0.3654 (0.1266)	0.0266 (0.1064)	-0.0678 (0.0813)	-0.0262 (0.0409)	0.5107 (0.1049)
Wheat/other food	Poor	0.1613 (0.1655)	-0.8948 (0.1872)	-0.0909 (0.0586)	-0.0539 (0.0361)	-0.0543 (0.1368)	0.0045 (0.0941)	-0.0284 (0.0800)	0.0004 (0.0469)	0.9651 (0.1144)
	Non-poor	-0.0434 (0.2018)	-0.9670 (0.2409)	-0.1726 (0.0685)	0.0876 (0.0721)	-0.1180 (0.1865)	-0.0163 (0.1612)	-0.0538 (0.1155)	0.1229 (0.0762)	1.1606 (0.1268)
Pulse	Poor	0.0065 (0.2574)	-0.4300 (0.2480)	-0.2285 (0.2340)	0.0476 (0.1227)	-0.2358 (0.2448)	-0.2044 (0.1782)	0.0154 (0.1423)	-0.2495 (0.1445)	1.2785 (0.1539)
	Non-poor	0.4272 (0.3186)	-0.7568 (0.3232)	-0.2409 (0.2971)	0.0084 (0.2108)	-0.5997 (0.3114)	-0.1844 (0.2735)	-0.2328 (0.1783)	0.7578 (0.2426)	0.8212 (0.1754)
Oil	Poor	-0.3155 (0.1775)	-0.1960 (0.1783)	0.0845 (0.1437)	-0.4956 (0.1547)	0.1226 (0.1713)	0.1053 (0.1263)	0.0244 (0.0996)	0.1862 (0.1236)	0.4842 (0.1046)
	Non-poor	0.0585 (0.3886)	0.4814 (0.3929)	0.0006 (0.2430)	-0.1874 (0.3287)	-0.8305 (0.3870)	-0.4937 (0.3312)	-0.0187 (0.2175)	-0.1015 (0.2652)	1.0913 (0.2193)
Vegetables/	Poor	-0.7327 (0.1146)	-0.0509 (0.1020)	-0.0334 (0.0433)	0.0020 (0.0259)	-0.2206 (0.1329)	-0.0525 (0.0697)	0.0408 (0.0575)	0.0186 (0.0345)	1.0286 (0.0796)
Fruits	Non-poor	-0.6266 (0.1484)	-0.0906 (0.1237)	-0.0988 (0.0438)	-0.1071 (0.0471)	0.0663 (0.1860)	-0.3500 (0.1175)	-0.0340 (0.0882)	0.0018 (0.0479)	1.2391 (0.1003)
Meat/egg/ milk	Poor	-0.4102 (0.2257)	-0.1020 (0.1969)	-0.1118 (0.0879)	0.0098 (0.0533)	-0.2562 (0.1951)	-0.5726 (0.1949)	-0.0936 (0.1180)	-0.0501 (0.0712)	1.5866 (0.1591)
	Non-poor	-0.1020 (0.2508)	-0.0084 (0.2136)	-0.0610 (0.0768)	-0.1213 (0.0805)	-0.6580 (0.2354)	0.1302 (0.2707)	-0.1114 (0.1483)	-0.1521 (0.0857)	1.0839 (0.1812)
Fish	Poor	-0.6238 (0.2086)	-0.1240 (0.1767)	0.0047 (0.0741)	-0.0170 (0.0444)	0.0474 (0.1704)	-0.0838 (0.1245)	-0.4996 (0.1451)	-0.0832 (0.0592)	1.3792 (0.1522)
	Non-poor	-0.4584 (0.2263)	-0.1326 (0.1805)	-0.0990 (0.0589)	-0.0169 (0.0622)	-0.1345 (0.2091)	-0.1798 (0.1744)	-0.3536 (0.1952)	-0.1086 (0.0645)	1.4834 (0.1857)
Spices	Poor	-0.0562 (0.1720)	0.0471 (0.1653)	-0.1868 (0.1206)	0.1279 (0.0881)	0.1609 (0.1624)	-0.0172 (0.1202)	-0.0842 (0.0947)	-0.6487 (0.1464)	0.6571 (0.1006)
	Non-poor	-0.2986 (0.2886)	0.5225 (0.3034)	0.6367 (0.2050)	-0.0703 (0.1943)	0.0822 (0.2869)	-0.4375 (0.2574)	-0.2220 (0.1645)	-1.1480 (0.3141)	0.9349 (0.1580)

Note: Numbers in parentheses are asymptotic standard errors.

The estimates of income elasticities indicate 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 intake for the surveyed households, a decline in the expenditure share of rice may decrease farm households' total calorie intake.

6.2.4 Calorie/protein intake elasticity

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 6.8 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). Although animal product has a higher income elasticity than other food items do, the actually consumed quantities are not big enough to have a large impact on its calorie share in total calorie intake. For instance, the calorie share of meat/egg/milk and fish in poor households are 2.54% and 1.5%, respectively. The shares in non-poor households are 4.27% and 1.97%, respectively.

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

Table 6.8 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%

Farm households' protein intake follows 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 6.9). 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 intake. In non-poor households, meat/egg/milk is the second largest protein source and contributes 17.73% of total protein intake. The protein share of meat/egg/milk in poor households is five percent less.

