DEVELOPMENT IMPACTS OF RURAL ROAD IMPROVEMENT PROJECTS IN BANGLADESH

by

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STATEMENT BY AUTHOR

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ABSTRACT

The central issue of this thesis is to assess the farm level impacts of rural road improvement projects in Bangladesh. In 1995 CARE International in Bangladesh initiated a household survey implemented under the Food For Work program. This study analyzes the agricultural data from a survey covering 1400 households over a period of three years to study the impact of their road improvements. A system of four-commodity supply functions and three input demand functions are estimated using a two-step procedure. To examine the effect of road improvement, transport cost is embedded in effective price of agricultural commodities and inputs in each equation. The results provide a picture of the positive impact of road improvement on agriculture in Bangladesh. The use of agricultural inputs and resulting outputs goes up as the transport cost goes down because of road improvement. The effect of transport cost on perishable cash crops like potatoes, vegetables and fruit is greater than that of main food crops of rice and wheat. The magnitude of the impact of road improvement on agriculture per household is small as one might expect, because the transport cost is only a small fraction of the product price. However, this small change in production, if aggregated over large number of households a single road serves, might become large.

Chapter 1: Introduction

After emerging as an independent country in 1971, Bangladesh has faced major problems of poverty and hunger. The per capita farmland availability is less than 0.20 acres and the economy is heavily dependent upon agriculture. Bangladesh has suffered two of the world's worst famines once in 1947, the Great Bengal famine, another in 1974 soon after independence. But Bangladesh has fertile land rejuvenated by floodwater each year, abundant water resources and a large, hard-working labor force. Using these resources to overcome the adversities of natural climate, cyclones, draughts and floods, the farmers of Bangladesh have created an economic miracle. From having been considered a development "basket case" Bangladesh is now almost self-sufficient in food grain production, which constitutes 60% of Bangladeshi diet. The nightmare of famine is now history. Contributions to this great success include the agricultural extension activity in 1970s promoting cultivation of high yielding crops, public investment in building flood control and irrigation infrastructure, and favorable agricultural policies for the expanded use of irrigation, fertilizers and pesticides (Dorosh 2000).

The quest for eradicating poverty through revolutionizing agriculture is still ongoing. The success story of *Grameen Bank* and its micro credit program in Bangladesh are well known. The co-operative movement and the agricultural development model developed in 1960s by Bangladesh Agricultural and Rural Development Academy located in *Comilla* has been a popular development model. Various government and non-government organizations (NGOs) conducted many innovative experiments of poverty elimination using food aid. CARE International started the Food For Work (FFW) programs in Bangladesh in mid seventies after the famine in 1974. FFW provides wages in kind (usually in wheat) to rural laborers for earth moving to build roads, flood control embankment and irrigation channels. These programs were operated with dual objectives of generating wage employment and developing rural infrastructure. They targeted low-income people by imposing a heavy work requirement. FFW generated more than 100 million workdays of employment each year, directly benefiting 4 million people in addition to the uses of the rural infrastructure. Nonetheless many potential benefits of FFW were not fully realized due to a high degree of resource leakage (30 to 35%) (Atwood 2000). FFW transferred 1 *taka* to a poor household at a cost of 2.6 *taka* (one dollar was equivalent to 55 *taka* in 2002). Moreover the timing of the project implementation became inappropriate to achieve project objectives. When FFW began in mid seventies, January through March was one of two slack seasons when the rural people sat idle and suffered from hunger. The peak project activities coincided with this hungry part of the year. But in recent time this is no longer true in many areas of the country because of the expansion of irrigation-based agriculture. Thus, the program competes increasingly with the agricultural labor demand. Large-scale distribution of FFW wheat occurs between January and April, after the monsoon rain, when drier weather and soils permit road building. When the FFW began in the mid 1970s, there was almost no domestic production of wheat. Today, however, the major wheat harvest (wheat production still accounts for only about 60% of domestic consumption) occurs in March and April, and distribution of FFW wheat (much of which is resold in the market) significantly depressed farm gate prices at harvest. Moreover, food insecurity continues to be more pronounced during September and October, the program largely fails to address this problem because of the difficulties in undertaking earthwork immediately after the monsoon season.

The development impacts of FFW began to be questioned by the late 1980s. The environmental damage caused by the roads became a matter of increasing concern. Roads impede flooding by obstructing flood water, barricade fish migration by dividing wetland, and use fertile top soil for embankments. There were also increasing concerns of too many rural roads being built. The country has a very extensive road network and the highest density of road to land area in developing countries of Asia: 70.2 kilometer per 100 square kilometer. The total length of roads is 130 thousand kilometers, but only about 10 thousand kilometers are all-weather roads. The rest are candidates for improvement. The need is not to build new roads, which had traditionally been the focus of FFW program, but to develop the existing network.

Table 1.1 Road network in Bangladesh

Road type	Total road length, kilometer	All weather roads, kilometer	Candidate for development, kilometer
National highway	2,539	2,539	
Regional highway	2,670	2,670	
Feeder road type-A	10,008	857	9,151
Feeder road type-B	8,403	1,919	6,484
Rural road type-1	32,674	2,001	30,673
Rural road type-2	44,861	375	44,486
Rural road type-3	29,450	0	0
Total	130,605	10,361	90,794

Source: World Bank 1996

In spite of these growing concerns, the use of food aid resources to fight poverty remains popular. The experience in Bangladesh suggests that rural public employment programs, which effectively target the poor, can simultaneously be well managed to make an effective way to reduce poverty while creating sustainable development. To explore ways to overcome the deficiencies in planning, administrating, and implementing food assisted programs a taskforce known as "Strengthening the Institution for Food Assisted Development (SIFAD)" consisting of government officials and donor agencies was formed in the late eighties. As a result, significant changes were made in the management of food aid resources by the mid nineties. The responsibility of most of the food resources was shifted from the ministry of relief and rehabilitation to various developmentally mandated ministries such as ministry of local government and rural development, ministry of water resources development and irrigation. The donor agencies and their implementing NGO's adjusted their developmental objectives and concentrated resources on proper design and implementation of activities. CARE International in Bangladesh has been a central player, using food aid resources to finance rural road improvements. Bangladesh had one of the world's largest FFW programs, about half of which was supported by USAID and channeled through CARE. As one of the key players of food resources users, CARE reassessed its goals of food aid projects. As opposed to short-term relief and employment generation, the current goal of CARE's food aid program in Bangladesh is to protect and promote household income and community resources and assets in food insecure underdeveloped rural areas by upgrading and sustaining environmentally sound rural roads.

CARE has made substantial changes in design and implementation of the food aid projects. Environmental impact assessments were made mandatory for each road project.

Some types of construction projects were excluded on environmental grounds. Irrigation canals and flood control embankments are examples. These types of projects had long been blamed for draining out wetland, creating water logging, obstructing fish migration, destroying soil fertility etc. CARE’s food aid programs began to focus more narrowly on improving the quality of key rural roads in preference to the more scattered relief-oriented activities of employment generation. The program also intensified the emphasis on sustainability of investment by building technically sound roads and integrating road construction with maintenance programs. The direct consequence of these new approaches was to use more cash money than the payment of wages in the form of food. Technically sophisticated and environmentally sound roads require building cross drainage structures for which financial resources are needed to purchase construction materials and hire qualified contractors.

It is important for food aid donors, implementing agencies such as CARE, and the government of Bangladesh to know if the new approach of food aid resource programming is achieving its renewed objective of sustainable development. Is the new approach really protecting and promoting household income and contributing overall welfare of the household? It is expected that the rural road improvement will make the agricultural inputs more readily and cheaply available to the farmer and facilitate better farm get price of their products. As a result the agricultural production will increase, the farmer will produce more cash crops and the farming will be more profitable. The household income of the farmers will increase, and poverty will ultimately be eradicated.

The objective of this thesis is to examine the responses of Bangladeshi farmers to changes in farm level prices induced by road improvements on the demand of variable inputs and the supply of agricultural outputs. How have reductions in transport cost caused by the road improvements affected the combination of input use and mix of crops produced? The following hypotheses will be examined in this study:

- Reductions of transport cost due to road improvements have increased the use of inputs, which in turn have increased agricultural production and the household incomes.
- Improved access to market has enabled farmers to improve agriculture production patterns; to grow and market higher-valued but more perishable products such as potatoes, vegetables and some cash crop such as fruit.

The rest of the thesis proceeds as follows: chapter 2 provides a brief introduction to Bangladesh and discusses briefly its agriculture. In chapter 3 reviews other research to examine how transport cost is incorporated into the models of agricultural productions in order to assess its effects, and to summarize the results other researchers have found on the impact of road improvements on agriculture. Chapter 4 gives a brief description of eight study sites. Chapter 5 develops the econometric model for the study. It discusses how a profit function has been modified to incorporate transport cost to analyze the effect of road improvements. Chapter 6 discusses the problem related to estimation and how these problems are addressed. Chapter 7 explains the estimated results; chapter 8 made the conclusion and discusses some of the limitation of the study and avenue for future research.

Chapter 2: Background

Bangladesh is the part of the old undivided Bengal that went to Pakistan and came to be known as East Pakistan when India got independence and partitioned in 1947 after 200 years of British rule. The Bengalis of East Pakistan struggled to secure their rightful place in Pakistan. As their efforts were thwarted, a bitter nine-month war of independence culminated in the new independent state the People's Republic of Bangladesh in 1971. Today the country is still struggling, this time to eradicate poverty and hunger. Bangladesh is the eighth most populous country in the world, with a population of almost half that of the US living in an area equal to half of US state of Arizona. It is the most densely populated of all countries having an area of 55,598 square miles (144,000 square kilometers). The population density is 2,212 per square miles (854 per square kilometer). In 1996 the country had an estimated population of 123 million. Almost half of the population is under 15 years. The average life expectancy is low, at 55.5 years, compared to over 70 years for developed countries such as US, Japan, and UK.

Due to the flatness of the land and the heavy monsoons and heavy rains that blow through each year, 6% of the total land area is permanently flooded. Over 118 inches (300 cm) of rain fall annually. The eastern Himalayas to the north of Bangladesh provide a major water supply to the Ganges-Brahmaputra-Meghna river systems that empty into the Bay of Bengal. The rivers bring down the rich alluvial soil that forms the Ganges Delta. The Ganges-Brahmaputra Delta is the largest delta in the world. It is more than twice the size of the Mississippi-Missouri Delta. Up to two-thirds of the land is flooded when heavy monsoon rains fall. During the dry season, the land becomes dry, and drought and consequently famine are major concerns. Farmers anxiously await the first monsoon rains; although coupled with this anticipation is a fear that the rains will be unsatisfactory. If the rains are too light they will be ineffective. If they are too heavy they could destroy the crops.

Agriculture is the most important economic sector in Bangladesh. It accounts for about 30% of the country's GDP and provides employment to two-thirds of the working population. Some 22.5 million acres (9.1 million hectares) of land are under cultivation. Most farms in Bangladesh are small; a quarter of the estimated seven million farms are only one acre (0.4 hectares) or less. Another half is between one and four acres. Most of the small farms are cultivated by the owners and their families and provide for their own food needs. The larger farms produce a surplus that is sold in the markets. Their owners manage the farm and are considered the elite of rural society.

A great variety of crops are produced in Bangladesh such as rice, wheat, jute, tea, fish, pulse, oil seeds, vegetables and spices. A complex cropping pattern and a cropping period with specific local characteristics leads to many land-use systems with specific combinations. A simplified version of the crop calendar is presented in figure 2.1.

Rice dominates the crop production of Bangladesh. Nearly three-quarters of country's crop area is planted to rice. Bangladesh is one of the world's largest producers of rice (Table 2.1). Each year, the country turns green with rice, nurtured by the monsoon rains and

Table 2.1 Rice production, 1995 (million tons)

China	187.334
India	119.442
Indonesia	49.744
Bangladesh	26.399
United states	7.887

flooding rivers. Silt-laden floodwater rejuvenates the soil each year. Each annual cycle can bear three rice crops from rich soil. The environment could not have been more carefully designed a stage for the Green Revolution, with many areas providing opportunities for three rice crops per year. Some rice varieties have evolved to grow in deeply flooded fields; these deepwater plants can grow by as much as fifteen feet. There are three rice cropping seasons that determine the entire cropping calendar: (1) summer rice *aus* that is traditionally planted during the pre-monsoon rains; (2) monsoon rice *aman* which is planted exclusively at the beginning of the monsoon season; and (3) *boro* which is planted in the flooded areas and irrigated during the dry winter season (post-monsoon). Bangladesh achieved impressive gains in rice production in the 1980s and in wheat production in the 1970s through investments in irrigation and flood control infrastructure, which increased fertilizer use and adoption of new seeds, especially in the *boro* season (figure 2.2). Average rice yields rose from 1.2 tons per hectare to 1.82 tons per hectare from early 1970s to the late 1990s. During this period, the area cultivated with HYVs (high yielding variety) rose rapidly, from an average of 15 percent of rice area in 1974-1976 to 51 percent in 1996-1998; at the same time irrigation spread rapidly, increasing from 12 percent to 28 percent of total rice area. By the late 1990s, 91% of *boro* area (winter rice) was irrigated, and 92% was cultivated with HYVs, as *boro's* share in rice production rose from 19% in the early 1970s to 41% in 1996-1998. The increase in average yield reflects a switch from local varieties to HYVs, mostly from local *aus* and *boro* (average yield 0.87 tons per hectare) to HYV *boro* rice (average yield 2.73 tons per hectare); and some from local to modern varieties in the *aman* season, which is the main rice-cropping season. Wheat production expanded considerably during the 1970s, from 100,000 metric tons per year at independence to more than 1 million per year through most of the 1980s. Thus, in the early 1990s Bangladesh seems to be approaching self-sufficiency in grain, with domestic production of food grain (rice and wheat) accounts for 93% of national food grain consumption. This has been a dramatic turnaround within a quarter of a century after facing a major famine in 1974.

Bangladesh's average yield of 1.77 tons per hectare (equivalent to 2.64 tons of paddy) is still low compared with Asian paddy yield of 4 tons per hectare in Indonesia and 5 to 6 tons in China and Korea. Average yield during the *boro* season, however, during which 90% of the rice area is planted with modern varieties, are 2.73 tons per hectare (4 tons of paddy). This suggests that Bangladesh could achieve full potential by promoting especially *boro* cultivation. This requires investing in irrigation, water control and improved roadway communication.

In spite of the dominance of rice in agricultural production, farmers in Bangladesh grow a wide variety of crops such as pulse crops, oil seeds, cash crops such as jute and sugar cane, vegetables and spices (figure 2.3).

Wheat is consistently gaining importance and is the second most important cereal following rice. There are traditional local varieties and adapted high-yielding varieties. The tremendous growth in wheat production can be traced to the increasing utilization of improved seed sown on larger areas and based on a growing attractiveness of baked wheat products in the regular diet. As mentioned earlier wheat production expanded considerably during the 1970s, from 100,000 metric tons per year in 1971 to more than 1 million per year through most of the 1980s.

Jute has traditionally been the main cash crop. Bangladesh is the world's largest exporter of jute. It makes up three-fourths of the world production. Jute fiber for sacks and carpets has historically been the region's key money earner. However, the world price of jute has nearly halved since the early 1970s because of the popularity of synthetic material as a substitute of jute, and there has been great price fluctuation in the world market. As a result, jute has been grown less and less; it is grown on only 7 percent of the land. Tea is another important cash crop. Bangladesh is the world's fifth largest exporter of tea. Other crops include cotton, sugar cane, tobacco and betel nuts and leaves (*pan*).

Pulse crops are an important source of protein. There have been decreases in the average per capita availability of pulses. This could possibly be explained by the increasing cultivation of winter season *boro* rice and wheat that were otherwise used for growing pulses. Oil seed include varieties for producing edible oil. The domestic demand does not meet by domestic production. The proportion of imported oil is high.

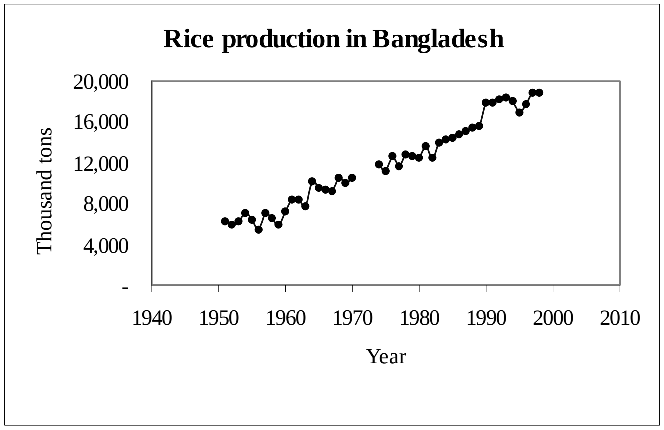
Vegetables include a very large number of cabbage varieties, roots and tubers, tree crops, green vegetables, tomatoes, onion, garlic, pepper pods (Chili), spices include coriander, anise, cumin, turmeric and ginger. These are grown in great quantity.

In many areas in Bangladesh, potato is one of the most important winter crops. Of the total area under potato about two-third is now under modern varieties, with yield that can be twice as much as those of local varieties. The production of modern variety of potato for domestic consumption is highly profitable and it has great export potential. Government encourages private enterprises to build cold storage facilities for potatoes.

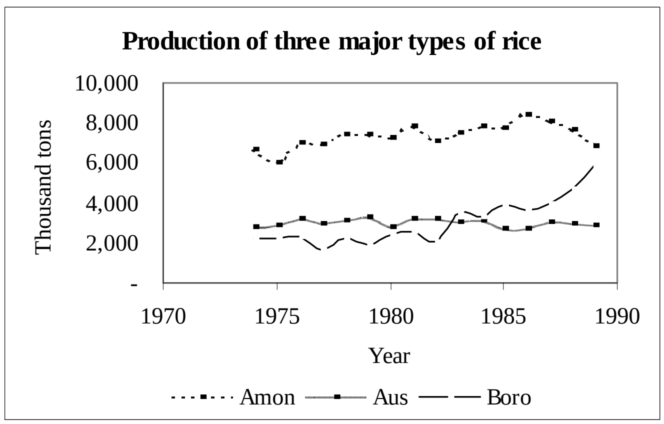
Crops	January	February	March	April	May	June	July	August	September	October	November	December
Transplanted *aus*			< ---	----------	----------	----------	--------->					
Broadcast *aus* rice			< ---	----------	----------	----------	--------->					
Transplanted *aman*						< ---	----------	----------	----------	----------	--->	
Broadcast *aman*			< ---	----------	----------	----------	----------	----------	----------	----------	>	
Boro (local variety)	----------	----------	----------	--->							< ---	----------
Boro (HYV)	----------	----------	----------	--->							< ---	----------
Wheat	----------	----------	--->								< ------	----------
Winter vegetable	----------	--->							< ------	----------	----------	----------
Summer Vegetable				< ---	----------	----------	----------	--->				
Jute			<	----------	----------	----------	----------	----------	------>			
Potato	--->								< ---	----------	----------	----------
Mustard	--->								< ---	----------	----------	----------
Pulse	----------	----------	----------	--->					< ---	----------	----------	----------
Corn (vutta)	< ----	----------	----------	--->					< ---	----------	----------	--->
Sweet potato	----------	--->							< ---	----------	----------	----------
Cotton	----------	>		< ---	----------	----------	----------	------< ---	----------	---> ----	----------	----------
Sugarcane	--->									< ---	----------	----------
Tobacco	----------	--->								< ---	----------	----------
Garlic	----------	>								< ---	----------	----------
Onion	--->										< ---	----------

Source: IUCN 1999

Figure 2.1 Crop calendar of Bangladesh



Data Source: Hossain, 1988, Graphic Illustration by Author



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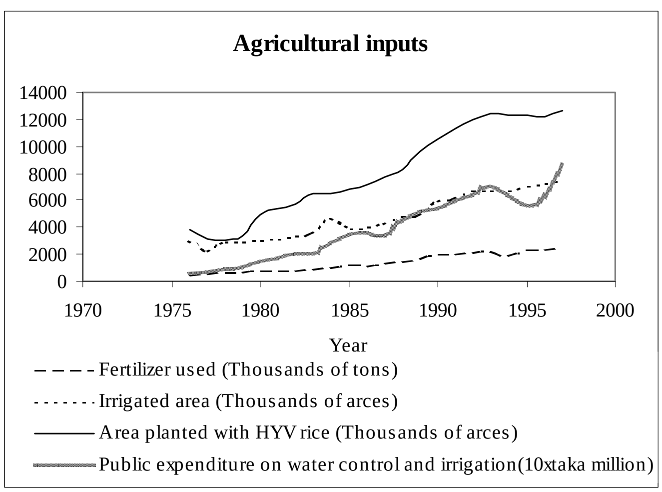
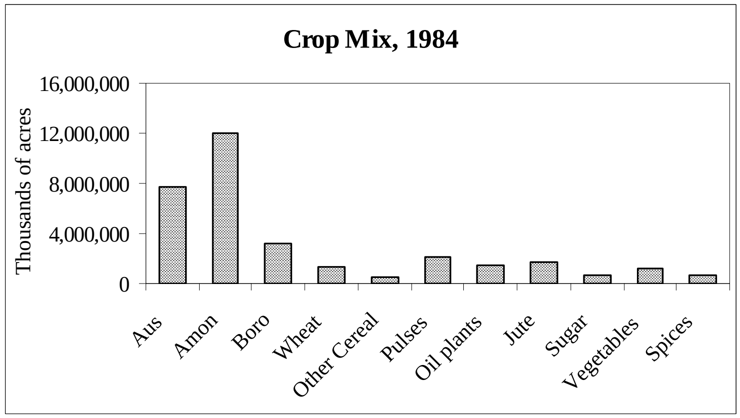
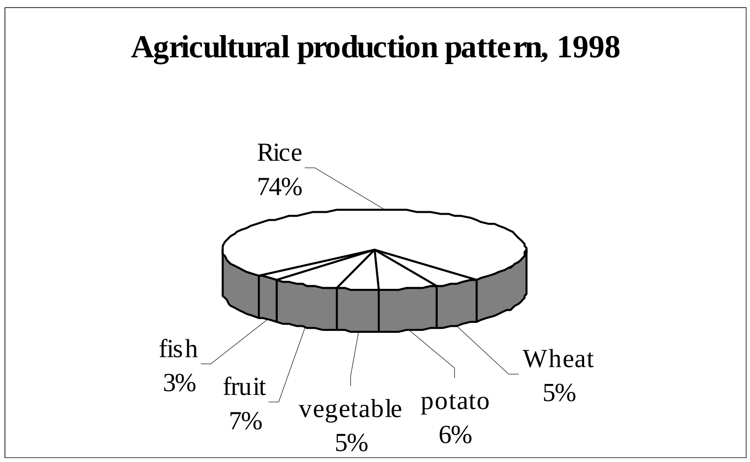


Data Source: Dorosh 2000, Graphic Illustration by Author

Figure 2.2 Rice productions in Bangladesh over time



Data Source: BBS 1986, Graphic Illustration by Author



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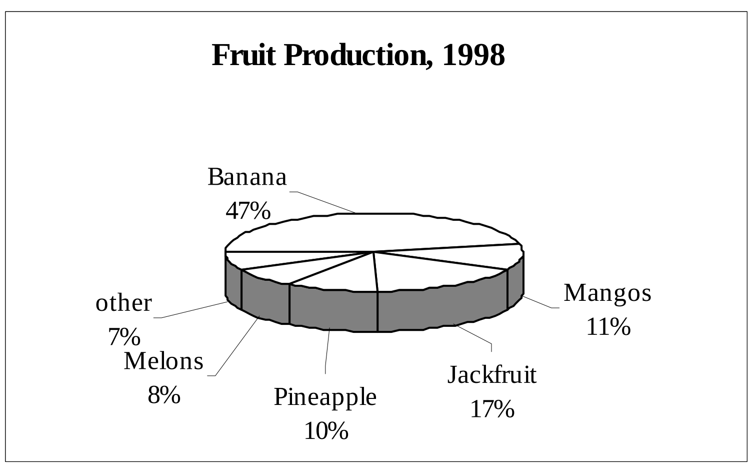
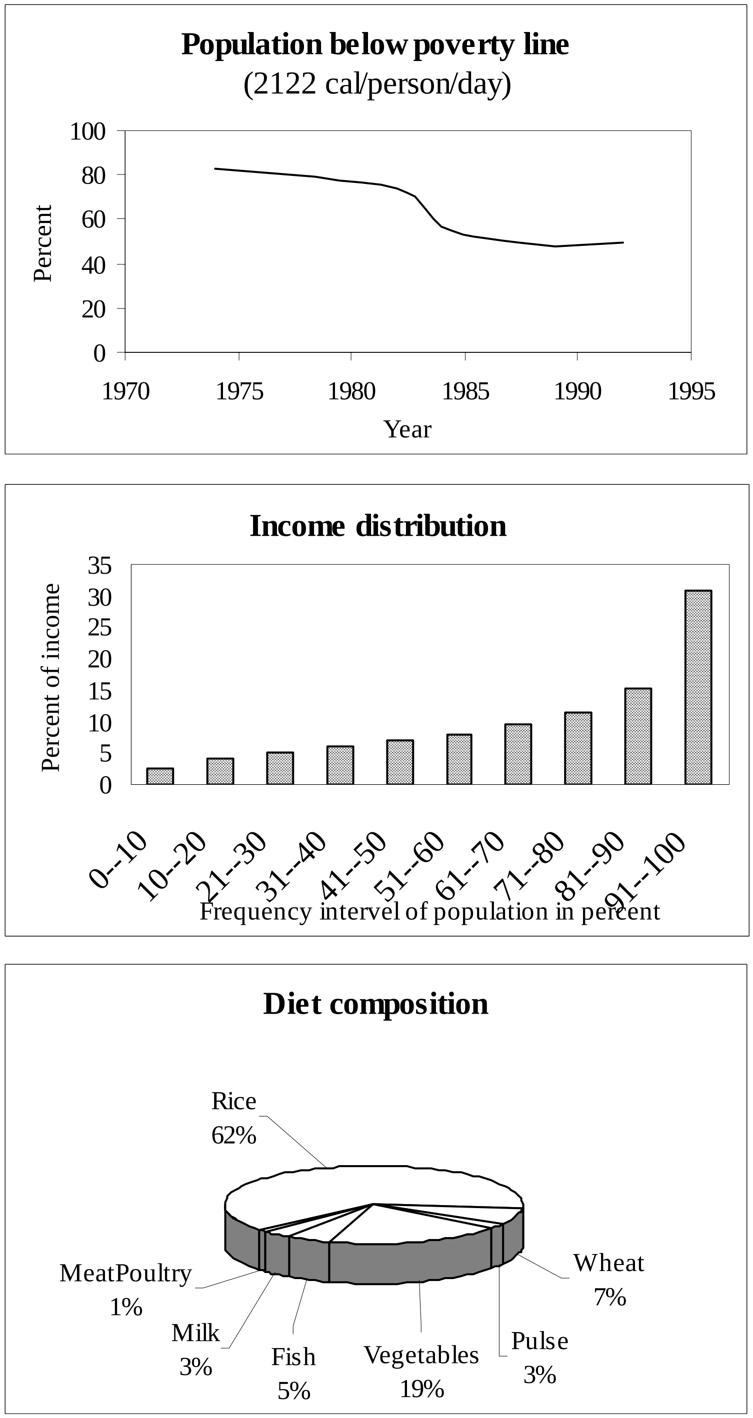


Data Source: Dietmar 1994, Graphic Illustration by Author

Figure 2.3 Cropping pattern in Bangladesh



Data Source: BBS 1991, Graphic Illustration by Author

Figure 2.4 Poverty situation in Bangladesh

Chapter 3: Literature Review

The literature selected for review in this chapter addresses two overall objectives. The first is to review various economic models that have been developed to identify and assess the impacts of road improvements. First, some market-level models are reviewed to understand the effect of road infrastructure on the economy in general. Then, household level models that incorporate transportation cost are discussed. The second objective is to review the empirical results from other research on the impact of road improvement on agriculture of developing economy. Some studies that specifically study the agriculture and road development in Bangladesh are included. This is a basis to develop refutable hypothesis for the current study.

Cost-benefit analysis has been widely used to assess the impacts of road improvements. Since roads are largely non-rival public goods, road access typically does

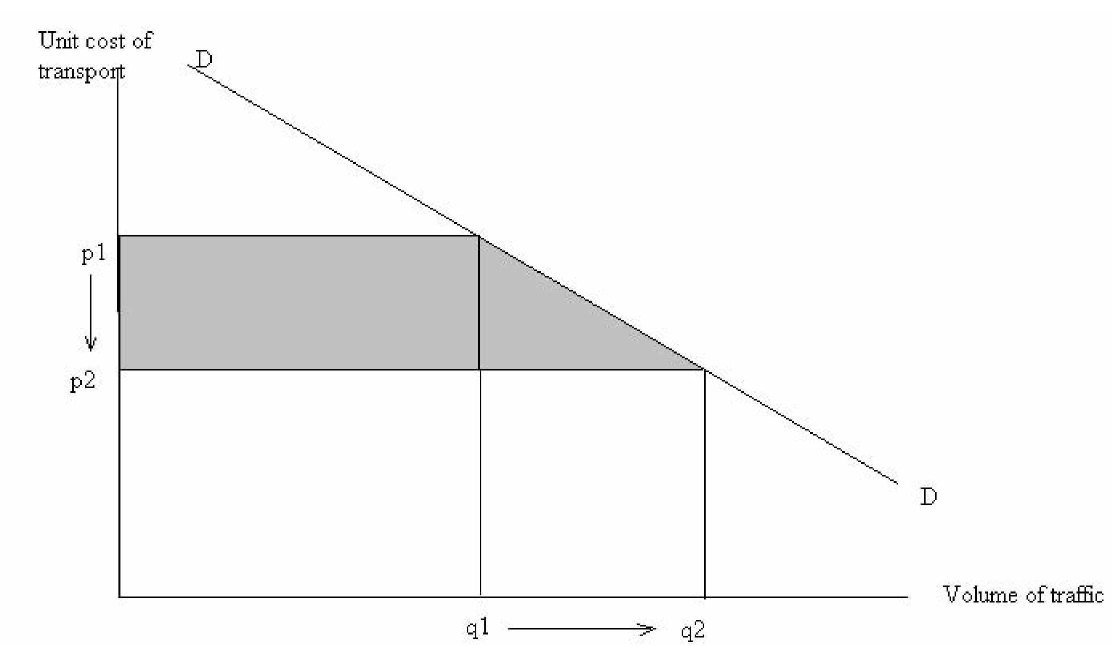


Figure 3.1 Consumers surplus from road improvement

not have a market price. Microeconomic cost-benefit analysis has employed the concept of consumer surplus gained from reduction of transport cost and increase of travel demand due to the improvement of the road, which induce saving of cost and time by the road user. This “user cost saving” measures benefits of investment in road development. The approach to estimate user cost savings as a measure of benefits (the shaded area) from a road project is shown in figure 3.1.

Using this method the average economic rate of return of road improvement projects are estimated as 29 percent by World Bank. Rates of that order might be described as adequate, but not exceptional. This approach is likely to miss important induced benefits of infrastructure. Transportation infrastructure may have a profound impact on the extent of the market and the ability of producers to exploit economics of scale and specialization. Widening the market then brings benefits in terms of increased competition in market. Transportation infrastructure also allows greater dissemination of knowledge and technology.

Boyer and Longman (1998) explained the link between transport cost and economics of scale and specialization. They pointed out the fact that trade between two regions does not stop, even if each location grow its own rice, vegetables, and catches its own fish. There will still be demand for transportation in the long run even if every place has identical resources. The reason can be found in the technology of production. For almost all goods and services that an economy produces, on a per unit basis, it is more expensive to operate at a very small production level. If the producer expands the market area and increases production, average production costs decline due to scale economies in production. As production expands, customers for those goods must be found at locations further and further from the production point and thus higher per unit transportation costs. The optimal size of operation will be found when the advantages in expanding scale to get lower production costs is counterbalanced by the increased costs of transporting goods longer distances. The trade-off between production scale economies and transportation costs diseconomies is shown in figure 3.2. In the absence of transportation cost it is optimal for a production unit to operate at x_2 because of the lowest production cost. The transport cost drug the optimal production level down to x_1. At this level the delivery cost, which is the combination of production cost and transport cost, is the lowest. It is possible to operate close to x1, where the production cost is lowest, if the unit transport cost can sufficiently be reduced.

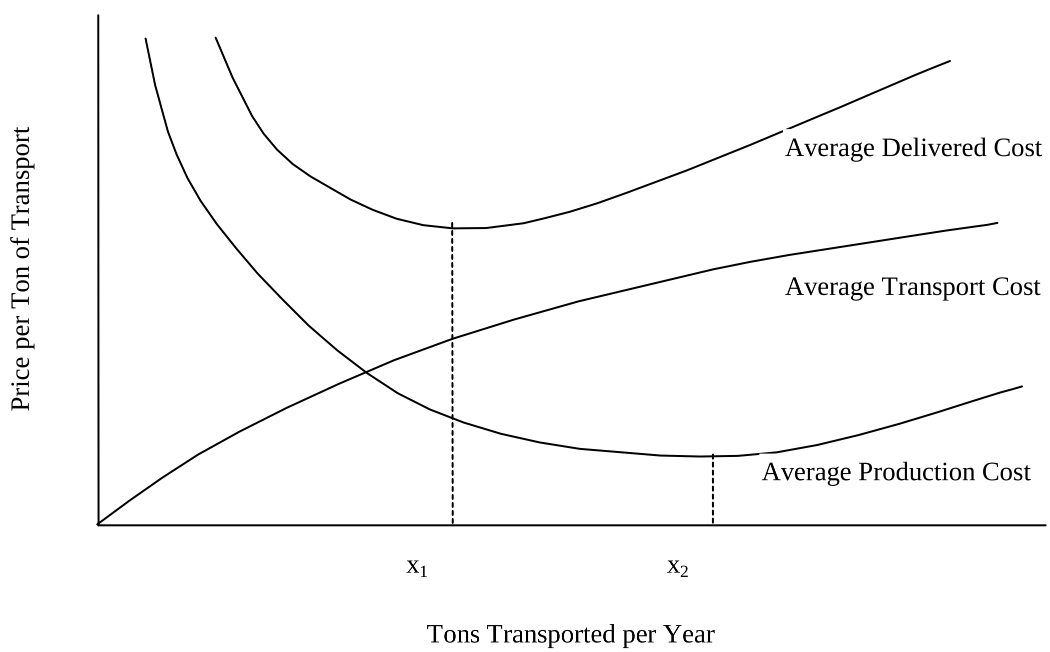


Figure 3.2 Transportation and economics of scale

The country as a whole can increase its standard of living if regions specialize, producing only a limited number of commodities using sufficiently large size of farm to have low production costs, and then trade with other regions for those goods and services that they do not produce. Thus, investment in public infrastructures like transportation facilities have a very high payoff - presumably through the mechanism of allowing greater regional specialization and taking greater advantages of production scale economies.

On the other hand, lower transportation cost will also increase consumer's choice. If transportation is expensive, scale economies will generally dictate that each region be served by a single inefficient small company, acting like a monopoly, leaving consumer without a choice. Consumers possibly will have to pay monopolist price in that case. With low cost of transportation, consumer can choose between suppliers in different locations. The encouragement to the economy that derives from the competition encouraged by improvements in transportation is a benefit that is hard to quantify.

By adopting a macroeconomic approach and using econometric techniques David Canning and Esra Bennathan (1999) eliminated the limitations of microeconomic cost benefit analysis through estimating the social rates of return to infrastructure development by looking at their effect on aggregate output and comparing these to their cost of construction. To find the benefit of infrastructure an aggregate production function of the following type is estimated

$$y = f(k, h, x) + \varepsilon$$

Here, the dependent variable y is aggregate output per worker, k, h and x explanatory variables represent per worker inputs of physical capital, human capital and infrastructure capital respectively, ε is a random error term. Note that infrastructure is included in the model as a factor of production.