Table 6.9 Share of individual food items in household total protein intake

Food items	Protein content (g/100g)	Household annual total consumption (kg)		Protein share of ith 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 decision with respect to output supply and input demand. The analysis of the farm household production decision above has shown that the expected farm profit will increase. That is, 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, which means when the adoption area of high yield rice increases by 1%, the expected profit increases by 0.08%. The impact of the profit increase on households' nutritional status then is estimated by calculating how income changes will affect 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.

Using the results from the estimation of a farm household's profit function and demand systems, farm households' calorie and protein intake elasticities with respect to the percentage of rice area in high yield variety were computed. The results show that the calorie elasticities range from 0.062 to 0.074 and protein elasticities range from 0.075 to 0.084 among households (Table 6.10). The effects of 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 6.10 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 are the same as other high yield varieties. The effects of such transgenic rice varieties as drought resistant on yield 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 intake will be larger than the ones produced in Table 6.10.

6.3 Results of consumption forecasting model

6.3.1 Determinants of farm household calorie intake

Table 6.11 describes the summary statistics of the dependent and independent variables used in the consumption forecasting model. Over the 388 households, the average daily calorie intake per resident household member in the hunger season is 2419 kcal, which is higher than the national average level. The high calorie intake per resident household member is due to the large variation in daily calorie intake among households.

Table 6.11 Descriptive statistics of the dependent and independent variables

Variable	Mean	Standard Deviation	5 Percentile	25 Percentile	75 Percentile
Daily calorie intake (kcal) per resident household member at hunger season (t+1)	2419.138	751.8167	1425.089	1876.44	2843.535
Agricultural income (taka) at t	7481.736	10021.06	53	1796.6	9162.55
Other income (taka) at t	941.7537	6642.853	0	0	433.25
Usual flood depth (Ft.)	3.322971	3.624889	0	1	4
Value (taka) of agricultural equipment, large trees, fishing tools at t	6178.242	17483.99	0	225	5145
Value (taka) of consumer durables at t	5975.425	12366.89	120	690	5845
Grain stock (kg, rice, paddy, wheat) at t	73.52577	174.8354	0	0	62.5
# of cattle (calves, dairy cow, bullock) at t	1.57732	1.743708	0	0	2
# of goat/sheep at t	0.56701	1.307163	0	0	1
# of chicken at t	8.036082	8.734602	0	2	11
At least one household member completed primary school at t (yes=1)	0.546392	0.498486	0	0	1
# of adult male at t	1.762887	1.104589	1	1	2
# of adult female at t	1.53866	0.797963	1	1	2
# of children at t	2.657216	1.52279	0	2	4
# of elderly at t	0.219072	0.483257	0	0	0
Household head age at t	46.57732	12.51735	29	37	55

Among all households, 5 percent of households' daily calorie intake per resident household member is equal to or less than 1425 kcal while 25% consumed less than 1876 kcal. This 25% of total population may represent the "ultra poor" households. Other studies in Bangladesh show that out of a total population of over 135 million people, about 20% —28 million people in more than six million households—suffer from chronic food insecurity and severe under-nutrition. On average, they can afford to consume only about 1800 kcal calories daily, which is far below the recommended daily average of 2300 kcal calories (WFP, 2006)

In addition to variation in calorie intake, surveyed households possess a different amount of income and assets. For instance, the average agricultural income at time t is approximately 7482 taka and the standard deviation is 10021 taka.

Table 6.11 also shows a number of household demographic characteristics. Among the surveyed households, approximately 55% of households have at least one member who completed primary education. On average, there are more adult male members than female members, and more children than elderly people in a household. The average age of the household head is 47 years.

Farm households' future calorie intake was estimated by a 3-step OLS procedure. The estimates of conditional mean and variance of log calorie intake per household resident during the hunger season are shown in Table 6.12. The results indicate that the effects of independent variables on household calorie intake vary considerably.

Table 6.12 3-step OLS estimates of conditional mean and conditional variance of logarithmic daily calorie intake per resident household member in the hunger season

	$E(\ln c_{t+1}/X_t) = X_t'\alpha$		$\ln Var(\ln c_{t+1}/X_t) = X_t'\beta$	
	Coefficient	t-stat	Coefficient	t-stat
Agricultural income at t	4.09E-06	2.07	5.55E-06	0.39
Other income at t	2.97E-06	3.65	-0.00003	-1.49
Usual flood depth	-0.006901	-1.47	0.0330267	1
Value of agricultural equipment, large trees, fishing tools at t	-2.88E-06	-5.79	-9.27E-06	-1.06
Value of consumer durables at t	4.70E-06	4.03	2.61E-06	0.24
Kg of grain stock (rice, paddy, wheat) at t	-3.74E-06	-0.04	0.0002332	0.3
# of cattle (calves, dairy cow, bullock) at t	0.0315271	3.16	0.046247	0.6
# of goat/sheep at t	0.0114402	1.25	-0.1131562	-1.25
# of chicken at t	0.0023879	1.29	0.0115368	0.85
At least one household member completed primary school at t (yes=1)	0.0016397	0.05	0.05643	0.22
# of adult male at t	0.0177795	1.21	-0.1479233	-1.15
# of adult female at t	-0.0082647	-0.38	0.1193309	0.67
# of children at t	-0.0616453	-6.62	0.0433057	0.56
# of elderly at t	-0.0136909	-0.41	0.300408	1.23
Household head age at t	0.0000651	0.06	0.0089536	0.96
intercept	7.903972	121.63	-4.622166	-8.39
R^2, F Observations	0.35 388	13.51	0.33 388	1.13