The purchasing power parity GDP per worker is used as a measure of output per worker. Human capital per worker is measured by the average years of schooling of the workforce. The two infrastructure variables used are the length of paved roads and kilowatts of electricity generating capacity. The production function is estimated for a panel of about 100 countries using data over the 40 years. The elasticity of output (e_x) with respect to infrastructure is estimated by holding physical capital and human capital constant. From this elasticity the marginal product of a unit of infrastructure capital is estimated by using $MP_x = e_x \frac{y}{x}$. This marginal product measures the output effect of an extra kilometer of paved road. To find the rates of return in terms of internal rate of return (IRR), this benefit is compared with the cost of extra kilometer of paved road construction. The finding indicates that infrastructure investment is not sufficient by itself to induce large changes in output. It has to be coupled with higher level of physical and human capital. Infrastructure can increase productivity of investment in those other types of capital.

Takayama and Judge (1970) modeled the interactions of transport cost with supply, demand, prices of commodity and quantity of trade in the context of spatially separated markets. To illustrate their model, suppose two regions trade a single good. The regions are separated but not isolated by a transportation cost per unit. Profit-seeking traders are free to trade in each region. A picture of the formulation for the one product two region case is shown in the figure 3.3. In the figure D_1, D_2, S_1, S_2 are the regional demand and supply functions, and $p`_1$ and $p`_2$ are the competitive equilibrium prices when there is no trade between the regions. Product from supply region moves to demand region when trade is allowed to take place. The price in the demand region falls and the price in the supply region rises. The resulting new equilibrium prices of two regions are p_1 and p_2. The difference between this new equilibrium prices is t_{12}, which is the transportation cost per unit between regions 1 and 2. The consumer in the demand region is benefited because of the fall of price and the producer of supply region is also benefited because of the price rise. The consumer in the supply region is adversely affected. However, there is a net gain in aggregate welfare, referred to as net social payoff. In this figure net social payoff is the area ABC when the transportation cost is excluded. When the transport cost incorporated into the model the net social payoff becomes the area ABC minus the rectangular area. At the competitive equilibrium prices p_1, p_2 and the equilibrium flow q_1=q_2 from region 2 to 1 the net social payoff is the maximum.

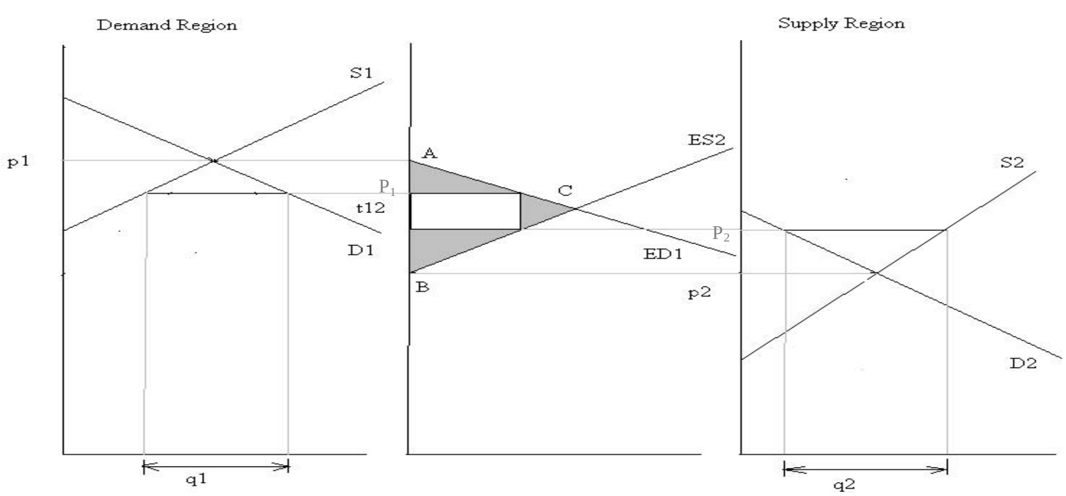


Figure 3.3 Net social payoffs from trading and transport cost

In this setting, the effects of road improvement in rural economy can be studied. For agricultural outputs, the rural areas are represented as region 2, the supply region, and for manufactured agricultural inputs such as fertilizer, pesticides and seeds, rural areas are represented as region 1, the demand region. Reduction in transport cost due to road improvement can affect the following:

- Increase the prices of agricultural output in supply regions: Farmers in rural areas get better prices for their products and consumers in the demand region (city and towns) also benefit because of decrease in price. However, the consumers in the villages of supply region face higher prices. Nonetheless, the net social payoff is increased.
- The prices of agricultural inputs decrease in rural areas: As a result, the use of agricultural inputs increases. This in turn affects the agricultural production favorably in the supply region.
- Trade of both inputs and outputs expand.

Omamo (1998) modeled the household behavior of semi-commercial farm-household produces multiple crops using multiple inputs with some fixed endowments. He incorporated transport cost into the household model. The household was modeled as a utility maximizer subject to production, consumption and trading decisions.

The problem was set up in the following model:

$$\max_{c,q,b,s} U(c,z),$$

subject to

budget constraint: $$\sum_i \left[p_i c_i + d_i b_i \right] \leq \sum_i \left[p_i (q_i + e_i) - d_i s_i \right],$$

quantity balance equation: $c_i \leq q_i + b_i - s_i$.

production function: $G(q_i, z) \geq 0$

where, q_i is farm output ($q_i > 0$), or factor used in production ($q_i < 0$), c_i consumption of i^{th} commodity, b_i purchase of i^{th} commodity, s_i sell of i^{th} commodity, e_i household endowment, z household characteristics. p_i is the market price of i^{th} output/input, which is exogenously given, and d_i unit transport cost, also exogenously given. He solved the optimization problem in a quadratic programming setting.

Omamo found that the higher transport cost caused by poor communication networks in rural area influenced the cropping choice. When a household is a net buyer of a staple, they avoid buying it from the market to avoid high transport cost, and produce larger quantity of this item for their own consumption. Conversely, high transport costs imply reduced production of goods for which a household is a net seller - e.g. most cash crops. He found that "…the seemingly inefficient food dominated cropping pattern on smallholder farms in Kenya are optimal responses to a market condition where the transport cost is high".

Ahmed and Hossain (1990) studied the impact of infrastructure on agriculture in Bangladesh. They use infrastructure in general term, not restricted to road infrastructure only. To determine the level of infrastructure, the authors used a composite index based on distance from the village to different elements of infrastructure, the principal means of transport, and the cost per mile of travel. The elements are primary market, secondary market, primary school, secondary school, college, post office, *thana* headquarter, bus stop, rail station, bank, and union council office. Some of the findings of this study are summarized below:

- ❒ The price of fertilizer is about 14 percent lower and the wage rate is 12 percent higher in villages that have developed infrastructures. The price of rice is about 6 percent higher in developed villages.
- ❒ The price elasticity of demand of fertilizer is –0.55. Since this input is highly price responsive, and the infrastructure affects prices, it is apparent that infrastructure has an effect on fertilizer use.
- ❒ Infrastructure affects production through its impact on the adoption of HYV. The availability of irrigation facilities is significantly correlated with the adoption of HYV. Due to the difference in the availability of irrigation, HYV adoption is much higher in the developed villages.
- ❒ The difference in fertilizer use is substantial – 92 percent higher in developed villages than in underdeveloped. Lower fertilizer prices account for 12 percent of the difference, and higher rate of adoption of HYV account for 64 percent.

Langworthy (1995) developed a conceptual model of impact of road improvement on household welfare. His model is summarized in figure 3.4.

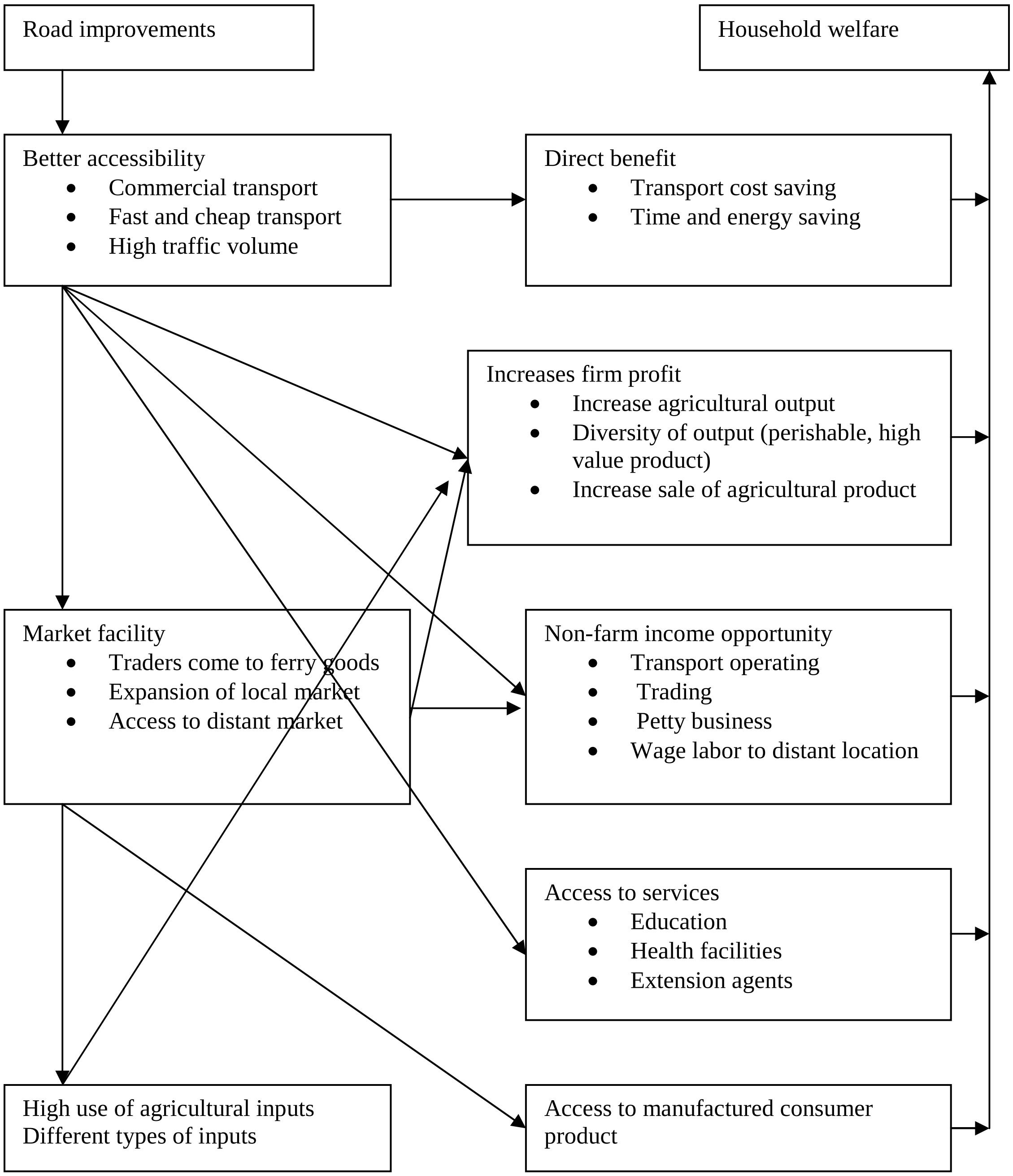


Figure 3.4 Road improvements and household welfare

Chapter 4: Description of the Study Areas

The majority of rural roads in Bangladesh were built under FFW programs in the seventies and early eighties. Between 1994 to 1999, a total of 12,000 kilometers of rural roads were improved by CARE through its Integrated Food For Development (IFFD) Project, in 47 out of 64 districts of the country. The IFFD project developed rural roads that connect small markets and farms to broader road networks. The road improvements included bridging gaps with small concrete structures, raising and compacting earthwork embankments where needed, turfing and planting trees on the road slope for better stability. Eight roads improved by the IFFD project constitute the study areas of the survey which provided the data for the research presented in this thesis. The traffic and freight movement increased substantially on roads improved by the project. The number of daily road users increased from 280 to 390 along an average of five-kilometer stretch of road after improvements. The freight movement increased from 140 tons per day to 215 tons per day. The passenger transport cost reduced by 25%, and freight transport cost by 40% (Mustafa 1998). If the roads are maintained properly the benefit is expected to flow over twenty years.

A brief description of the surroundings of eight study roads located in different parts of the country is given below. The agricultural activities, communication system, and overall change before and after the road improvements are described here. The information is based on author's field trip to the study area during data collection period and CARE conducted qualitative impact assessment report, Coelho (1999).

Ghior

The *Ghior* road is 4.50 kilometers in length, connecting six villages with a large market center. Before the road improvement, the villages were virtually isolated. Foot traffic and horse carts were the only modes of transport during dry season and boat traffic during rainy season. After road improvements, more efficient transport modes such as three-wheeler rickshaws and even some motorized vehicles started plying along the roads. A river passes through the study villages which floods almost every year, making agricultural production risky in rainy season. Like most other parts of Bangladesh, the dominant winter crop in the locality is the high yielding variety of rice, which is grown during January through March. Some farmers grow wheat at the same time. Next to rice, potato is cultivated widely in the study area during October through December. Many farmers grow potato in a second season from January through March. Oil seeds, chilies, lentils and vegetables are also popular in this area throughout the winter season. Poorer households often supplement their incomes from agricultural sources by off farm activities. Off farm income is also a source of working capital for agricultural production, especially at the beginning of the winter season. The most popular off farm sources of income are agricultural wage, petty business, and transport operating.

Debidwar

This 13.5 kilometer earthen road starts from a major highway. It passes through several remote villages and low-lying *bill* (vast natural depression) area. It connects two bigger village markets, one located at the head end and other at the tail end. It also connects two more small markets along its way. Before improvements, it was very difficult even for foot traffic to use the road because there were several un-bridged gaps created by small canals. After the widening of the road and bridging the gaps, the road became busy; bicycle, three wheeler rickshaw, motorized vehicles began to ferry people and goods from one end to the other.

The villages at the tail end used to be very remote and surrounded by vast areas of low-lying farmland. Farmers here grow mostly rice in both dry and rainy seasons. Potato is the next most widely cultivated crop in the winter season. Farmers at the head end of the road, which is connected to better infrastructure facilities, grow more potato than the farmers at the tail end of the road because of their advantage in higher land elevation. The rainy season jute cultivation has been declining in recent years because of the uncertainty of price. The Jute market is very volatile in Bangladesh in general. Mustard, oilseeds and vegetables are some of the minor winter crops. Pulses used to be a major winter crop but these have given away to wheat because of higher yield and better prices. The use of irrigation and HYV crops has increased a lot in recent years. Taking advantage of the new road, traders make fertilizer widely available at a cheaper price to farmers. Traders go to the remote villages to buy potatoes, wheat, and rice in bulk from the homestead of the farmer and offer good prices. This commercial service was not common before the road was improved. A new cluster of shops emerge in the middle of the road making consumer goods and agricultural inputs more available.

Mohanganj

This is a 3.5 kilometer earthen road that connects several villages with administrative headquarters of the region, which is also a big market center. The road runs through a very low-lying area that is regularly inundated during the rainy season. A canal runs parallel to the road, connecting the villages at the tail end of the road to the market center. This canal remains navigable for a part of the year. Another connection of the same tail end villages to the market center is a paved road, which is little bit longer but more convenient.

Major changes in agricultural production took place in this area 8-10 years ago with the adoption of high yielding farming technology. The improved roads help farming by making it easier to buy agricultural inputs and sell surplus agricultural output at the main market. The cropping pattern has shifted over time from jute, *aman* rice and mustard, towards more HYV *boro* rice, potato and vegetables, mainly because of the higher return from these crops. The traditional method ploughing and fertilizing with cow dung and water hyacinth still exist. They still irrigate using tree trunk as they did 10 years ago.

Many inhabitants living along the road are fisherman. They catch fish in the nearby rivers, canals and *haor* (vast natural depression flooded most part of the year). Road improvements bring convenience, speed and lower cost of transporting their catch to the cold storage for preserving.

Dacope

This 8 kilometer road connects four villages with a small town, which is also an administrative headquarters and the biggest marketplace in the region. This region lies within the estuarine delta region bordering *Sundarban*, the biggest mangrove forest in the country, and is edged by numerous streams and rivers flowing down into the Bay of Bengal. A high fertile silt plain, with heavy clayey soil, the area has a rich and versatile agricultural potential where fruit tree such as banana and papaya grow as well as rice and vegetables.

Ten years ago the area produced mainly rice and jute, but now the main economic activity is the cultivation of shrimp and some crabs. The activity began in 1993. Subsequently, local farmers have completely given up HYV *boro* cultivation and switched to shrimp, alternating with *amon* rice. The cash income from shrimp cultivation is huge. Shrimp cultivation needs a high level of inputs. The land has to be prepared with the help of a tractor; large quantities of fertilizer are applied. Shrimp cultivation requires flooding the field with saline water for six months a year from February to July or August. Monsoon rain in July or August flush out the salinity, *amon* rice is planted. Adoption of shrimp replace HYV *boro* production which cannot tolerate the level of salinity that shrimp cultivation bring to the soil. The yield of *amon* also declines due to the salinity. Many other crops have also started disappearing from the area, such as sesame and various types of vegetables. All vegetables have to be purchased from the markets that come from neighboring areas. Potatoes can only be grown in the homestead.

Kachua

This 6.5 kilometer earthen road connects several villages with the administrative headquarters and trade center of this region. Before the improvements of the road, boat and foot traffic were the only modes of transport. Several canals criss-cross this area, making the road discontinuous. All kinds of transport can now ply along the road during the dry season after bridging those gaps and widening the road surface. In the rainy season the road becomes difficult to use even for the foot traffic because of the sticky, clayey surface of the road. People still use the small markets located along the length of the road for daily groceries especially during the rainy season.

The major crops grown here are rice, banana and betel nut, along with some jute and mustard. There has been some major change in cropping patterns in this area. Banana production has increased in recent times, replacing jute and vegetable. There has been some shift towards HYV *boro* rice. Road improvements seem to have induced some of the changes. Farmers now use more fertilizer and purchase seeds, which are now convenient and cheap to carry. The sale of the agricultural products has increased. Now traders buy goods from farmer's homesteads and offer better prices because of the reduced transport cost facilitated by the improved road. There has been some shrimp cultivation in this area, but not much.

Ulipur

This 5.35 kilometer earthen road connects villages to a trade center located at the tail end of the road and with a paved road leading to the administrative headquarters and trade center located several kilometers away from the head end. The road used to be narrow and sandy with several small gaps, making it impossible for vehicles to travel smoothly.