Agricultural income positively affects both ex ante mean and ex ante variance of calorie intake. On the one hand, increases in agricultural income increase the amount of calories a household consumes. On the other hand, the variance of consumption increases as well. That is, a household's calorie intake becomes more dispersed. This increase in dispersion is probably because various risk factors—drought, flood, insect and disease—affect agricultural production. Exposure to these risks can cause agricultural output to fluctuate. Consequently, income from agricultural production varies over time. Therefore, if a household's calorie intake depends only on agricultural income, as income varies consumption spreads over a larger range. In this research, the effect of transgenic rice on households' calorie intake is assumed to be the same as that of agricultural income.

Making this assumption enables this research to illustrate the potential income effect of the adoption of transgenic rice, and therefore, how transgenic rice will affect a household's calorie intake. Some technological characteristics of transgenic rice that are able to reduce the fluctuation of agriculture and stable agricultural production, such as drought resistant, insect resistant, are not addressed. Therefore, theoretically, transgenic rice's impact on improving calorie intake may be higher than is indicated in Table 6.12.

Compared with agricultural income, other income has a positive effect on ex ante mean and a negative effect on ex ante variance. Other income thus can increase the calorie intake and reduce the dispersion of the calorie intake at the same time. Among the surveyed households, other income resources include remittances, rental income of properties and equipment, and income from social assistance programs. There are a number of social assistance programs operated by the Bangladesh government, international organizations, and non-governmental organizations. For instance, the United Nations' World Food Programme (WFP) has worked in Bangladesh since 1974. Most of its activities focus on development and disaster preparedness. To date, about 4 million people in Bangladesh annually benefit from the WFP, of which 2 million people (95% women) participate directly in its food-assisted programs. For instance, approximately 500,000 people receive food and skills training through the Vulnerable Group Development (VGD) program. Participants in the Integrated Food Security (IFS) program receive food, cash and a 'development package' similar to those in the VGD program. In return, they build up physical assets - homestead raising, fishponds - through Food For Work activities (WFP, 2006).

Flooding occurs almost every year in Bangladesh. The result in Table 6.12 illustrates the impact of usual flood on households' calorie consumption. The higher the flood level, the fewer calories households consume. Consumption is also more dispersed.

Household composition affects its ex ante consumption too. More adult male members increase the ex ante mean of calorie consumption and reduce the variance. More females, children, and elderly, on the contrary, reduce the ex ante mean of calorie consumption and increase its variance.

6.3.2 Nutritional vulnerability profiles

To obtain the ex ante probability distribution of each household's future nutrient consumption from the estimated results, the assumption that daily calorie intake per resident household member follows the log-normal distribution is tested first. The skewness/kurtosis test for normality fails to reject the assumption (Table 6.13). Therefore, assuming lognormality, predications of each household's ex ante mean and variance of logarithmic calorie intake per resident member in the hunger season are sufficient to characterize a household's ex ante probability distribution of future consumption. Each household's ex ante probability of future calorie consumption is obtained by substituting the values of regressors for that household into the equations whose estimated coefficients are presented in Table 6.12.

Table 6.13 Skewness/kurtosis test for normality

Variable	Pr(Skewness)	Pr(Kurtosis)	adjusted chi2(2)	Prob>chi2
Logarithm of daily calorie intake per resident household member at hunger season	0.879	0.59	0.31	0.8551

To establish the nutritional vulnerability profile for rice farm households, the probability threshold is set at 0.5 and daily per resident member calorie intake threshold is at 1800 kcal, 2105 kcal, 2300 kcal, and 2828 kcal. The 1800 kcal level is the minimum standard set by the World Bank in the World Food Program. The 2105 kcal level is the average calorie consumption level in Bangladesh. The 2300 kcal level is the recommended standard by the World Bank in the World Food Program. The 2828 kcal level is the average calorie consumption level in developing countries. Thus, a farm household being nutritional vulnerable means that the probability of per resident member's daily calorie consumption falling below the predetermined level (i.e. 1800 kcal or 2105 kcal) is equal to or higher than 0.5 (V>=0.5). Table 6.14 presents the predicted household vulnerability.

Table 6.14 Predicted household vulnerability at different calorie consumption levels

Vulnerable V>=0.5	Per resident member daily calorie intake level			
	<1800 kcal	<2105 kcal	<2300 kcal	<2828 kcal
Yes	0 (0%)	21 (5.4%)	76 (19.6%)	301 (77.6%)
No	388 (100%)	367 (94.6%)	312 (80.4%)	87 (22.4%)
Total households (%)	388 (100%)	388 (100%)	388 (100%)	388 (100%)

The results show that at the 1800 kcal level, no household is vulnerable, which means that at the post harvest time all households have a probability higher than 0.5 of consuming at least 1800 kcal per capita per day at the hunger time. At 2105 kcal level, among 388 households, 21 households are vulnerable by definition. As the consumption threshold increases, households on average become more vulnerable. For instance, 76 households are vulnerable at the World Bank recommended 2300 kcal level. In comparison, approximately 78% (301 households) of all households will not achieve the average consumption level in developing countries.