Major crops in this region are HYV *boro* and *aman* rice, wheat and jute, along with some seasonal crops such as onion, garlic and potato. Modern techniques of farming such as power tilling, chemical fertilizer and HYV seeds, have brought substantial increases in production and a general rise in incomes in recent years. However, it has been reported that although overall production increased because more land was brought under HYV rice production, the yield is diminishing with more pressure on the land. Jute production has decreased in favor of rice. The use of small-scale irrigation with shallow tube wells is widespread in this area.

Gopalpur-1

This 5.1 kilometer road starts from a paved road and ends at another paved road connecting a number of villages and small markets to larger markets and administrative headquarters. Before improving the road, there were several major gaps on the road, forcing villagers to travel along longer and less easily traveled paths. Now people can move easily to a distant market very quickly to sell their agricultural product and get better prices. Small producers have benefited from selling of their product to traders who now can offer higher prices as a result of the reduction of transport cost. The small markets located near the middle of the road have grown bigger by taking advantage of improved communication. As opposed to *Katchua*, *Mohanganj* and *Dacope* the road works better in rainy seasons than in dry seasons because of its sandy surface.

The improved road has brought enormous changes in agricultural production and marketing. Because of the proximity of this area to the main market of the region and the improved communication, farmers grow different kinds of fruit, potato and HYV *boro* rice. This area is famous for the production of pineapple, guava and jackfruit. Farmers also grow mustard and vegetables mostly for sale to the market, some for home consumption. Many farmers use shallow tube wells for irrigation. The use of fertilizer has also increased. Labor become short supply in pick agriculture season during HYV *boro* rice cultivation. Like other areas in Bangladesh the production of jute has greatly reduced in quantity because of shrinking export demand and resulting price uncertainty.

Gopalpur-2

This 8.5-kilometer road is not as busy as the *gopalpur-1* road because of the existence of better alternative paved road to big markets and administrative center. This road connects small villages and farmland to the local markets. This road also remains accessible during the rainy season. Farmers in this area produce rice, potato, mustard and vegetable. Homestead sale of rice is common; it saves transport cost and payment of market toll. Numerous traders come to this area in all seasons, especially during the rice and potato season. Before the road was improved, only jute was sold at the homestead during the rainy season, traders used to carry goods by boat.

Chapter 5: Econometric Model

This chapter discusses the model used to examine the factors which affect how farmers in rural Bangladesh sell their agricultural outputs, buy inputs and choose market locations for making transactions. It specifically incorporates the transportation cost as a factor in these decisions. The kinds of data required and the types of manipulation of data necessary for the analysis are also discussed.

Rural households face a large number of geographic locations where they may undertake market transactions, each with its own specific market price relevant for the household. Farmers may exchange their commodity at the homestead to a trader who operates door to door, or they may sell the crop and buy inputs in local small market close to the farmers homestead, or in a larger market located farther away. The prices offered to the farmer in these locations are generally different. This is because of the different transport costs faced by the traders at different locations. Farmers can choose which price to take based on two things, the prices offered in different market places and the proximity of his household from those markets. The farmer may chose to sell his crop in the small local market where the prices offered is not so favorable compared to the prices offered at a distant, larger market, to avoid greater transportation cost (including time cost). The farmer may be indifferent between taking lower prices from a local market at a lower transport cost (time cost included) and taking higher prices from a big market at a higher transport cost. Farmers may trade between market price and transport cost at different locations, but the net prices he receives or pays are assumed to be the same in all market locations. This conclusion is true when a spatial equilibrium among markets obtains. Given the intense competition among petty businessmen and small traders in rural Bangladesh, this assumption is plausible. In this situation the price of inputs and outputs prevail in any market location and the corresponding unit transportation cost can be chosen as the "reference price" for the purpose of analysis. In this study the price prevailing in the main market of the locality and the unit transport cost to get to that market is chosen as the set of "reference price." Note that "reference price" set is an artificial construct. The household does not necessarily exchange at the location of this reference price, but actual net prices are assumed equivalent to this calculated price. Majority of the households under survey bought or sold agricultural inputs or outputs at the homestead from *ferrywala*. Since households do not incur transportation cost for this kind of transaction, analyzing effect of transport cost is not possible using prices from homestead exchange, although it is the primary mode of transaction. Introduction of artificial "reference price" is necessary. In order to establish consistent set of "reference prices" and corresponding transport cost, the approach is to identify the main market for each study area and use the prices of inputs/outputs that prevail in that market. The "main market" is the market where farmers went most frequently for transacting their commodity. This is identified from the data by observing the highest frequency of transactions that took place out of all market locations on each road. For six out of eight study areas two different markets are identified as the main markets, one for tail-end household and one for head-end household. More detail on market choice is shown in table 5.1. For two roads the main markets of tail end and head-end household is the same.

The main markets are generally the same for transacting different commodities such as rice, wheat, jute, fertilizer etc. Its status, as main market also remains unchanged over different years although the relative importance may have changed. The location of main market place generally agrees with the direct response of the respondent when they were asked which market they used most frequently.

The average of each agricultural output and input at the main market is used for the reference price calculation. The price of that market where most of the transactions took place is chosen. See Appendix-B for more detail.

Table 5.1 Location of the main market

Road name	For head end household	For tail end household
Debidwar	Head end	Tail end
Gopalpur-1	Off road	Mid road
Dacope	Head end	Off road
Ulipur	Head end	Tail end
Mohanganj	Head end	Head end
Ghior	Head end	Tail end
Kachua	Head end	Off road
Gopalpur-2	Off road	Off road

Household information on purchases and sales of agricultural products was collected every two months. The information includes transport cost and travel time per trip from each household to different market locations, the mode of transport used including foot, the number of trips each household made and the quantity sold within two months period. Using this data the transport cost can be estimated as follows:

Transport cost in *taka* per kilogram per kilometre = {Money cost of transport per trip to the main market + Time cost of transport per trip to the main market} ÷ {Quantity sold in the main market since last interview

÷ Total number of trips to the main market since last interview} ÷ Distance from homestead to the main market

The problem of using the above formula is that the survey data set does not include distance from each homestead to the main market. Distance information is only available from homestead to nearest paved road. There is no problem when the main market is located on the intersection of paved road, and this is the case for head end households of Debidwar, Dacope, Ghior and Kachua. For other locations the distance to the market centre must be estimated by converting the travel time on foot from homestead to main market into kilometre of distance. The conversion is accomplished by using the relationship between travel time by foot (T, in minutes) and distance (D, in kilometres), $D = 0.15 + 0.0578 * T$. This relationship is first established by regressing the travel time by foot with distance to paved road. The assumption is that the average speed of waking is same for all households.

Time cost of transport per trip to the main market is determined by multiplying time spent on transporting by the wage rate and then dividing in half to account for unemployment. It is assumed that a farmer could use half of the time spent on transporting on wage earning activities.

It is assumed that the unit transport cost is same for all types of agricultural outputs and inputs. This study deals with mostly rice, wheat, potato and chemical fertilizer; with a smaller number of observations of fish, vegetables and fruits. Assuming the same unit transport cost for all these commodities is reasonable. There are some bulky products, such as jute, for which the unit transport cost is different, but the proportion of these bulky products in total goods transported is not significant. So the use of a flat unit transport cost for all commodities should not deviate our analysis too much.

The set of reference prices of commodities are the average prices prevailing in the main market. These are same for all households in a particular locality. The unit transport cost is the cost to get to the main market from each household. It includes the money cost paid for commercial transport services and the cost of time spent evaluated by the wage rate. The unit transport cost varies as the distance to the main market from the household varies. It is unique for a particular household. The effective prices are the prices the farmer really receive for his outputs or pay for his inputs after subtracting (for output) or adding (for input) the transport cost he faces for making the transactions. For calculation purposes the reference prices of the main market is used for all households whether or not they actually transacted at those market. The uniqueness of transport cost makes the effective prices of commodities unique even the prices in the main market are the same for households in a particular region.

Not only the farm level prices of agricultural inputs and outputs that were bought or sold and the corresponding transport costs are needed for the analysis to perform, but also the quantity of agricultural inputs used and the quantity of agricultural outputs produced and the amount of land farmed by each household are also required. In the data set, direct information is available on the quantity of outputs produced and quantity of variable and fixed inputs used. Three agricultural outputs: cereals (rice and wheat), potato, cash crop (including vegetables and fruits), fish (shrimp) and four variable inputs: fertilizer, irrigation, labor and transport cost; and one fixed input which is land under cultivation are used in the analysis. The purpose of this selection of inputs and outputs is to simplify the analysis. Also, other inputs used and outputs produced by the households are relatively smaller in quantity.

Applying the assumption of profit maximizing behaviour the production problem of a Bangladeshi farmer can be set up formally. Consider a farmer who uses $\mathbf{x}_1$ quantity of agricultural inputs that need to be transported from the market to his homestead. He pays a unit price (in *taka* per kilogram) $\mathbf{r}_1$ to buy these inputs, and unit transport cost (in *taka* per kilogram) t to carry them. He may use other types of inputs of $\mathbf{x}_2$ quantity that do not need to transport. Irrigation and labor are examples. The market price of this kind of inputs is $\mathbf{r}_2$. Using various combinations of these variable inputs and allocating z quantity of land, considered to be a fixed input, to various crops he produces $\mathbf{y}$ combination of crops. He could sell his agricultural outputs to the market at a unit price $\mathbf{p}$. Again he has to pay a unit transport cost t to carry it to the market for selling.

The net price can be defined as $\tilde{\mathbf{p}} = \mathbf{p} - \mathrm{t}$ for agricultural output, $\tilde{\mathbf{r}}_1 = \mathbf{r}_1 + \mathrm{t}$ for agricultural input that need to be transported, and $\tilde{\mathbf{r}}_2 = \mathbf{r}_2$ for those inputs that do not need to transport. For the purpose of this study the prices at the main market of the locality is used. The farm profit can be estimated as $\pi = \tilde{\mathbf{p}}\mathbf{y} - \tilde{\mathbf{r}}_1\mathbf{x}_1 - \tilde{\mathbf{r}}_2\mathbf{x}_2$. Here all the outputs are evaluated with the net price of $\tilde{\mathbf{p}}$. In fact the farmer keeps a significant amount of production for consumption. However for the purpose of estimating farm profit, it can be assumed that all the produces are sold in the market.

The profit-maximizing farmer adjusts the quantity of variable inputs and outputs to maximize profit since the prices are exogenously given; farmer has to take the prices. Mathematically the farmer's problem is express as:

$$\max_{\mathbf{y},\mathbf{x}}\left\{\tilde{\mathbf{p}}\mathbf{y}-\tilde{\mathbf{r}}_1\mathbf{x}_1-\tilde{\mathbf{r}}_2\mathbf{x}_2 | (\mathbf{x},\mathbf{y},\mathrm{z})\in \mathrm{T}\right\}$$

where T is a production possibility set.

Setting the first order condition equal to zero the above maximization problem can be solved for the optimal quantities of variable inputs, denoted by $-\mathbf{x}^*(\tilde{\mathbf{p}},\tilde{\mathbf{r}}_1,\tilde{\mathbf{r}}_2,\mathrm{z})$, and the optimal quantities of outputs, denoted by $\mathbf{y}^*(\tilde{\mathbf{p}},\tilde{\mathbf{r}}_1,\tilde{\mathbf{r}}_2,\mathrm{z})$. By setting the first order condition equal to zero the marginal cost is actually equated with the marginal revenue and thereby the behaviour of the profit-maximizing farmer is maintained. These optimal quantities can be substituted back in the objective function $\pi=\tilde{\mathbf{p}}\mathbf{y}-\tilde{\mathbf{r}}_1\mathbf{x}_1-\tilde{\mathbf{r}}_2\mathbf{x}_2$ to get a profit function $\pi(\tilde{\mathbf{p}},\tilde{\mathbf{r}}_1,\tilde{\mathbf{r}}_2,\mathrm{z})$. This profit function should represent the farm technology of a profit-maximizing farmer upon maintaining its properties.

Instead of setting up the objective function and solving the first order condition, which will be cumbersome for complex production function, we can start with specifying a profit function $\pi(\tilde{\mathbf{p}},\tilde{\mathbf{r}}_1,\tilde{\mathbf{r}}_2,\mathrm{z})$ and get the demand function $-\mathbf{x}^*(\tilde{\mathbf{p}},\tilde{\mathbf{r}}_1,\tilde{\mathbf{r}}_2,\mathrm{z})$ and supply function $\mathbf{y}^*(\tilde{\mathbf{p}},\tilde{\mathbf{r}}_1,\tilde{\mathbf{r}}_2,\mathrm{z})$ simply by differentiation. This way of manipulation is based on the duality relationship between production function and profit function developed by Shepherd and extended by Hottling. More discussion on this is available in Appendix-4.

To simplify notation all the price vectors can be stacked in a single vector called $\mathbf{q} = [\tilde{\mathbf{p}}, \tilde{\mathbf{r}}_1, \tilde{\mathbf{r}}_2]'$, and the corresponding variable quantity vector can be stacked in another vector called $\mathbf{u} = [\mathbf{y}, -\mathbf{x}_1, -\mathbf{x}_2]'$. The profit function can then be written as $\pi(\mathbf{q}, z)$.

Differentiating the profit function with respect to price vector the demand and supply function can be obtained as follows:

$$\frac{\partial \pi(\mathbf{q}, z)}{\partial \mathbf{q}} = \mathbf{u}^*(\mathbf{q}, z)$$

where, $\mathbf{u}^*(\mathbf{q}, z)$ are the supply functions of agricultural output and $-\mathbf{u}^*(\mathbf{q}, z)$ are the demand functions for inputs.

The household survey found that 25% of total farmers under the survey did not produce rice at all; 20% did not use any fertilizer. A similar pattern was found in all agricultural inputs and outputs. This suggests that the underlying probability distribution of cultivation of each crop or the use of each input is likely to be truncated, meaning that the probability is zero for some farmer and positive for other. This phenomenon creates a problem in estimation of demand and supply function derived above. If we estimate the demand equation by ordinary least squares (OLS), regressing quantity demanded with the explanatory variables without accounting for truncation the resulting estimates will be biased, even asymptotically. In this situation ML estimation is appropriate. In single-equation application ML estimation is common and straightforward. But ML estimation of a system of equations is difficult when error terms are contemporaneously correlated. Heien and Wessells (1990) handled this problem within the context of OLS by augmenting each equation in the system by a selectivity regressor derived from probit estimates in an earlier step, and the system of equations is estimated with seemingly unrelated regression in the second step. Shonkwiller and Yen (1999) made some modifications to the Heien and Wessells procedure, and suggested following modification of the system of equation, $\mathrm{u_i} = \mathrm{f}(\mathbf{q}, \mathrm{z}, \boldsymbol{\beta}_\mathrm{i}) + \varepsilon_\mathrm{i}$.

$$\mathrm{u_i} = \Phi(\boldsymbol{\Omega}'\boldsymbol{\alpha}_\mathrm{i})\mathrm{f}(\mathbf{q}, \mathrm{z}, \boldsymbol{\beta}_\mathrm{i}) + \delta_\mathrm{i}\varphi(\boldsymbol{\Omega}'\boldsymbol{\alpha}_\mathrm{i}) + \zeta_\mathrm{i}$$

Here, $\Phi(\boldsymbol{\Omega}'\boldsymbol{\alpha}_\mathrm{i})$ and $\varphi(\boldsymbol{\Omega}'\boldsymbol{\alpha}_\mathrm{i})$ are the cumulative distribution function and probability distribution function of growing i^{th} crop or using i^{th} inputs. $\boldsymbol{\Omega}$ is the vector of household characteristics. $\boldsymbol{\alpha}_\mathrm{i}$, $\boldsymbol{\beta}_i$ and δ_i are parameters to be estimated. This newly defined system of equation can be estimated by a two-step procedure. In the first step the estimates $\hat{\boldsymbol{\alpha}}$ using binary outcome of cropping decision can be obtained within a probit framework and the quantities $\Phi(\boldsymbol{\Omega}'\hat{\boldsymbol{\alpha}}_\mathrm{i})$ and $\varphi(\boldsymbol{\Omega}'\hat{\boldsymbol{\alpha}}_\mathrm{i})$ can then be computed. In the second step the estimates $\hat{\boldsymbol{\beta}}_i$ and $\hat{\delta}_i$ can be obtained from the estimation of the demand system by seemingly unrelated regression (SUR) technique.

A number of location-specific household factors affect crop choice. The soil in the coastal region is not suitable for potato cultivation but it is good for shrimp farming. Farmers in the same region may decide to grow different crops in different years depending on the weather conditions. Cropping decisions may also depend on the characteristics of the household; how much land they possess, whether the farm has access to irrigation facilities, is the farmland in the low lying *bill* areas, how much capital they have, how good is the communication facilities to the market so on and so forth. All these factors have to be incorporated in the probit framework to estimate the probability distribution of growing different kinds of crops or using various agricultural inputs.

Using the model described here it is possible to quantify the impacts of decision variables on the quantity of productions. This can be done by estimating the elasticity of i^{th} commodity with respect to own ($i = j$) and cross ($i \neq j$) prices as follows:

$$\varepsilon_{ij} = \frac{\partial u_i}{\partial p_j}\frac{p_j}{u_i} = \Phi_i f'_{ip_j}\frac{p_j}{u_i}$$

Farmers' responsiveness of i^{th} commodity with respect to the change in transport cost t induced by road improvements can be computed as follows:

$$\varepsilon_{it} = \frac{\partial u_i}{\partial t}\frac{t}{u_i} = \Phi_i f'_{it}\frac{t}{u_i}$$

Note that t is embedded in the effective prices as $\tilde{p} = p - t$ for output and $\tilde{p} = p + t$ for input, where p is the market price.

Chapter 6: Estimation

To operationalize the model presented in the previous section, the first task is to specify the form of a profit function $\pi(\mathbf{q}, z)$. We are interested in the value of the function which gives the level of profit, $\pi(\mathbf{q}, z)$, the gradient of the function which represent the output supply $\mathbf{u}(\mathbf{q}, z)$ and input demand $-\mathbf{u}(\mathbf{q}, z)$, and the Hessian, e.g. the matrix of elasticity $\frac{\partial^2 \pi(\mathbf{q}, z)}{\partial \mathbf{q_i q_j}}$. For a technology with n netputs there can be ½(n+1) (n+2) such effects. The form of the profit function has to be flexible enough so that it does not impose a prior value to any of these ½(n+1) (n+2) parameters. The data should be able to determine these effects. A second-order Taylor-series expansion about a point can approximate any true function, which has ½(n+1) (n+2) parameters. It is capable of providing a flexible functional form for the profit function. The normalized quadratic profit function is a popular functional form that can be considered as a second order Taylor-series expansion. The normalized quadratic profit function can be written as follows:

$$\pi(\mathbf{q}, \mathrm{z}) = \beta_0 + \sum_{i=1}^{k-1} \beta_i q_i + \tfrac{1}{2} \sum_{i=1}^{k-1} \sum_{j=1}^{k-1} \beta_{ij} q_i q_j + \sum_{i=1}^{k-1} \beta_{i7} z q_i + \beta_8 z$$

In our study there are seven input or output commodities ($k = 7$), z is the one fixed input, which is the total land under cultivation, q_j are the normalized effective prices (market price net of unit transport cost) of commodities. Wage rate is used for normalization of the prices of all the other inputs and outputs. The output supply functions and input demand functions, as shown below, are obtained by differentiation of the profit function with respect to output and input prices.

$$u_i = \beta_i + \sum_{j=1}^{k-1} \beta_{ij} q_j + \beta_{i7} z \qquad \text{for } i = 1,2,3,4$$

$$-u_i = \beta_i + \sum_{j=1}^{k-1} \beta_{ij} q_j + \beta_{i7} z \qquad \text{for } i = 5,6$$

$$-u_n = \beta_0 - \tfrac{1}{2} \sum_{i=1}^{k-1} \sum_{j=1}^{k-1} \beta_{ij} q_i q_j + \beta_{i7} z \qquad \text{for } n = 7$$

where u_i is supply of i^{th} output, $-u_i$ is demand for i^{th} input and $-u_n$ is demand for the numeraire input.

The profit function is the optimal solution of a profit-maximizing problem. To ensure profit maximization, the profit function can be estimated without any restriction and tested to see if the properties are maintained. If the estimated function fails to satisfy the properties, prior restrictions need to be imposed on the function during estimation. In our study the unrestricted estimation failed to satisfy the desired properties, so prior restrictions were imposed to maintain the properties. The first maintained property is homogeneity, which says that the profit function is homogeneous of degree one in prices, i.e. $\pi(\lambda \mathbf{q}, z) = \lambda \pi(\mathbf{q}, z)$ for $\lambda > 0$. This property is maintained by normalizing the function with the price of 6^{th} commodity. The second property says that the Hessian matrix, the second partial derivative of profit function with respect to prices is symmetric, i.e. $\frac{\partial^2 \pi(\mathbf{q}, z)}{\partial \mathbf{q}_i \partial \mathbf{q}_j} = \frac{\partial^2 \pi(\mathbf{q}, z)}{\partial \mathbf{q}_j \partial \mathbf{q}_i}$ for $i \neq j$. This property is maintained by restricting $\beta_{ij} = \beta_{ji}$ in the demand system. The third restriction says that the profit function is convex; which is synonymous to say that the Hessian matrix $\frac{\partial^2 \pi(\mathbf{q}, z)}{\partial \mathbf{q}_i \partial \mathbf{q}_j}$ is positive semi-definite. The Hessian matrix was forced to become positive semi definite by setting $\boldsymbol{\beta} = \mathbf{A}\mathbf{A}^{`}$ during estimation. Here, $\boldsymbol{\beta}$ is the Hessian matrix and $\mathbf{A}$ is a lower triangular squire matrix for which $A_{ij} = 0$ for j > i. For our case the condition $\boldsymbol{\beta} = \mathbf{A}\mathbf{A}^{`}$ becomes the following. Appendix-D provides detail discussion on this.

$$\begin{bmatrix} \beta_{11} & & & & & \\ \beta_{12} & \beta_{22} & & & & \\ \beta_{13} & \beta_{23} & \beta_{33} & & & \\ \beta_{14} & \beta_{24} & \beta_{34} & \beta_{44} & & \\ \beta_{15} & \beta_{25} & \beta_{35} & \beta_{45} & \beta_{55} & \\ \beta_{16} & \beta_{26} & \beta_{36} & \beta_{46} & \beta_{56} & \beta_{66} \end{bmatrix} = \begin{bmatrix} a_{11}^2 & & & & & \\ a_{21}a_{11} & a_{21}^2 + a_{22}^2 & & & & \\ a_{31}a_{11} & a_{21}a_{31} + a_{32}a_{22} & a_{31}^2 + a_{32}^2 + a_{33}^2 & & & \\ a_{41}a_{11} & a_{21}a_{41} + a_{42}a_{22} & a_{31}a_{41} + a_{32}a_{42} + a_{43}a_{33} & ..... & & \\ a_{51}a_{11} & a_{21}a_{51} + a_{52}a_{22} & a_{31}a_{51} + a_{32}a_{52} + a_{53}a_{33} & ..... & ..... & \\ a_{61}a_{11} & a_{21}a_{61} + a_{62}a_{22} & a_{31}a_{61} + a_{32}a_{62} + a_{63}a_{33} & ..... & ..... & ..... \end{bmatrix}$$

The property of symmetry and convexity are related. We know from Young's theorem that if $\frac{\partial^2 \pi(\mathbf{q}, z)}{\partial \mathbf{q}_i \partial \mathbf{q}_j}$ is a positive semi definite matrix then it must be symmetric. But it is not true the other way around, meaning the symmetry conditions cannot assure convexity.

To take care of the estimation problem associated to censoring in the data, which is discussed in the model section, the demand system derived above must be modified as follows:

$$u_i = \Phi(\boldsymbol{\Omega}, \boldsymbol{\alpha}_i)(\beta_i + \sum_{j=1}^{k-1} \beta_{ij} q_j + \beta_{i7} z) + \delta_i \varphi(\boldsymbol{\Omega}, \boldsymbol{\alpha}_i) \qquad \text{for } i = 1,2,3,4$$

$$-u_i = \Phi(\boldsymbol{\Omega}, \boldsymbol{\alpha}_i)(\beta_i + \sum_{j=1}^{k-1} \beta_{ij} q_j + \beta_{i7} z) + \delta_i \varphi(\boldsymbol{\Omega}, \boldsymbol{\alpha}_i) \qquad \text{for } i = 5,6$$

$$-u_n = \boldsymbol{\Phi}(\boldsymbol{\Omega}, \boldsymbol{\alpha}_i)(\beta_0 - \tfrac{1}{2} \sum_{i=1}^{k-1} \sum_{j=1}^{k-1} \beta_{ij} q_i q_j + \beta_{i7} z) + \delta_i \varphi(\boldsymbol{\Omega}, \boldsymbol{\alpha}_i) \qquad \text{for } n = 7$$

As defined in the earlier chapter, $\Phi(\mathbf{\Omega}'\boldsymbol{\alpha}_i)$ and $\varphi(\mathbf{\Omega}'\boldsymbol{\alpha}_i)$ are the cumulative distribution function and probability distribution function of growing ith crop or using ith inputs. $\mathbf{\Omega}$ is the vector of household characteristics. $\boldsymbol{\alpha}_i$, $\boldsymbol{\beta}_i$ and δ_i are parameters to be estimated. This newly defined system of demand equations can be estimated by a two-step procedure:

Step-1: Probit: Obtain estimates $\hat{\alpha}$ using binary outcome of cropping decision and calculate $\Phi(\Omega'\hat{\alpha}_i)$ and $\varphi(\Omega'\hat{\alpha}_i)$ for each output/input i ,

Step-2: SUR: Obtain estimates β_i and δ_i from the demand system

One may attempt to estimate the seven demand equations independently, equation by equation, using ordinary least square (OLS). In this way the parameter could be estimated consistently, if not efficiently. Zellner (1962) showed that if the equations are estimated as a system would yield coefficient estimators at least asymptotically more efficient than equation by equation least squire estimates. This extra gain in efficiency is due to the use of the fact that many of the unexplained factors (accumulated in the error term) of individual equation may have some relationship. For example, the error term (hence the unexplained part) of cereal equation may co-vary with the error term of potato equation because rainy season flooding damage rice but also bring extra fertility and higher production of potato, which is grown immediately after the rainy season. The model could not use this useful information if estimated equation by equation. Other than efficiency in parameter estimates there is another reason to estimate the demand functions as a system of equations. The parameters of the systems are constrained across equations. In our case we imposed the symmetry ($\beta_{ij} = \beta_{ji}$) and convexity restrictions ($\boldsymbol{\beta} = \mathbf{AA}'$).

The multivariate generalized least square procedure, which stacks all the equation into a single system, is capable of using the covariance of error terms among the equations. The equations are linked only by their error terms. Because of this fact this kind of generalized least square estimation is named as *seemingly unrelated regression*. Stacking m number of equation, k number of variables in each equation with n number of data points we get:

$$\begin{bmatrix} y_1 \\ y_2 \\ .. \\ .. \\ y_m \end{bmatrix}_{mn\times1} = \begin{bmatrix} \tilde{p}_1 & 0 & & & 0 \\ 0 & \tilde{p}_2 & & & 0 \\ & & .. & & \\ & & & .. & \\ 0 & 0 & & & \tilde{p}_m \end{bmatrix}_{mn\times k} \begin{bmatrix} \beta_1 \\ \beta_2 \\ .. \\ .. \\ \beta_m \end{bmatrix}_{k\times1} + \begin{bmatrix} \xi_1 \\ \xi_2 \\ .. \\ .. \\ \xi_m \end{bmatrix}_{mn\times1}$$

$$\text{Or } y_{mn\times1} = \tilde{p}_{mn\times k}\beta_{k\times1} + \xi_{mn\times1}$$

We can treat this formulation as a single equation, with the parameter estimates as follows:

$$\hat{\beta}_{SUR} = (\tilde{p}`\hat{\Sigma}^{-1} \otimes I\tilde{p})^{-1}\tilde{p}`\hat{\Sigma}^{-1} \otimes Iy$$

$$Var(\hat{\beta}_{SUR}) = \hat{\sigma}^2(\tilde{p}`\hat{\Sigma}^{-1} \otimes I\tilde{p})^{-1}$$

A review of SUR estimation is given in Appendix-E.

Once the demand system is estimated, farmers' responses of the variable quantities to changes in prices can be estimated by calculating the elasticity of i^{th} commodity with respect to own ($i = j$) and cross ($i \neq j$) price using the general formula $\varepsilon_{ij} = \frac{\partial y_i}{\partial p_j}\frac{p_j}{y_i}$. The elasticity of i[th] commodity with respect to transport cost t is $\varepsilon_{it} = \frac{\partial y_i}{\partial t}\frac{t}{y_i}$. The elasticity formula for the regular and numeraire commodity and transport cost can be derived (Appendix-C) as follows:

Output elasticities, for $i = 1,2,3,4$

$$\varepsilon_{ij} = \Phi_i \beta_{ij}\left(\tilde{p}_j + \tilde{t}\right)\frac{1}{y_i} \qquad \text{for } j = 1\ldots\ldots6$$

$$\varepsilon_{i7} = -\Phi_i\left(\sum_{j=1}^{6}\beta_{ij}\tilde{p}_j\right)\frac{1}{y_i} \qquad \varepsilon_{it} = -\Phi_i\left(\sum_{j=1}^{4}\beta_{ij} + \beta_{i5}\right)\frac{\tilde{t}}{y_i}$$

Input elasticities, $i = 5,6$

$$\varepsilon_{ij} = -\Phi_i \beta_{ij}\left(\tilde{p}_j + \tilde{t}\right)\frac{1}{y_i} \qquad \text{for } j = 1\ldots\ldots6$$

$$\varepsilon_{i7} = \Phi_i\left(\sum_{j=1}^{6}\beta_{ij}\tilde{p}_j\right)\frac{1}{y_i} \quad \varepsilon_{it} = \Phi_i\left(\sum_{j=1}^{4}\beta_{ij} - \beta_{i5}\right)\frac{\tilde{t}}{y_i}$$

Input elasticity of numeraire input, $i = 7$

$$\varepsilon_{ij} = 2\Phi_i\left\{\left(\sum_{i=1}^{6}\beta_{ji}\tilde{p}_i\right) + \left(\beta_j + \beta_{j7}z\right)\right\}\frac{\tilde{p}_j}{y_i p_7} \qquad \text{for } j = 1\ldots\ldots6$$

$$\varepsilon_{i7} = -\Phi_i\left(2\sum_{i=1}^{6}\sum_{j=1}^{6}\beta_{ij}\tilde{p}_j\tilde{p}_j + \sum_{j=1}^{6}\beta_j\tilde{p}_j + \sum_{j=1}^{6}\beta_{j7}z\tilde{p}_j\right)\frac{1}{y_i p_7}$$

$$\varepsilon_{it} = 2\Phi_i\left[-\sum_{i=1}^{4}\sum_{j=1}^{4}\beta_{ij}\left(\tilde{p}_i + \tilde{p}_j\right) + \sum_{j=1}^{4}\beta_{j5}\left(\tilde{p}_j - \tilde{p}_5\right) - \sum_{j=1}^{4}\beta_{j6}\tilde{p}_6 + \beta_{56}\tilde{p}_6 + \beta_{55}\tilde{p}_5 - \sum_{j=1}^{4}\beta_j + \beta_5 - \sum_{j=1}^{4}\beta_{j7}z + \beta_{57}z\right]\frac{\tilde{t}}{y_i p_7}$$

Chapter 7: Results

The main results from the estimated model are presented in the Table 7.1 below. The detailed estimates of the price elasticities of the demand system are presented in Table A1. The parameter estimates of the demand system are presented in Table A2 through Table A8 and that of probit model in Table A9 through Table A15. All tables are included in appendix-A.

Table 7.1 Transport cost elasticity of demand: the effects of marginal changes in transport cost

Cereal y_1	**Potato** y_2	**Cash crop** y_3	**Fish** y_4	**Fertilizer** y_5	**Irrigation** y_6	**Labor** y_7
-0.0040	-0.0134	-0.0187	0.0006	-0.0602	-0.0059	0.0267

When the road is improved and the transport cost goes down, the use of agricultural inputs and the resulting agricultural production is expected to go up. The data supports the relation between road improvement and agricultural production in general. The negative sign of elasticity of almost all agricultural commodities with respect to transport cost shows that the supply of agricultural output and demand of input increase with the decrease of transport cost.

The transport cost elasticity of fertilizer demand is the highest, -0.0602, which means that if the transport cost goes down by 50%, which was found in the traffic and freight survey conducted on the similar roads (Mustafa 1998), the use of fertilizer goes up by roughly 3%. The effect of transport cost on potato and cash crop (mostly vegetables and fruit) production is greater than that of cereal (rice, wheat) production. The transport cost elasticity is -0.0134, -0.0187 for potato and cash crop, and -0.0040 for cereals. These results support the hypothesis that transport cost reductions causes producers to switch toward production of higher value but more perishable products and away from traditional rice production.

As can be expected, the magnitude of the elasticity is small. This might be because the transport cost is a small fraction, 10% at best, of commodity price. A 50% decrease in transport cost is equivalent to an approximately 5% change in effective price. This study deals with the effect of tiny change in effective price on agricultural production decision. However, these findings do not necessarily suggest that the effect of road improvement on agriculture is insignificant. Approximately 1400 households receive the benefits from the improvements of each road of five kilometers long on average. If a small change in production is aggregated over a large number of farmers, and over a longer period of time (the life of the road) the effect might become large. On the other hand the improvement cost of the road is small, only 1,500,000 taka (US$ 27,000) per five kilometers long road on average (Mustafa 1998).

Road improvement induced reduction of transportation cost might affect the likelihood of producing a particular crop as well as the quantity of production. Some of the crops may become worthwhile to grow because of the new effective prices for those farmers who chose not to grow when the road was bad. In fact some of these cases are reported in the qualitative survey (Coelho1999) conducted on the households under study.

The model used in this study did not incorporate the effect of transport cost on the likelihood of producing crops. This fact can be tied with the finding of low values of elasticity of demand and supply with respect to transport cost. Probably the elasticity is being under estimated, since only one road effect is accounted for (Shaha 1997). To capture the full effects of road improvements it is necessary to set up the model to take into account the effects not only on the quantity produced of existing crop but also the likelihood of inclusion of a new crop in the production plan. This is left for future research.

Positive sign on estimated elasticities appear for fish production and hired labor demand, indicating the opposite effect of transport cost than hypothesized. However, the elasticity of fish production with respect to transport cost is very small, close to zero, suggesting no relation between the two. This fact might be explained by the fact that the data on fish production (shrimp) were available from only one study site out of the eight sites, because of its unique location and salinity of surface water. The study site is located in a coastal area surrounded by network of rivers. Transportation of fish by boat is more popular than by road, which is often discontinued by un-bridged big rivers. The positive sign of elasticity of demand of agriculture labor with respect to transport cost seem to suggest that increase of local demand is outweighed by the opportunity of working at a distant location using the improved road. It is to be noted that the relationship between transport cost and demand for hiring agricultural labor is not direct. There is no transport cost associated with hiring local agricultural labor. This is affected indirectly through changes in transport cost of other commodities. Note that the input demand is a function of prices of all commodities. The same is true for irrigation. The road improvements affect directly the use of fertilizer; irrigation and hired labor supplement it.

In addition to the results related to the impacts of road improvement, some other interesting findings emerge from the estimates of the demand system (Table A2 through Table A8, which is summarized in Table A1).

Own price responsiveness of cereal production (mostly rice) is not significant in general (low t-statistic). This might be because of the high reliance of the household in Bangladesh on rice as a source of food. Roughly 60% of Bangladeshi diet is comprised of rice. Also the climate and soil condition is suitable for rice cultivation. It does not matter much what the price is, the farmers seem to grow rice. However, cash crop production shows very different results. Potato is responsive to its own price (t-statistic is 3.16). This is expected because potato is cultivated mostly to earn income by selling it in the market, not for household consumption (considered as cash crop). In Bangladesh fertilizer is used intensively in potato production. As a result estimated coefficient related to fertilizer is negative and statistically significant (t-statistic 2.30). Similarly, cash crops like vegetables, fruit, and jute productions are also responsive to its own price (t-statistic 1.65) because of the similar reasoning. Again the parameter estimate of fertilizer is negative and statistically significant (t-statistic 3.45) showing high intensity of fertilizer requirement for cash crop production especially for vegetables.