The results clearly indicate that vulnerability exists among surveyed rice farm households. Furthermore, it is also possible that the actual number of nutritionally vulnerable households is higher than the one produced by this research. Two factors may contribute to the under-estimation of vulnerability. First, as shown in the descriptive statistics (Table 6.11), in the sample the average daily per capita calorie intake is approximately 2419 kcal, and is higher than the national average of 2105 kcal in Bangladesh. Since the calorie intake is computed by converting food consumption into calorie intake, this may suggest that either the surveyed rice farm households in general are better off than others in the country, or households may overstate in the survey the amount of food they consumed. Second, in the computation of vulnerability, the probability threshold is set at 0.5. When a household's probability of consumption shortfall is lower than 0.5 but close to 0.5 (i.e. 0.49, 0.48), it is categorized as non-vulnerable by definition. These households, however, in reality, are likely to be as vulnerable as those households whose probability of consumption shortfall is just above the 0.5 threshold.

The results from the farm household model indicate that the adoption of transgenic rice will increase farm household agricultural income. When agricultural income increases, the prediction on each household's future consumption shows that the probability of falling below the predetermined nutrient consumption level declines. That is, each household is less likely to become vulnerable. The impact of the agricultural income increase on overall household vulnerability profile is illustrated by setting calorie intake at 2105 kcal (Table 6.15). When agricultural income increases by 10%, 20% and 30%, one household, one household, and two households, respectively, are no longer vulnerable. A similar trend is observed when calorie consumption is set at other levels.

Table 6.15 The impact of agricultural income increase on household vulnerability at 2105 kcal consumption level

Vulnerable	At current income level	Income increase by		
		10%	20%	30%
Yes	21(5.4%)	20(5.2%)	20(5.2%)	19(4.6%)
No	367(94.6%)	368(94.8%)	368(94.8%)	369(95.4%)
Total households (%)	388(100%)	388(100%)	388(100%)	388(100%)

CHAPTER 7: CONCLUSIONS

7.1 Introduction

Since its first commercial release in 1996, transgenic crops have witnessed both unprecedented rapid growth and hot debate on their economic, health and environmental impacts. In 2005, 8.5 million farmers in 21 countries adopted transgenic crops. The global area of transgenic crops reached 90 million hectares. In the first decade of commercial production of transgenic crops, the annual growth rate of transgenic crops was maintained at a double-digit level. The United States with a total planting area of 49.8 million hectares (55% of global area) remains the largest transgenic crop production country, followed by Argentina, Brazil, Canada and China. Transgenic soybean continued to be the principal biotech crop in 2005, occupying 54.4 million hectares (60% of global biotech area), followed by maize (21.2 million hectares at 24%), cotton (9.8 million hectares at 11%) and canola (4.6 million hectares at 5% of global biotech crop area).

As one of the most importance staple crops in the world, rice accounts for more than 30 percent of total calorie supply and more than half of the calories consumed by the poor in Asia. Transgenic rice has not been commercially released on a large scale—only *Bt* rice was officially released in Iran in 2004—but research is under way. With its potentials to address adverse production conditions, including drought, diseases and insects, transgenic rice has raised hope that yield and quality improvements in rice will accelerate and help in the battle against under-nutrition, especially in the context of the prevalence of under-nutrition in Asian developing countries.

The double-digit growth rate has clearly indicated farmers' confidence in adopting transgenic crops, but debates on their impacts, however, never cease. In recent years, there have been a number of studies on the impacts of transgenic crops with a primary focus on their distributional and welfare effects. However, little research addresses its impact on farmers' well-being at the household level. This research provides empirical evidence on the potential effects of transgenic rice on farm households' income and nutritional well-beings—including the impacts on their current nutritional status, and nutritional vulnerability over time. To this end, a farm household model is developed to analyze the ex ante effects of transgenic rice on farm households' nutritional status and a consumption forecasting model is developed to project farm households' nutritional vulnerability profile in Bangladesh.

The farm household model estimated the supply of outputs (rice, all other crops and animal products) and demand of inputs (labor and fertilizer) in a farm household's production decisions. Due to the ex ante nature of this research, the effects of transgenic rice are assumed to be similar to these of other high yield varieties. It is further assumed that the impact of transgenic rice on farm household profit is reflected in the percentage of rice area in HYVs and that the yield effect of transgenic rice is the same as HYVs. The estimation shows that the total profit elasticity with respect to the percentage of rice area in high yield variety is 0.08. To quantify farm households' food consumption decisions, both poor and non-poor households' demand for rice, wheat/other food, pulse, oil, vegetables/fruits, meat/egg/ milk, fish, and spices were estimated. Income elasticities were used to compute calorie and protein elasticities with respect to introducing transgenic rice. The estimation shows that the calorie elasticity with respect to the percentage of rice area in HYVs is 0.074 in poor and 0.062 in non-poor, respectively. The protein elasticity is 0.084 in poor and 0.075 in non-poor, respectively. Therefore, the results indicate that transgenic rice is likely to play a positive role in improving farm households' nutritional status in terms of total calorie/protein intake. The magnitude, however, according to the model, is likely to be moderate, if only the profit effect is considered.

Farm households' calorie intake in the future (hunger season) was predicted by a multivariate regression function with the logarithmic daily per resident calorie intake as the dependent variable. The independent variables include variables that represent households' income, flood exposure, assets, and demographic composition. Farm households' nutritional vulnerability profiles based on the estimation of ex ante mean and variance show that vulnerability exists among surveyed rice farm households. The model also predicts that the income increase induced by the adoption of transgenic rice will reduce each individual household's probability of suffering future consumption shortfall and subsequently reduce its vulnerability. The overall vulnerability profile of farm households improves.

7.2 Policy implications

This research shows that the adoption of transgenic rice will benefit farm households, especially poor farm households, in terms of improved nutritional intake and reduced nutritional vulnerability in developing countries. Transgenic rice therefore is likely to play a positive role in poverty alleviation and in improving resource poor households' nutritional well being. To achieve the ultimate goal of reducing under-nutrition in developing counties, policies that promote the research and dissemination of transgenic rice should be encouraged both in the international research community and at the national level.

Public research in transgenic rice is necessary. Currently, most investment in biotechnology research is made by the private sector. The private sector, however, in its pursuit of profit, often either choosing to invest in crops (cotton, maize) or traits (herbicide tolerant) that are less relevant to poor farmers in developing countries, or charging a premium for new biotech-products. It is likely that the transgenic rice would follow the same pattern if it were developed by the private sector. Research by the public sector, such as the international research centers and national research institutes, thus will be more likely to benefit marginalized farmers.

Public support for transgenic rice needs to be fostered. Starting from the commercialization of the first transgenic crops, negative public attitudes have been an obstacle that prevents or delays the release of transgenic crops. In general, the public attitude in developing countries is more supportive compared with that in developed countries. Concerns over the environment and human health effects as well as the uncertain economic impacts of biotech products, are reasons behind people's opposition. As more impact studies are available and empirical evidence disseminated, support may increase. The positive economic effects of transgenic rice on reducing under-nutrition, as illustrated by this research, can be used for educational purposes.

This research also implies that, to address the under-nutrition problems in developing countries, policy interventions may be combined. First, while illustrating the positive effects of transgenic rice on reducing under-nutrition in developing countries, the results also indicate that its impact is moderate. This implies that transgenic rice alone can not cure the poverty and under-nutrition problems. Second, the results, especially the ones from the nutritional vulnerability measurement, show that there are a variety of factors that will affect both the mean and variance of farm households' future consumption. For instance, income from other sources will increase the mean and reduce the variance of nutrient intake. Other income consists of income from non-agricultural businesses as well as social assistance. Relevant policy interventions such as income diversification and continuation of social supporting programs will be helpful in reducing nutritional vulnerability at the household level.

7.3 Future research

In this research, data availability was a major concern 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. Limited by data, this research focuses on how transgenic rice will increase the overall level (mean) of households' nutritional consumption. As more data are available, their impact on reducing the variance of future consumption can also be studied in depth. Furthermore, future studies of how other factors rather than transgenic rice will affect farm households' nutritional vulnerability in the context of introducing transgenic rice will be of relevance to addressing under-nutrition issue in developing countries.

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APPENDIX A: Derivation of elasticity

On the production side, the direct and all cross-price elasticities can be calculated as follows.

1. Cross-price elasticities, i=1,…n output

$\varepsilon_{ij} = s_j + \beta_{ij} / s_i$

Proof:

By definition: $\varepsilon_{ij} = \frac{\partial q_i}{\partial p_j}\frac{p_j}{q_i}$ and $s_i = \alpha_i + \sum_j \beta_{ij} \ln p_j + \sum_m \delta_{im} \ln z_m$, assuming price is exogenous, a change in p_i does not change p_j . By Shepard Lemma, $\frac{\partial \pi}{\partial p_j} = q_j$.

$$\frac{\partial s_i}{\partial p_j} = \frac{\partial s_i}{\partial \ln p_j}\frac{\partial \ln p_j}{\partial p_j} = \frac{\partial s_i}{\partial \ln p_j}\frac{1}{p_j} = \frac{\beta_{ij}}{p_j}$$

$$\frac{\partial s_i}{\partial p_j} = \frac{\partial\left(\frac{p_i q_i}{\pi}\right)}{\partial p_j} = \frac{p_i\left(\frac{\partial q_i}{\partial p_j}\right)\pi - p_i q_i\left(\frac{\partial \pi}{\partial p_j}\right)}{\pi^2} = \frac{p_i\left(\frac{\partial q_i}{\partial p_j}\right)\pi - p_i q_i q_j}{\pi^2} = \frac{p_i\left(\frac{\partial q_i}{\partial p_j}\right) - \frac{p_i q_i q_j}{\pi}}{\pi}$$