The level of significance of coefficient estimates for the censor correction parameter, δ_1, is high for all outputs. This reflects the presence of censoring in the data, meaning a significant proportion of farmers choose not to grow a particular crop. The effect of this phenomenon on parameters estimates is significant.

Two-step estimation employed in this study has some associated problems. Murphy and Topel (1985) showed that the covariance matrix of the second-step estimator is incorrect. Further efficiency in the parameter estimate can be gained by adjusting the covariance matrix by the procedure suggested by them. Two-step estimation causes the model to be hetaroskedastic too, correction of which could make the parameter estimate efficient. These corrections are beyond the scope of this study. High standard error of many parameter estimates can be attributed to this.

There are problems in estimating transport cost, which may have some bearing on the parameters estimated. The transport cost is estimated by the use of the information provided by the farmer. The farmers usually use less efficient mode of transport such as bullock cart, push cart, and head-load. Bicycle and rickshaw are the most efficient mode of transport they can possibly afford. These modes of transport require less sum of money to hire or own, but the cost per unit of transported goods is very high. The unit cost of transport is a lot less for the mechanized mode of transport such as lorry, truck, tractor than those used by the farmer, but it requires a huge sum of money to hire or own. Also most of the farmers sell a relatively small quantity of their produce at a time for which hiring a truck or tractor is not worthwhile. Only traders operate door to door buying and accumulating a huge quantity of agricultural goods can hire the mechanized modes of transport. For them the unit transport cost is much less than the farmers used to pay. The price the trader offers to the farmers may not be as high as offered in the main market a distance away, but certainly the price net of transport cost is higher. This may be the reason why selling output at the homestead to a trader became the most popular way of transaction after improvements of the road. It also explains the increased number of mechanized mode of transport after the improvement of the road reported in the traffic and freight survey (Mustafa 1998). Unfortunately, the estimation of transport cost failed to account for this effect because of the lack of transport cost data from the traders. This limitation possibly underestimates the effect of road improvement and might be linked with the small elasticity of many of the agricultural commodity demand with respect to transport cost.

To compute farm profit, it is assumed that all transportable inputs and outputs are transported to or from the market. This may be true for fertilizer, but not certainly true for the agricultural outputs. In fact, on average the study households transport 50% of all outputs to market for selling, the rest is kept home for consumption. Households probably feel safe against uncertainty and risk caused by price fluctuations, yield variations and various natural calamities by keeping it at home, and thereby assuring future consumption. Probably the households put greater value to this part of their products than the market value. These features of the household decision making are absent in the model analyzed in this study. It would be an interesting avenue of study to examine how this phenomenon affects the parameter estimate.

Chapter 8: Conclusion

The central issue of this study is to assess the impact of food-aid funded rural road improvement projects on the agriculture in Bangladesh. Food aid has been a major input to fight poverty and hunger in Bangladesh. Some of the aid goes directly to the poor people as humanitarian assistance through vulnerable group feeding programs, school-feeding programs, and digester relief programs. Presently, the major part of food aid is used to achieve longer-term objectives of sustainable development through improvements and maintenance of rural infrastructure. Reconstruction and maintenance of the rural road network, flood protection embankment and irrigation canal are some examples of the later category of projects. The government of Bangladesh alone or jointly with non-governmental organizations (NGO), implements these projects. CARE International has been spending millions of dollars worth of food aid each year provided by USAID under PL480 to improve the rural road network. One of the goals of rural road improvements is to reduce the effective prices (market price net of unit transport cost) of the agricultural inputs that are purchased in distant markets. These reductions in effective prices cause the demand for agricultural inputs to go up. After the improvements of the roads the farmers will probably use input more intensively, this is expected to increase the agricultural production. The reduction of transport cost also increases the effective price the farmers receive from selling the agricultural products in distant markets. This price incentive should encourage farmers to increase production. Also, improved access to markets may enable farmers to alter their cropping patterns; to grow and market higher-valued but more perishable products such as potato, vegetables and some cash crop such as fruit, switching away from traditional rice cultivation. All these effects will generate additional income for the farmer. The current study analyzes the agricultural data from a household survey to examine these effects of road improvements on the level and pattern of agricultural production. The government of Bangladesh, donor agencies and implementing agencies like CARE wanted to know if these hypothesized impacts of the FFW program have materialized. In 1995, CARE initiated a large scale household survey covering 1400 households over a period of three years. This survey monitored every two months the agricultural and non-agricultural activities of the households, including consumption patterns and nutrition status.

In this study it is assumed that farmers make cropping decisions based on profit maximize behavior. A flexible functional form of profit function (normalized quadratic) is estimated to approximate the true function. Four commodity supply functions and three input demand functions are derived from profit function using the Hotteling’s Lemma. Transport cost is embedded in the effective price of agricultural inputs and outputs (market price net of transport cost) in each equation to examine the effect of road improvement. Seemingly unrelated regression technique is used to estimate the seven equations as a system.

The dependent variables of the system of equations are heavily censored. Many farmers did not produce rice, for example, or did not use fertilizer at all. This censored data is handled with care using econometric technique. The technique involves augmenting each equation in the system by a selectivity regressore derived from probit estimates in an earlier step, and the system of equations is estimated with seemingly unrelated regression in the second step. This two step estimation help analyze the sequential process of decision making by the farmer, where a dichotomous choice of whether or not to produce a particular crop is followed by a continuous choice of how much to produce. The dichotomous choice of growing a particular crop is represented by probit model and the continuos choice of how much to grow is modeled by SUR. Augmentation of each SUR equation by the probit regressor help analyze the effect of marginal change in transport cost on both stages in a single framework.

The results provide a clear picture of the positive impact of road improvement on agriculture in Bangladesh. When the transport cost goes down because of road improvement, the use of agriculture inputs goes up. The agriculture production also increased not only because of the higher level of input use but also the incentive of higher effective price the farmer receive from selling their crop to distant markets.

The magnitude of the impact of road improvement on agriculture is small as one might expect, because the transport cost is only a small fraction of the product price. However, this small change in production, if aggregated over large number of household a single road serves, might become significant.

The effect of transport cost on perishable products like potato, vegetables and fruit is greater than that of cereal (rice, wheat). The possibility to grow and market higher-valued but more perishable products, switching away from traditional rice cultivation seem to be supported by the data.

In this study, the impacts of rural road improvements on agriculture is assessed and found favorable results. In a broader context, improved roads play a significant role in various aspects of social and economic development and help improve people's lives. Some of the life saving facilities, such as emergency vehicles becomes accessible to rural areas after road improvement. Patients of rural villages can be carried to the hospital located in the towns for treatment and urgent maternity care. Health extensions agents, law enforcing agencies can operate in remote villages with an improved road system. Attending school becomes easier, social visits become more convenient. Given all the benefits an improved road network can bring, the investment of food aid for road improvement becomes worthwhile for social change.

Appendix A: Detailed Results

Table A1: Elasticity of demand: the effects of marginal changes in prices

	Cereal y_1	Potato y_2	Cash crop y_3	Fish y_4	Fertilizer y_5	Irrigation y_6	Labour y_7
cereal, p_1	0.0681	-0.0051	0.1181	-0.0101	0.3768	-0.0497	-0.5010
Potato, p_2	-0.0022	0.2690	0.0225	-0.0060	0.0592	0.0793	-0.0259
Cash crop, p_3	0.0293	0.0126	0.1962	-0.0007	0.6411	0.0496	-0.0434
Fish, p_4	-0.1572	-0.2100	-0.0452	0.0356	-0.1059	0.1664	1.4948
Fertilizer, p_5	-0.0361	-0.0128	-0.2471	0.0007	-0.8080	-0.0631	0.0454
Irrigation, p_6	0.0140	-0.0506	-0.0565	-0.0030	-0.1863	-0.0598	-0.1879
Labor, p_8	0.0880	0.0103	0.0307	-0.0169	0.0833	-0.1168	-0.8007
Transport, t	-0.0040	-0.0134	-0.0187	0.0006	-0.0602	-0.0059	0.0267

$$y_1 = \Phi(\boldsymbol{\Omega}'\boldsymbol{\alpha}_1)\,[a_1 + b_{11}p_1 + b_{12}p_2 + b_{13}p_3 + b_{14}p_4 + b_{15}p_5 + b_{16}p_6 + c_1 z + d_{11}\,\text{Debidwar} + d_{12}\,\text{Gopalpur} + d_{13}\,\text{Dacope} + d_{14}\,\text{Ulipur} + d_{15}\,\text{Mohanganj} + d_{16}\,\text{Ghior} + d_{17}\,\text{Kachua} + t_{11}\,\text{Year-1} + t_{12}\,\text{Year-2}] + \delta_1\phi(\boldsymbol{\Omega}'\boldsymbol{\alpha}_1)$$

Table A2: Dependent Variable: Cereal Supply (y_1)

Description	Parameter	Estimate	Std Err	t- value
Intercept	a_1	330.65	177.40	1.86
Price of cereal, p_1 (Taka/kg)	b_{11}	-43.87	778.61	-0.06
Price of potato, p_2 (Taka/kg)	b_{12}	229.58	269.06	0.85
Price of cash crop, p_3 (Taka/kg)	b_{13}	-42.85	27.32	-1.57
Price of fish, p_4 (Taka/kg)	b_{14}	-603.27	262.35	-2.30
Price of fertilizer, p_5 (Taka/kg)	b_{15}	102.62	113.46	0.90
Price of irrigation, p_6 (Taka/unit land)	b_{16}	874.54	902.25	0.97
Total area farmed	c_1	180.43	6.81	26.51
Regional dummy - Debidwar	d_{11}	-2309.20	229.90	-10.04
Regional dummy - Gopalpur	d_{12}	-223.83	189.60	-1.18
Regional dummy - Dacope	d_{13}	-1087.30	170.10	-6.39
Regional dummy - Ulipur	d_{14}	-118.87	185.10	-0.64
Regional dummy - Mohanganj	d_{15}	-422.36	165.90	-2.55
Regional dummy - Ghior	d_{16}	-1302.20	161.80	-8.05
Regional dummy - Kachua	d_{17}	447.89	165.60	2.70
Time dummy - Year-1	t_{11}	-353.52	108.30	-3.26
Time dummy - Year-2	t_{12}	-701.85	105.40	-6.66
Censor correction parameter	δ_1	3892.09	216.30	17.99

R-Square: 0.3907

$$y_2 = \Phi(\boldsymbol{\Omega}^{`}\boldsymbol{\alpha_2})\,[\,a_2 + b_{12}p_1 + b_{22}p_2 + b_{23}p_3 + b_{24}p_4 + b_{25}p_5 + b_{26}p_6 + c_2 z + d_{21}\,\text{Debidwar} + d_{22}\,\text{Gopalpur} + d_{24}\,\text{Ulipur} + d_{26}\,\text{Ghior} + t_{21}\,\text{Year-1} + t_{22}\,\text{Year-2}] + \delta_2\phi(\boldsymbol{\Omega}^{`}\boldsymbol{\alpha_2})$$

Table A3: Dependent Variable: Potato supply (y_2)

Description	Parameter	Estimate	Std Err	t- value
Intercept	a_2	-405.41	123.40	-3.28
Price of cereal, p_1 (Taka/kg)	b_{12}	-43.87	778.61	-0.06
Price of potato, p_2 (Taka/kg)	b_{22}	3551.33	1124.28	3.16
Price of cash crop, p_3 (Taka/kg)	b_{23}	66.64	335.86	0.20
Price of fish, p_4 (Taka/kg)	b_{24}	-38.62	27.49	-1.40
Price of fertilizer, p_5 (Taka/kg)	b_{25}	-144.30	359.20	-0.40
Price of irrigation, p_6 (Taka/unit land)	b_{26}	-249.54	273.26	-0.91
Total area farmed	c_2	15.41	9.85	1.56
Regional dummy - Debidwar	d_{21}	508.74	139.40	3.65
Regional dummy - Gopalpur	d_{22}	-187.20	102.80	-1.82
Regional dummy - Ulipur	d_{24}	-34.56	151.20	-0.23
Regional dummy - Ghior	d_{26}	512.42	89.83	5.70
Time dummy - Year-1	t_{21}	-3.39	80.74	-0.04
Time dummy - Year-2	t_{22}	28.59	79.45	0.36
Censor correction parameter	δ_2	1109.15	145.40	7.63

R-Square: 0.1565

$$y_3 = \Phi(\boldsymbol{\Omega}`\boldsymbol{\alpha_3})[a_3 + b_{13}p_1 + b_{23}p_2 + b_{33}p_3 + b_{34}p_4 + b_{35}p_5 + b_{36}p_6 + c_3 z$$
$$+ d_{31}\,\text{Debidwar} + d_{32}\,\text{Gopalpur} + d_{33}\,\text{Dacope} + d_{34}\,\text{Ulipur} + d_{35}\,\text{Mohanganj}$$
$$+ d_{36}\,\text{Ghior} + d_{37}\,\text{Katchua} + t_{31}\,\text{Year-1} + t_{32}\,\text{Year-2}] + \delta_3\phi(\boldsymbol{\Omega}`\boldsymbol{\alpha_3})$$

Table A4: Dependent Variable: Cash Crop supply (y_3)

Description	Parameter	Estimate	Std Err	t Value
Intercept	a_3	174.97	51.31	3.41
Price of cereal, p_1 (Taka/kg)	b_{13}	229.58	269.06	0.85
Price of potato, p_2 (Taka/kg)	b_{23}	66.64	335.86	0.20
Price of cash crop, p_3 (Taka/kg)	b_{33}	232.31	140.71	1.65
Price of fish, p_4 (Taka/kg)	b_{34}	-1.86	9.16	-0.20
Price of fertilizer, p_5 (Taka/kg)	b_{35}	-625.46	181.38	-3.45
Price of irrigation, p_6 (Taka/unit land)	b_{36}	-62.43	14921.21	0.00
Total area farmed	c_3	16.44	1.17	14.08
Regional dummy - Debidwar	d_{31}	-147.97	42.84	-3.45
Regional dummy - Gopalpur	d_{32}	70.51	38.23	1.84
Regional dummy - Dacope	d_{33}	-366.33	43.29	-8.46
Regional dummy - Ulipur	d_{34}	320.15	46.10	6.94
Regional dummy - Mohanganj	d_{35}	-103.90	43.05	-2.41
Regional dummy - Ghior	d_{36}	138.98	36.88	3.77
Regional dummy - Katchua	d_{37}	168.32	42.31	3.98
Time dummy - Year-1	t_{31}	118.90	26.83	4.43
Time dummy - Year-2	t_{32}	46.10	26.57	1.74
Censor correction parameter	δ_3	-172.15	91.25	-1.89

R-Square: 0.2066

$$y_4 = \Phi(\boldsymbol{\Omega}`\boldsymbol{\alpha_4})\,[a_4 + b_{14}p_1 + b_{24}p_2 + b_{34}p_3 + b_{44}p_4 + b_{45}p_5 + b_{46}p_6 + c_4 z + t_{41}\,\text{Year-1} + t_{42}\,\text{Year-2}] + \delta_4\phi(\boldsymbol{\Omega}`\boldsymbol{\alpha_4})$$

Table A5: Dependent Variable: Fish supply (y_4)

Description	Parameter	Estimate	Std Err	t Value
Intercept	a_4	-24.13	6.21	-3.89
Price of cereal, p_1 (Taka/kg)	b_{14}	-42.85	27.32	-1.57
Price of potato, p_2 (Taka/kg)	b_{24}	-38.61	27.49	-1.40
Price of cash crop, p_3 (Taka/kg)	b_{34}	-1.86	9.16	-0.20
Price of fish, p_4 (Taka/kg)	b_{44}	3.19	1.02	3.13
Price of fertilizer, p_5 (Taka/kg)	b_{45}	3.60	16.29	0.22
Price of irrigation, p_6 (Taka/unit land)	b_{46}	-7.29	903.23	-0.01
Total area farmed	c_4	2.84	0.29	9.89
Time dummy - Year-1	t_{41}	-22.70	5.43	-4.18
Time dummy - Year-2	t_{42}	-46.71	5.69	-8.20
Censor correction parameter	δ_4	69.22	6.88	10.06

R-Square: 0.3389

$$-y_5 = \Phi(\mathbf{\Omega`\alpha_5})\,[a_5 + b_{15}p_1 + b_{25}p_2 + b_{35}p_3 + b_{45}p_4 + b_{55}p_5 + b_{56}p_6 + c_5 z$$
$$+ d_{51}\,\text{Debidwar} + d_{52}\,\text{Gopalpur} + d_{53}\,\text{Dacope} + d_{54}\,\text{Ulipur} + d_{55}\,\text{Mohanganj}$$
$$+ d_{56}\,\text{Ghior} + d_{57}\,\text{Katchua} + t_{51}\,\text{Year-1} + t_{52}\,\text{Year-2}] + \delta_5\phi(\mathbf{\Omega`\alpha_5})$$

Table A6: Dependent Variable: Fertilizer Demand ($-y_5$)

Description	Parameter	Estimate	Std Err	t -value
Intercept	a_5	-303.19	95.42	-3.18
Price of cereal, p_1 (Taka/kg)	b_{15}	-603.27	262.35	-2.30
Price of potato, p_2 (Taka/kg)	b_{25}	-144.30	359.20	-0.40
Price of cash crop, p_3 (Taka/kg)	b_{35}	-625.46	181.38	-3.45
Price of fish, p_4 (Taka/kg)	b_{45}	3.60	16.29	0.22
Price of fertilizer, p_5 (Taka/kg)	b_{55}	1684.67	980.34	1.72
Price of irrigation, p_6 (Taka/unit land)	b_{56}	169.65	40565.16	0.00
Total area farmed	c_5	-15.74	0.95	-16.50
Regional dummy - Debidwar	d_{51}	217.95	53.62	4.06
Regional dummy - Gopalpur	d_{52}	109.42	40.16	2.72
Regional dummy - Dacope	d_{53}	442.11	53.95	8.19
Regional dummy - Ulipur	d_{54}	40.90	75.22	0.54
Regional dummy - Mohanganj	d_{55}	341.73	55.17	6.19
Regional dummy - Ghior	d_{56}	-139.50	37.42	-3.73
Regional dummy - Katchua	d_{57}	100.38	48.17	2.08
Time dummy - Year-1	t_{51}	5.49	25.32	0.22
Time dummy - Year-2	t_{52}	42.13	28.91	1.46
Censor correction parameter	δ_5	53.86	40.99	1.31