$$= \frac{p_i\left(\frac{\partial q_i}{\partial p_j}\right) - s_i q_j}{\pi} = \frac{p_i\left(\frac{q_i}{q_i}\right)\left(\frac{\partial q_i}{\partial p_j}\right) - s_i q_j}{\pi}$$

so:

$$\frac{p_i p_j\left(\frac{q_i}{q_i}\right)\left(\frac{\partial q_i}{\partial p_j}\right) - s_i q_j p_j}{\pi} = \beta_{ij}$$

$$\Rightarrow \frac{p_i q_i\left(\frac{p_j}{q_i}\right)\left(\frac{\partial q_i}{\partial p_j}\right) - s_i q_j p_j}{\pi} = \beta_{ij}$$

$$\Rightarrow s_i\left(\frac{p_j}{q_i}\frac{\partial q_i}{\partial p_j}\right) - s_i s_j = \beta_{ij}$$

$$\Rightarrow \varepsilon_{ij} = s_j + \beta_{ij} / s_i$$

2. Direct-price elasticities, i=1,…n output

$\varepsilon_{ii} = -1 + s_i + \beta_{ii}/s_i$

Proof:

By definition: $\varepsilon_{ii} = \frac{\partial q_i}{\partial p_i}\frac{p_i}{q_i}$, $s_i = \alpha_i + \sum_j \beta_{ij} \ln p_j + \sum_m \delta_{im} \ln z_m$, and $\frac{\partial \pi}{\partial p_i} = q_i$

$$\frac{\partial s_i}{\partial p_i} = \frac{\partial s_i}{\partial \ln p_i}\frac{\partial \ln p_i}{\partial p_i} = \frac{\partial s_i}{\partial \ln p_i}\frac{1}{p_i} = \frac{\beta_{ii}}{p_i}$$

$$\frac{\partial s_i}{\partial p_i} = \frac{\partial\left(\frac{p_i q_i}{\pi}\right)}{\partial p_i} = \frac{q_i \pi + p_i\left(\frac{\partial q_i}{\partial p_i}\right)\pi - p_i q_i\left(\frac{\partial \pi}{\partial p_i}\right)}{\pi^2} = \frac{q_i \pi + p_i\left(\frac{\partial q_i}{\partial p_i}\right)\pi - p_i q_i q_i}{\pi^2}$$

$$= \frac{q_i + p_i\left(\frac{\partial q_i}{\partial p_i}\right) - \frac{p_i q_i q_i}{\pi}}{\pi} = \frac{q_i + p_i\left(\frac{\partial q_i}{\partial p_i}\right) - s_i q_i}{\pi} = \frac{q_i + p_i\left(\frac{q_i}{q_i}\right)\left(\frac{\partial q_i}{\partial p_i}\right) - s_i q_i}{\pi}$$

$$\Rightarrow \frac{p_i q_i + p_i q_i\left(\frac{p_i}{q_i}\right)\left(\frac{\partial q_i}{\partial p_i}\right) - s_i p_i q_i}{\pi} = s_i + s_i \varepsilon_{ii} - s_i s_i = \beta_{ii}$$

Thus:

$$\varepsilon_{ii} = -1 + s_i + \beta_{ii}/s_i$$

3. Rice output elasticity with respect to fixed factor (z_m, which can represent the new technology), i=rice

By definition: $\varepsilon_{iz} = \frac{\partial q_i}{\partial z_m}\frac{z_m}{q_i}$. Assume changes in z_m will not affect p_i.

From $s_i = \alpha_i + \sum_j \beta_{ij} \ln p_j + \sum_m \delta_{im} \ln z_m$, we have

$$\frac{\partial s_i}{\partial z_m}=\frac{\partial s_i}{\partial \ln z_m}\frac{\partial \ln z_m}{\partial z_m}=\frac{\partial s_i}{\partial \ln z_m}\frac{1}{z_m}=\frac{\delta_{im}}{z_m}$$

$$\frac{\partial s_i}{\partial z_m}=\frac{\partial\left(\frac{p_i q_i}{\pi}\right)}{\partial z_m}=\frac{p_i\left(\frac{\partial q_i}{\partial z_m}\right)\pi-p_i q_i\left(\frac{\partial \pi}{\partial z_m}\right)}{\pi^2}=\frac{p_i\left(\frac{\partial q_i}{\partial z_m}\right)\pi-p_i q_i\left(\frac{\partial \pi}{\partial z_m}\right)}{\pi^2}$$

$$=\frac{p_i\left(\frac{\partial q_i}{\partial z_m}\right)-\frac{p_i q_i\left(\frac{\partial \pi}{\partial z_m}\right)}{\pi}}{\pi}=\frac{p_i\left(\frac{\partial q_i}{\partial z_m}\right)-s_i\left(\frac{\partial \pi}{\partial z_m}\right)}{\pi}$$

so:

$$\frac{\partial s_i}{\partial \ln z_m}\frac{1}{z_m}=\frac{p_i\left(\frac{\partial q_i}{\partial z_m}\right)-s_i\left(\frac{\partial \pi}{\partial z_m}\right)}{\pi}=\frac{p_i\left(\frac{q_i}{q_i}\right)\left(\frac{\partial q_i}{\partial z_m}\right)-s_i\left(\frac{\partial \pi}{\partial z_m}\right)}{\pi}$$

$$\Rightarrow\frac{p_i z_m\left(\frac{q_i}{q_i}\right)\left(\frac{\partial q_i}{\partial z_m}\right)-s_i\left(\frac{\partial \pi}{\partial z_m}\right)z_m}{\pi}=\delta_{im}$$

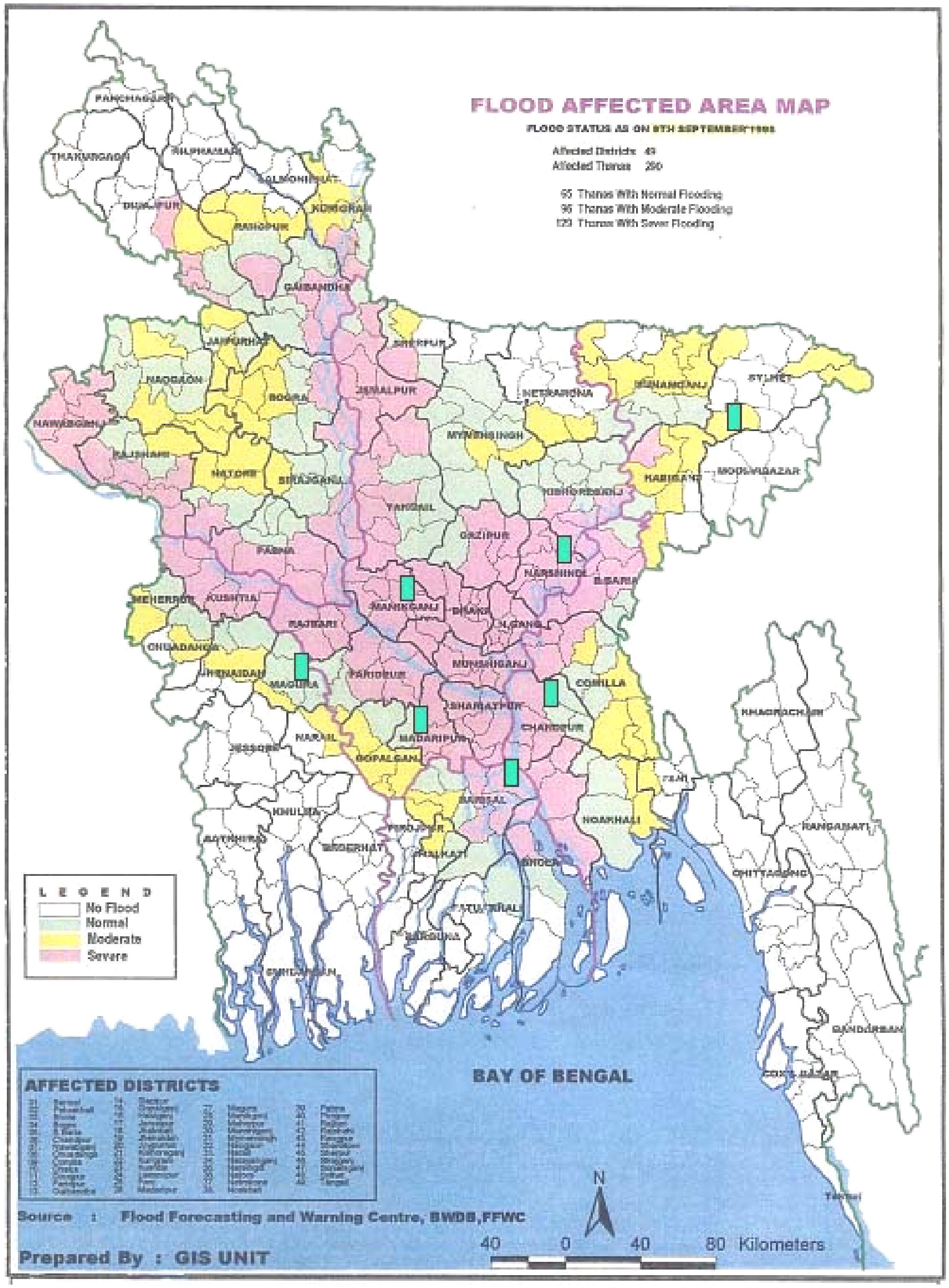
$$\Rightarrow\frac{p_i q_i\left(\frac{z_m}{q_i}\right)\left(\frac{\partial q_i}{\partial z_m}\right)-s_i\left(\frac{\partial \pi}{\partial z_m}\right)z_m}{\pi}=\delta_{im}$$

$$\Rightarrow s_i\left(\frac{z_m}{q_i}\frac{\partial q_i}{\partial z_m}\right)-\frac{s_i\left(\frac{\partial \pi}{\partial z_m}\right)z_m}{\pi}=\delta_{im}$$

$$\Rightarrow \varepsilon_{im}=\left(\frac{\partial \pi}{\partial z_m}\frac{z_m}{\pi}\right)+\delta_{im}/s_i$$

$$\Rightarrow \varepsilon_{im}=\beta_r+\sum_i \delta_{ir}\ln p_i+\delta_{im}/s_i$$