R-Square: 0.2546

$$-y_6 = \Phi(\boldsymbol{\Omega}`\boldsymbol{\alpha_6})\,[a_6 + b_{16}p_1 + b_{26}p_2 + b_{36}p_3 + b_{46}p_4 + b_{56}p_5 + b_{66}p_6 + c_6 z$$
$$+ d_{61}\,\text{Debidwar} + d_{62}\,\text{Gopalpur} + d_{64}\,\text{Ulipur} + d_{65}\,\text{Mohanganj} + d_{66}\,\text{Ghior}$$
$$+ t_{61}\,\text{Year-1} + t_{62}\,\text{Year-2}] + \delta_6\phi(\boldsymbol{\Omega}`\boldsymbol{\alpha_6})$$

Table A7: Dependent Variable: Irrigation Demand ($-y_6$)

Description	Parameter	Estimate	Std Err	t Value
Intercept	a_6	-135.83	39.79	-3.41
Price of cereal, p_1 (Taka/kg)	b_{16}	102.62	113.46	0.90
Price of potato, p_2 (Taka/kg)	b_{26}	-249.54	273.26	-0.91
Price of cash crop, p_3 (Taka/kg)	b_{36}	-62.43	14921.2	0.00
Price of fish, p_4 (Taka/kg)	b_{46}	-7.29	903.23	-0.01
Price of fertilizer, p_5 (Taka/kg)	b_{56}	169.65	40565.1	0.00
Price of irrigation, p_6 (Taka/unit land)	b_{66}	70.28	14763.0	0.00
Total area farmed	c_6	-29.49	0.92	-32.16
Regional dummy - Debidwar	d_{61}	112.93	25.79	4.38
Regional dummy - Gopalpur	d_{62}	-11.70	29.73	-0.39
Regional dummy - Ulipur	d_{64}	54.97	36.15	1.52
Regional dummy - Mohanganj	d_{65}	184.10	31.41	5.86
Regional dummy - Ghior	d_{66}	76.15	27.93	2.73
Time dummy - Year-1	t_{61}	113.42	15.30	7.41
Time dummy - Year-2	t_{62}	175.72	16.66	10.55
Censor correction parameter	δ_6	17.78	28.61	0.62

R-Square: 0.4786

$$-y_7 = \Phi(\boldsymbol{\Omega}`\boldsymbol{\alpha}_7)\,[a_0 - \tfrac{1}{2}b_{11}p_1^2 - b_{12}p_1p_2 - b_{13}p_1p_3 - b_{14}p_1p_4 - b_{15}p_1p_5 - b_{16}p_1p_6 - \tfrac{1}{2}b_{22}p_2^2 - b_{23}p_2p_3 - b_{24}p_2p_4 - b_{25}p_2p_5 - b_{26}p_2p_6 - \tfrac{1}{2}b_{33}p_3^2 - b_{34}p_3p_4 - b_{35}p_3p_5 - b_{36}p_3p_6 - \tfrac{1}{2}b_{44}p_4^2 - b_{45}p_4p_5 - b_{46}p_4p_6 - \tfrac{1}{2}b_{55}p_5^2 - b_{56}p_5p_6 - \tfrac{1}{2}b_{66}p_6^2 + c_7 z + d_{71}\,\text{Debidwar} + d_{72}\,\text{Gopalpur} + d_{73}\,\text{Dacope} + d_{74}\,\text{Ulipur} + d_{75}\,\text{Mohanganj} + d_{76}\,\text{Ghior} + d_{77}\,\text{Kachua} + t_{71}\,\text{Year-1} + t_{72}\,\text{Year-2}] + \delta_7\phi(\boldsymbol{\Omega}`\boldsymbol{\alpha}_7)$$

Table A8: Dependent Variable: Demand for hiring labor ($-y_7$)

Description	Parameter	Estimate	Std Err	t -value
Intercept	a_0	20.62	16.36	1.26
Interaction of prices-cereal*cereal p_1^2	b_{11}	874.54	902.25	0.97
Interaction of prices-cereal*potato, p_1p_2	b_{12}	-43.87	778.61	-0.06
Interaction of prices-cereal*cash crop, p_1p_3	b_{13}	229.58	269.06	0.85
Interaction of prices-cereal*fish, p_1p_4	b_{14}	-42.85	27.32	-1.57
Interaction of prices-cereal*fertilizer, p_1p_5	b_{15}	-603.27	262.35	-2.30
Interaction of prices-cereal*irrigation, p_1p_6	b_{16}	102.62	113.46	0.90
Interaction of prices – potato*potato, p_2^2	b_{22}	3551.33	1124.28	3.16
Interaction of prices-potato*cash crop, p_2p_3	b_{23}	66.64	335.86	0.20
Interaction of prices-potato*fish, p_2p_4	b_{24}	-38.61	27.49	-1.40
Interaction of prices-potato*fertilizer, p_2p_5	b_{25}	-144.30	359.20	-0.40
Interaction of prices-potato*irrigation, p_2p_6	b_{26}	-249.54	273.26	-0.91
Interaction of prices-cashcrop *cashcrop, p_3^2	b_{33}	232.31	140.71	1.65
Interaction of prices-cash crop*fish, p_3p_4	b_{34}	-1.86	9.16	-0.20
Interaction of prices-cashcrop*fertilizer, p_3p_5	b_{35}	-625.46	181.38	-3.45
Interaction of prices-cashcrop*irrigation, p_3p_6	b_{36}	-62.43	14921.21	0.00
Interaction of prices-fish*fish, p_4^2	b_{44}	3.19	1.02	3.13
Interaction of prices-fish*fertilizer, p_4p_5	b_{45}	3.60	16.29	0.22
Interaction of prices-fish*irrigation, p_4p_6	b_{46}	-7.29	903.23	-0.01
Interaction of prices-fertilizer*fertilizer, p_5^2	b_{55}	1684.67	980.34	1.72
Interaction of prices-fertilizer*irrigation, p_5p_6	b_{56}	169.65	40565.16	0.00
Interaction of prices-irrigation*irrigation, p_6^2	b_{66}	70.28	14763.03	0.00
Total area farmed	c_7	-6.10	0.25	-24.15
Regional dummy-Debidwar	d_{71}	10.36	12.81	0.81
Regional dummy-Gopalpur	d_{72}	60.19	10.06	5.98
Regional dummy-Dacope	d_{73}	43.08	12.30	3.50
Regional dummy-Ulipur	d_{74}	-33.12	18.47	-1.79
Regional dummy-Mohanganj	d_{75}	49.82	14.80	3.37
Regional dummy-Ghior	d_{76}	-0.03	8.95	0.00
Regional dummy-Kachua	d_{77}	15.63	13.83	1.13
Time dummy-Year-1	t_{71}	6.04	6.39	0.95
Time dummy-Year-2	t_{72}	4.88	6.53	0.75
Censor correction parameter	δ_7	-30.79	9.52	-3.23

R-Square: 0.3617

Table A9: Dependent Variable: Cereal (rice, wheat) Cultivated (yes/no)

	Estimate	Std. Error	Chi-Square	Pr > ChiSq
Intercept	2.990	0.419	51.019	<.0001
Total area farmed	0.053	0.008	43.242	<.0001
% of low elevation land	-0.175	0.120	2.135	0.1439
Number of adult equivalent in the HH	-0.006	0.023	0.072	0.7887
Hired agricultural labor? dummy	-0.960	0.079	148.383	<.0001
Used irrigation? dummy	-1.025	0.093	122.759	<.0001
Annual income from non-farm activity	-0.100	0.020	25.860	<.0001
Distance from HH to main market	0.051	0.039	1.697	0.1927
Debidwar, regional dummy	-0.414	0.440	0.886	0.3466
Gopalpur, regional dummy	0.204	0.649	0.099	0.753
Dacope, regional dummy	-0.532	0.449	1.404	0.2361
Ulipur, regional dummy	-1.242	0.429	8.398	0.0038
Mohanganj, regional dummy	-1.520	0.427	12.661	0.0004
Ghior, regional dummy	-1.088	0.427	6.502	0.0108
Kachua, regional dummy	-0.566	0.439	1.664	0.1971
Year-1, time dummy	-0.478	0.470	1.033	0.3096
Year-2, time dummy	-0.730	0.436	2.801	0.0942
Debidwar*year1	0.282	0.540	0.273	0.6017
Debidwar*year2	-1.107	0.495	5.009	0.0252
Gopalpur *year1	-0.442	0.746	0.351	0.5536
Gopalpur *year2	-1.134	0.694	2.671	0.1022
Dacope *year1	-0.220	0.529	0.174	0.677
Dacope *year2	0.371	0.504	0.541	0.4619
Ulipur *year1	0.100	0.524	0.036	0.8492
Ulipur *year2	0.958	0.502	3.644	0.0563
Mohanganj *year1	0.942	0.531	3.145	0.0762
Mohanganj *year2	0.682	0.491	1.933	0.1644
Ghior *year1	0.621	0.534	1.352	0.2449
Ghior *year2	0.302	0.491	0.379	0.5382
Kachua *year1	-0.092	0.533	0.030	0.8628
Kachua *year2	0.098	0.503	0.038	0.8458

Log Likelihood -808.245344

Table A10: Dependent Variable: Potato Cultivated (yes/no)

	Estimate	Std. Error	Chi-Square	Pr > ChiSq
Intercept	-1.234	0.161	58.634	<.0001
Total area farmed	0.023	0.004	30.719	<.0001
% of low elevation land	-0.501	0.102	24.115	<.0001
Number of adult equivalent in the HH	0.090	0.014	41.206	<.0001
Hired agricultural labor ? dummy	-0.394	0.077	26.184	<.0001
Used irrigation? dummy	-0.253	0.076	11.051	0.0009
Annual income from non-farm activity	-0.080	0.017	20.776	<.0001
Distance from HH to main market	-0.064	0.033	3.852	0.0497
Debidwar, regional dummy	1.628	0.174	87.599	<.0001
Gopalpur, regional dummy	1.040	0.178	34.336	<.0001
Dacope, regional dummy	0.051	0.239	0.045	0.8327
Ulipur, regional dummy	0.533	0.179	8.869	0.0029
Mohanganj, regional dummy	0.195	0.193	1.020	0.3125
Ghior, regional dummy	0.388	0.178	4.756	0.0292
Kachua, regional dummy	-0.032	0.278	0.014	0.907
Year-1, time dummy	0.520	0.173	9.081	0.0026
Year-2, time dummy	0.791	0.171	21.315	<.0001
Debidwar*year1	-0.655	0.232	7.962	0.0048
Debidwar*year2	-1.034	0.232	19.920	<.0001
Gopalpur *year1	-0.326	0.239	1.860	0.1727
Gopalpur *year2	-1.523	0.242	39.688	<.0001
Dacope *year1	0.457	0.269	2.899	0.0887
Dacope *year2	-1.598	0.358	19.924	<.0001
Ulipur *year1	-0.116	0.242	0.231	0.6306
Ulipur *year2	-0.490	0.241	4.114	0.0425
Mohanganj *year1	-0.810	0.269	9.091	0.0026
Mohanganj *year2	-0.797	0.261	9.315	0.0023
Ghior *year1	-0.130	0.237	0.301	0.5835
Ghior *year2	-0.605	0.239	6.420	0.0113
Kachua *year1	-0.876	0.396	4.898	0.0269
Kachua *year2	-0.652	0.354	3.403	0.0651

Log Likelihood -1498.880383

Table A11: Dependent Variable: Cash crop (Jute, Chili, Oil seed, Fruit, Vegetable) Cultivated (yes/no)

	Estimate	Std. Error	Chi-Square	Pr > ChiSq
Intercept	0.842	0.207	16.602	<.0001
Total area farmed	0.031	0.009	12.077	0.0005
% of low elevation land	-0.372	0.127	8.597	0.0034
Number of adult equivalent in the HH	0.137	0.029	22.397	<.0001
Hired agricultural labor? dummy	-0.162	0.100	2.627	0.1051
Used irrigation? dummy	-0.192	0.109	3.099	0.0783
Annual income from non-farm activity	-0.079	0.022	12.441	0.0004
Distance from HH to main market	-0.136	0.046	8.570	0.0034
Debidwar, regional dummy	0.000	0.192	0.000	0.9984
Gopalpur, regional dummy	0.953	0.331	8.313	0.0039
Dacope, regional dummy	-0.506	0.239	4.464	0.0346
Ulipur, regional dummy	0.785	0.256	9.407	0.0022
Mohanganj, regional dummy	0.637	0.254	6.290	0.0121
Ghior, regional dummy	0.483	0.229	4.446	0.035
Kachua, regional dummy	0.430	0.198	4.729	0.0297
Year-1, time dummy	1.003	0.239	17.551	<.0001
Year-2, time dummy	0.486	0.180	7.291	0.0069
Debidwar*year1	-0.496	0.324	2.337	0.1263
Debidwar*year2	-0.129	0.269	0.231	0.6307
Gopalpur *year1	-0.625	0.559	1.249	0.2637
Gopalpur *year2	-0.517	0.437	1.398	0.2371
Dacope *year1	-0.068	0.317	0.046	0.8298
Dacope *year2	1.502	0.373	16.220	<.0001
Ulipur *year1	-0.207	0.523	0.156	0.6927
Ulipur *year2	0.070	0.405	0.030	0.8627
Mohanganj *year1	-0.336	0.436	0.595	0.4407
Mohanganj *year2	0.236	0.412	0.328	0.5669
Ghior *year1	-0.851	0.362	5.522	0.0188
Ghior *year2	-0.993	0.292	11.575	0.0007

Log Likelihood -585.8124004

Table A12: Dependent Variable: Fish Cultivated (yes/no)

	Estimate	Std. Error	Chi-Square	Pr > ChiSq
Intercept	-4.581	0.243	355.590	<.0001
Total area farmed	0.029	0.005	28.235	<.0001
% of low elevation land	1.653	0.125	174.197	<.0001
Number of adult equivalent in the HH	0.078	0.023	12.027	0.0005
Hired agricultural labor? dummy	-0.506	0.144	12.277	0.0005
Annual income from non-farm activity	0.110	0.029	14.107	0.0002
Distance from HH to main market	0.605	0.038	248.359	<.0001

Log Likelihood -406.4283098

Table A13: Dependent Variable: Fertilizer used (yes/no)

	Estimate	Std. Error	Chi-Square	Pr > ChiSq
Intercept	2.618	0.316	68.632	<.0001
Total area farmed	0.031	0.007	18.127	<.0001
% of low elevation land	-0.190	0.122	2.457	0.117
Number of adult equivalent in the HH	0.003	0.024	0.020	0.8884
Hired agricultural labor? dummy	-1.150	0.087	174.510	<.0001
Used irrigation? dummy	-1.252	0.107	136.407	<.0001
Annual income from non-farm activity	-0.116	0.022	28.989	<.0001
Distance from HH to main market	0.029	0.040	0.540	0.4625
Debidwar, regional dummy	-0.062	0.330	0.036	0.8506
Gopalpur, regional dummy	0.538	0.496	1.176	0.2783
Dacope, regional dummy	-0.259	0.335	0.596	0.4402
Ulipur, regional dummy	-0.235	0.350	0.450	0.5026
Mohanganj, regional dummy	-0.566	0.334	2.879	0.0897
Ghior, regional dummy	0.255	0.357	0.513	0.474
Kachua, regional dummy	0.146	0.340	0.185	0.6669
Year-1, time dummy	-0.365	0.341	1.145	0.2847
Year-2, time dummy	-0.343	0.327	1.101	0.2941
Debidwar*year1	0.363	0.421	0.746	0.3877
Debidwar*year2	0.188	0.402	0.220	0.6394
Gopalpur *year1	0.890	0.750	1.408	0.2354
Gopalpur *year2	-0.006	0.582	0.000	0.9921
Dacope *year1	0.324	0.399	0.658	0.4172
Dacope *year2	-0.783	0.383	4.193	0.0406
Ulipur *year1	0.511	0.460	1.236	0.2662
Ulipur *year2	0.680	0.446	2.329	0.127
Mohanganj *year1	0.699	0.430	2.645	0.1039
Mohanganj *year2	0.900	0.414	4.723	0.0298
Ghior *year1	0.072	0.458	0.025	0.8753
Ghior *year2	-0.115	0.435	0.070	0.7912
Kachua *year1	0.805	0.440	3.345	0.0674
Kachua *year2	0.408	0.417	0.961	0.327

Log Likelihood -690.5571445

Table A14: Dependent Variable: Irrigation used (yes/no)

	Estimate	Std. Error	Chi-Square	Pr > ChiSq
Intercept	1.035	0.135	59.146	<.0001
Total area farmed	-0.025	0.005	28.341	<.0001
% of low elevation land	-0.156	0.088	3.135	0.0766
Number of adult equivalent in the HH	0.061	0.016	15.085	0.0001
Hired agricultural labor? dummy	-1.262	0.070	322.521	<.0001
Annual income from non-farm activity	-0.154	0.016	89.943	<.0001
Distance from HH to main market	-0.434	0.031	196.918	<.0001
Debidwar, regional dummy	0.275	0.142	3.760	0.0525
Gopalpur, regional dummy	1.645	0.208	62.275	<.0001
Ulipur, regional dummy	0.944	0.170	30.988	<.0001
Mohanganj, regional dummy	1.538	0.169	83.048	<.0001
Ghior, regional dummy	0.340	0.144	5.534	0.0187
Year-1, time dummy	-0.011	0.114	0.009	0.9234
Year-2, time dummy	-0.039	0.115	0.113	0.7367
Debidwar*year1	-0.335	0.194	2.986	0.084
Debidwar*year2	0.455	0.199	5.224	0.0223
Gopalpur *year1	0.260	0.294	0.782	0.3766
Gopalpur *year2	0.078	0.275	0.080	0.7778
Ulipur *year1	0.090	0.233	0.150	0.6983
Ulipur *year2	0.068	0.227	0.090	0.7646
Mohanganj *year1	-0.689	0.220	9.821	0.0017
Mohanganj *year2	-0.843	0.220	14.715	0.0001
Ghior *year1	0.334	0.203	2.726	0.0987
Ghior *year2	0.490	0.201	5.941	0.0148