APPENDIX B: Map of flood affected areas of Bangladesh as of September 9, 1998 and selected thanas in the sample



APPENDIX C: Summary description of the content of the household questionnaire

1.	Household information	Sec A1 contains the usual information on the roster, like age, gender, civil status, time of absence from the household and so on. In addition it asks if the individual send or receive money for support.
2.	Education	Sec A2 concerns with the questions on education level for all individuals age 6 and older, dropout, and if any development programs running with the school.
3.	Status and history of employment, job search, training and public works	The employment section is limited to all household members age 10 and over. In sec B1 there are questions relative to the labor participation, the main type of work and the reason for not participating. Sec B2 contains questions relative to the job search strategy and the attitude towards accepting a job (willingness to relocate and minimum wage). Also contains the history of employment held before the current employment. Sec B3 accommodates information on Training and public works. Here the main questions relate to the number of weeks spent in public works and job training for each year since 1995.
4.	Dependent job, Permanent and daily labor	Sec B 4 contains information on primary and secondary dependent job: Type of job, industry, time allocated, type of contract, salary and benefits on three different times frame.
5.	Casual jobs, daily labor	Sec B 5 informs on time spent, tasks, wage rates etc. of causal jobs for three time periods.
6.	Non-ag self employment, Business Activities	Cottage Activities, non-agri self-employment's information for three different time periods.
7.	Agricultural activity, access to agricultural land, production and allocation of production	Sec C is dedicated to the agricultural production Availability of agricultural land, agricultural assets and livestock. In sec 6.1 the number of weeks worked during the past year and the hours worked last week are reported. Details on access (for each of the past four years) and type and acquisitions of agricultural land (orchard, pastures and cropland) are reported here.
8.	Fishing activity and	Sec D is dedicated to the management of ponds and

	livestock	fishing activities. Sec E reports the type and number of livestock available and the production of animal products derived from them.
9.	Allocation of family labor	Sec F contains information on the allocation of family labor among the alternative agricultural activities
10.	Social assistance, availability of benefits	The sections on social assistance and social benefits constitute a central part of the questionnaire. In sec G, there is the level and the number of months several benefits received, currently and in the last three years.
11.	Household furniture and durables and other assets	Section H, relatives to the household durable, contains the number of items, the current value and the year of acquisition as well the time and reason for disposal.
12.	Credit	Section I contains detailed information on the amount of credit received, the interest rate and the repayment.
13.	Housing and Sanitation	Section J on housing contains the usual questions relative to the quality of the dwelling and the rent paid together with other monthly expenses.
14.	Regular and occasional non-food spending	Non food expenditures include regular non-food spending for the past month in sec O and occasional non-food spending occurred in the past 12 months in sec 11.2 (12 items).
15.	Food expenditure and consumption	The food section (sec K, L, N) contains consumption of food consumed at home and away from home. For all the items that have been consumed during the last month quantities consumed from purchases, own production and received from other sources are listed along with the purchase value, if quantities are not known, and current price.
16.	Health status	Health status includes type of disability and treatment for chronic illness (sec P) and treatment, cost and type of consultation for acute illness occurred in the past 4 weeks.
17.	Anthropometry	Height and weight have been collected for all children below 10 years of age and all females between the age of 13 and 45.

Source: Del Ninno, 2001.

APPENDIX D: Summary content of community level information

Level	Coverage	Questionnaire	Data Processing
ROUND 1 NOV 98			
Thana	Agricultural production between 95 to 98	R1_Thana	Word Tables
Union	Information about the Flood, prices and other characteristics.	R1_Union	Only 3 variables were entered in Excel
Village	Mostly labor data	R1_Village	Available in Excel & Stata
ROUND 2 MAY99			
Union	Labor, NGO programs, Prices, Rainfall, Program intervention, daily wages	R2_Union	Available in Excel & Stata
ROUND 3 NOV 99			
Thana	Intervention programs at Thana level	R3_Thana	Available in Excel & Stata
Union	Data on program intervention	NA	Available in Excel & Stata
Village	Labor, Prices, cost of farming, Time of crops, Start and receding time of flood water per year (1997-1999). Economic activity, law and order. Food intervention programs and NGO programs	R3_Village	Available in Excel & Stata

Source: Del Ninno, 2001.

Vita

Yan Liang

Yan Liang was born in Shandong, China in 1969. She received a bachelor degree and a master degree in Agricultural Economics from Shandong University of Technology in 1992 and from Chinese Academy of Agricultural Sciences in 1995, respectively. From 1995 to 1998 she worked as an Assistant Research Fellow in the Institute of Agricultural Economics at Chinese Academy of Agricultural Sciences, Beijing, China. From 1998 to 2002 she worked as an Associate Research Fellow in the International Service for National Agricultural Research (ISNAR) at Hague, the Netherlands. She also worked as a consultant for the Food and Agricultural Organization of the United Nations (FAO) from 1996 to 1997 and in 2005. She studied for her doctoral degree and worked as a research assistant at Virginia Polytechnic Institute and State University from 2002 to 2006. Upon receiving her doctoral degree, she plans to work as a Postdoctoral Research Associate in the Department of Agricultural Economics at Mississippi State University. Yan Liang is married to Songming Zhao.