Log Likelihood -1390.946269

Table A15: Dependent Variable: Agricultural hired labor used (yes/no)

	Estimate	Std. Error	Chi-Square	Pr > ChiSq
Intercept	1.296	0.195	44.144	<.0001
Total area farmed	0.135	0.008	255.584	<.0001
% of low elevation land	0.010	0.104	0.009	0.9254
Number of adult equivalent in the HH	-0.038	0.019	4.169	0.0412
Used irrigation? dummy	-1.167	0.075	239.966	<.0001
Annual income from non-farm activity	-0.063	0.018	12.947	0.0003
Distance from HH to main market	-0.003	0.033	0.010	0.9223
Debidwar, regional dummy	0.131	0.216	0.367	0.5448
Gopalpur, regional dummy	-0.540	0.217	6.169	0.013
Dacope, regional dummy	0.005	0.249	0.001	0.9828
Ulipur, regional dummy	0.165	0.237	0.488	0.485
Mohanganj, regional dummy	-0.755	0.225	11.273	0.0008
Ghior, regional dummy	0.034	0.225	0.023	0.8784
Kachua, regional dummy	0.197	0.239	0.684	0.4082
Year-1, time dummy	-0.172	0.218	0.629	0.4279
Year-2, time dummy	-0.393	0.208	3.552	0.0595
Debidwar*year1	0.398	0.295	1.821	0.1772
Debidwar*year2	-0.419	0.278	2.281	0.131
Gopalpur *year1	-0.148	0.292	0.257	0.6121
Gopalpur *year2	-0.114	0.282	0.163	0.6865
Dacope *year1	-0.057	0.309	0.034	0.8542
Dacope *year2	0.560	0.309	3.272	0.0705
Ulipur *year1	-0.156	0.318	0.241	0.6237
Ulipur *year2	0.066	0.308	0.045	0.8315
Mohanganj *year1	0.267	0.304	0.772	0.3797
Mohanganj *year2	0.369	0.293	1.583	0.2083
Ghior *year1	-0.265	0.304	0.758	0.384
Ghior *year2	-0.569	0.289	3.865	0.0493
Kachua *year1	-0.143	0.310	0.213	0.6447
Kachua *year2	0.180	0.303	0.352	0.5531

Log Likelihood -1166.926319

Appendix B: An Example to Determine Main Market

Example: How the location of "main market" and price of rice in that market is determined in Gopalpur-1

Tail end of the road				Head end of the road			
Year	Market location where transaction took place	Number of transaction took place	Price of rice	Year	Market location where transaction took place	Number of transaction took place	Price of rice
Baseline	Home	49	5.97	Baseline	Home	69	6.01
	Tail end	9	6.95		Mid road	12	6.81
	Mid road	**90**	**6.20**		**Off road**	**95**	**6.41**
	Home+Mid	25	6.57		Home+Off	26	6.26
	Tail+Mid	18	6.33		Mid+Off	22	6.13
	Off road	12	7.19				
Post 1	Home	52	5.72	Post 1	Home	67	5.15
	Tail end	26	6.45		Mid road	23	5.94
	Mid road	**100**	**5.79**		**Off road**	**89**	**6.40**
	Home+Mid	23	5.67		Home+Off	22	5.40
	Tail+Mid	28	5.97				
	Off road	10	6.76				
Post 2	Home	15	7.46	Post 2	Home	42	8.05
	Tail end	7	7.61		Mid road	5	9.45
	Mid road	**30**	**7.57**		**Off road**	**45**	**8.32**
	Home+Mid	5	7.70		Home+Off	12	7.89
	Tail+Mid	10	7.75		Mid+Off	18	9.14
	Off road	6	8.07				

Note: the bold face letters indicate the "main market" and prices of rice over three years

Appendix C: Derivation of Elasticity of Demand

Normalized quadratic profit function

$$\pi(\tilde{\mathbf{p}}, z) = \beta_0 + \sum_{j=1}^{k-1} \beta_j \tilde{p}_j + \tfrac{1}{2} \sum_{j=1}^{k-1} \sum_{j=1}^{k-1} \beta_{jj} \tilde{p}_j \tilde{p}_j + \sum_{j=1}^{k-1} \beta_{j7} z \tilde{p}_j + \beta_8 z$$

where $p_1, p_2, p_3, p_4, p_5, p_6, p_7$ are prices of rice, potato, cash crop, fish, fertilizer, irrigation, labor respectively, unit transport cost t (assumed same for all goods), z land under cultivation and

$$\tilde{p}_j = \frac{p_j - t}{p_7} \text{ for } j = 1,2,3,4 \qquad \tilde{p}_j = \frac{p_j + t}{p_7} \text{ for } j = 5 \qquad \tilde{p}_j = \frac{p_j}{p_7} \text{ for } j = 6 \qquad \tilde{t} = \frac{t}{p_7}$$

First Stage: Probit Model

From probit estimate we get the cdf and pdf

$$\Phi_i(x_i) = \tfrac{1}{\sqrt{2\pi}} \int e^{-\frac{1}{2}x_i^2} dx_i \qquad \text{...........(1)}$$

$$\phi_i(x_i) = \tfrac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}x_i^2} \qquad \text{...........(2)}$$

where, $x_i(\Omega, z, D) = \alpha_i + \sum_{k=1}^{5} \alpha_{ik} \Omega_k + \alpha_{i6} z + \sum_{l=7}^{19} \alpha_{il} D_l$

Ω_k Household characteristics

D_l Dummy variables (region, year)

Second Stage: System of Demand Equation derived from the profit function

$$y_i = f_i(p_j, t, z, D_l) + \varepsilon_i \qquad \text{...........(3)}$$

Where

$$\text{for } i = 1,2,3,4 \quad f_i(p_j, t, z, D_l) = \beta_i + \sum_{j=1}^{6} \beta_{ij}\tilde{p}_j + \beta_{i7} z + \sum_{l=8}^{17} \beta_{il} D_l$$

$$\text{for } i = 5,6 \quad f_i(p_j, t, z, D_l) = -\beta_i - \sum_{j=1}^{6} \beta_{ij}\tilde{p}_j - \beta_{i7} z - \sum_{l=8}^{17} \beta_{il} D_l$$

$$\text{for } i = 7 \quad f_i(p_j, t, z, D_l) = \left(\sum_{i=1}^{6}\sum_{j=1}^{6} \beta_{ij}\tilde{p}_i\tilde{p}_j + \sum_{j=1}^{6} \beta_j \tilde{p}_j + \sum_{j=1}^{6} \beta_{j7} z \tilde{p}_j \right) \frac{1}{p_7} - \sum_{l=8}^{17} \beta_{il} D_l$$

After correction for censoring the demand system takes the form

$$y_i = \Phi_i(\Omega_k, z, D_l, \alpha_{ij}) f_i(p_j, t, z, D_l, \beta_{ij}) + \delta_i \phi_i(\Omega_k, z, D_l, \alpha_{ij}) + \zeta_i$$

Elasticity:

$$\varepsilon_{ij} = \frac{\partial y_i}{\partial p_j}\frac{p_j}{y_i} = \Phi_i f'_{ip_j} \frac{p_j}{y_i} \qquad \ldots\ldots\ldots\ldots(4)$$

$$\varepsilon_{it} = \frac{\partial y_i}{\partial t}\frac{t}{y_i} = \Phi_i f'_{it} \frac{t}{y_i} \qquad \ldots\ldots\ldots\ldots(5)$$

Derivatives:

$\underline{i = 1,2,3,4}$

$$f'_{ip_j} = \beta_{ij}\frac{1}{p_7} \qquad \text{for } j = 1\ldots\ldots.6$$

$$f'_{ip_7} = -\left(\sum_{j=1}^{6} \beta_{ij}\tilde{p}_j \right)\frac{1}{p_7} \quad f'_{it} = \left(-\sum_{j=1}^{4} \beta_{ij} + \beta_{i5} \right)\frac{1}{p_7}$$

$\underline{i = 5,6}$

$$f'_{ip_j} = -\beta_{ij}\frac{1}{p_7} \qquad \text{for } j = 1\ldots\ldots.6$$

$$f'_{ip_7} = \left(\sum_{j=1}^{6} \beta_{ij} \tilde{p}_j \right) \frac{1}{p_7} \qquad f'_{it} = \left(\sum_{j=1}^{4} \beta_{ij} - \beta_{i5} \right) \frac{1}{p_7}$$

<u>$i = 7$</u>

$$f'_{ip_j} = 2\left(\sum_{i=1}^{6} \beta_{ji} \tilde{p}_i \right) \frac{1}{p_7^2} + \left(\beta_j + \beta_{j7} z \right) \frac{1}{p_7^2} \qquad \text{for } j = 1.......6$$

$$f'_{ip_7} = -\left(2\sum_{i=1}^{6} \sum_{j=1}^{6} \beta_{ij} \tilde{p}_j \tilde{p}_j + \sum_{j=1}^{6} \beta_j \tilde{p}_j + \sum_{j=1}^{6} \beta_{j7} z \tilde{p}_j \right) \frac{1}{p_7^2}$$

$$f'_{it} = \left[2\left\{ -\sum_{i=1}^{4} \sum_{j=1}^{4} \beta_{ij} \left(\tilde{p}_i + \tilde{p}_j \right) + \sum_{j=1}^{4} \beta_{j5} \left(\tilde{p}_j - \tilde{p}_5 \right) - \sum_{j=1}^{4} \beta_{j6} \tilde{p}_6 + \beta_{56} \tilde{p}_6 + \beta_{55} \tilde{p}_5 \right\} + \left\{ -\sum_{j=1}^{4} \beta_j + \beta_5 - \sum_{j=1}^{4} \beta_{j7} z + \beta_{57} z \right\} \right] \frac{1}{p_7^2}$$

Expression for elasticity: substituting the above results into equation (4) and (5)

<u>$i = 1,2,3,4$</u>

$$\varepsilon_{ij} = \Phi_i \beta_{ij} \left(\tilde{p}_j + \tilde{t} \right) \frac{1}{y_i} \qquad \text{for } j = 1......6$$

$$\varepsilon_{ip_7} = -\Phi_i \left(\sum_{j=1}^{6} \beta_{ij} \tilde{p}_j \right) \frac{1}{y_i} \qquad \varepsilon_{it} = -\Phi_i \left(\sum_{j=1}^{4} \beta_{ij} + \beta_{i5} \right) \frac{\tilde{t}}{y_i}$$

<u>$i = 5,6$</u>

$$\varepsilon_{ij} = -\Phi_i \beta_{ij} \left(\tilde{p}_j + \tilde{t} \right) \frac{1}{y_i} \qquad \text{for } j = 1......6$$

$$\varepsilon_{ip_7} = \Phi_i \left(\sum_{j=1}^{6} \beta_{ij} \tilde{p}_j \right) \frac{1}{y_i} \qquad \varepsilon_{it} = \Phi_i \left(\sum_{j=1}^{4} \beta_{ij} - \beta_{i5} \right) \frac{\tilde{t}}{y_i}$$

<u>$i = 7$</u>

$$\varepsilon_{ij} = 2\Phi_i \left\{ \left(\sum_{i=1}^{6} \beta_{ji} \tilde{p}_i \right) + \left(\beta_j + \beta_{j7} z \right) \right\} \frac{\tilde{p}_j}{y_i p_7} \qquad \text{for } j = 1.......6$$

$$\varepsilon_{ip_7} = -\Phi_i\left(2\sum_{i=1}^{6}\sum_{j=1}^{6}\beta_{ij}\tilde{p}_j\tilde{p}_j + \sum_{j=1}^{6}\beta_j\tilde{p}_j + \sum_{j=1}^{6}\beta_{j7}z\tilde{p}_j\right)\frac{1}{y_i p_7}$$

$$\varepsilon_{it} = 2\Phi_i\left[\left\{-\sum_{i=1}^{4}\sum_{j=1}^{4}\beta_{ij}\left(\tilde{p}_i + \tilde{p}_j\right) + \sum_{j=1}^{4}\beta_{j5}\left(\tilde{p}_j - \tilde{p}_5\right) - \sum_{j=1}^{4}\beta_{j6}\tilde{p}_6 + \beta_{56}\tilde{p}_6 + \beta_{55}\tilde{p}_5\right\} + \left\{-\sum_{j=1}^{4}\beta_j + \beta_5 - \sum_{j=1}^{4}\beta_{j7}z + \beta_{57}z\right\}\right]\frac{\tilde{t}}{y_i p_7}$$

Note that in this study it is assumed that the prices and transport cost does not affect the decision of choosing a particular crop to grow. The probability of growing a crop is a function of only region specific household characteristics and not the market prices or change in transport cost due to road improvement. This assumption has a significant impact on the computation of marginal effects. The general expression for marginal effects becomes $\varepsilon_{ij} = \frac{\partial y_i}{\partial p_j}\frac{p_j}{y_i} = \Phi(\mathbf{\Omega}, \boldsymbol{\alpha}_\mathbf{i})f'(\mathbf{p}, t, z, \boldsymbol{\beta}_\mathbf{i})\frac{p_j}{y_i}$, when region specific household characteristics are the only determinants. The commodity specific expressions for marginal effects derived in this annex are based on these assumptions. The general expression of marginal effects becomes the following when market prices and transport costs are taken into consideration in addition to household characteristics.

$$\varepsilon_{ij} = \frac{\partial y_i}{\partial p_j}\frac{p_j}{y_i} = [\Phi'(\mathbf{\Omega}, \mathbf{p}, t, z, \boldsymbol{\alpha}_\mathbf{i})f(\mathbf{p}, t, z, \boldsymbol{\beta}_\mathbf{i}) + \Phi(\mathbf{\Omega}, \mathbf{p}, t, z, \boldsymbol{\alpha}_\mathbf{i})f'(\mathbf{p}, t, z, \boldsymbol{\beta}_\mathbf{i}) + \delta_i\varphi'(\mathbf{\Omega}, \mathbf{p}, t, z, \boldsymbol{\alpha}_\mathbf{i})]\frac{p_j}{y_i}$$

Appendix D: Technical Aspects of Profit Function

The focus of this study is to estimate a system of demand equations. There are at least two distinct methods of deriving a system of profit maximization input demand and output supply functions. One method would be to postulate a functional form for a production function, and then use Lagrangian or mathematical programming techniques in order to solve the profit maximization problem. The second method would be to postulate a functional form for a profit function and obtain the system of derived demand function by differentiation using Hotteling's Lama. The difficulty with the former method is that, if we take a "flexible" functional form (the reason of using this form will be discussed later) for the production function then it is usually impossible to obtain the derived demand functions as explicit functions in the unknown parameter of production function. For profit function it is very easy to use a flexible functional form. The derived demand functions can be calculated by differentiation of the profit function.

In fact, there is not much difference between the two approaches. By estimating the parameters of the profit function we actually estimate the parameter of the production function and vice versa. Lau (1978) clarified this point by showing that the primal production function and the dual profit function are related directly through Hessain matrices. In particular, $-\left[F_{ij}\right]^{-1} = \left[G_{ij}\right]$ where $\left[F_{ij}\right]$ and $\left[G_{ij}\right]$ are the $(n \times n)$ Hessain matrices of the production function and the profit function respectively. $\left[G_{ij}\right]$ contains all the parameters of the profit function, which is equal to the negative of the inverse of the parameters of the production function $-\left[F_{ij}\right]^{-1}$. So by estimating the parameters of the profit function we actually indirectly estimate the parameter of the underlying production function. Bette and Taylor (1993) cited an example how the production function can be recovered from a profit function using a simplified functional form. However, recovering the production function from a flexible functional form to represent a profit function it is not straightforward. The main justification of using profit function instead of production function lies in the convenience of using flexible functional form.

The profit function is formulated on the assumption of profit maximization behavior. Production behavior may deviate from the idealized profit maximizing behavior pattern and fail to achieve exactly the desired marginal products of inputs. This may happen when the objective function of the farm differs from profit maximization. The firm's objective could be utility maximization, not profit maximization. Utility depends not only on profit, but also on other variables like uncertainty and the leisure component in a production plan. It then follows that classical first order conditions for profit maximization mis-specify the true behavioral conditions, and therefore estimation of a system of commodity demand equations containing erroneous first-order conditions can deteriorate the quality of estimates.

D1 Convexity of Profit Function

The profit function relies heavily on convexity property. The profit function is always convex if the output and input markets are competitive under the assumption of profit maximization. If the estimated profit function is non-convex, the own- and cross-price supply and demand elasticity will not have the theoretically expected signs and magnitudes; which is inconsistent with the basic behavioral postulate of the theory of production. To obtain economically meaningful estimates in practical applications the convexity property should at least be tested, or impose when the test fail to demonstrate maintaining convexity property.

In the past, empirical estimation of the parameters of these functions has been limited to those of rather simple algebraic form for which the convexity is either automatically or readily satisfied or can be easily imposed. For example, the linear function is always convex (and concave); the Cobb-Douglas production function that estimated by the factor share method is always convex. Thus, there has not been any pressing need for the development of convexity.

However, the extensive use of flexible functional form in empirical economic analysis has made it necessary to maintain convexity. For an arbitrary set of parameters, these functions do not necessarily satisfy convexity condition, either locally or globally. Hence there is a need to test or maintain these hypotheses.

Is it necessary that the profit function have to be globally convex? In most applied econometric studies, local convexity conditions will suffice, since only variables with values within a certain domain will be relevant. Moreover, in the cases where the function has to be estimated from actual data, it does not make too much sense to extrapolate the results too far away from the sample data anyhow. Thus, for all practical purposes one needs only to maintain the convexity properties within a prescribed domain.

D2 Imposing Convexity

The solution to the problem of convexity makes use of the properties of the Hessian matrix of a convex function. A twice-differentiable real-valued function is convex on an open convex set if and only if the Hessian is positive semi-definite everywhere on the open convex set. For a profit function the Hessian matrix is symmetric. A symmetric Hessian matrix **B** is positive definite (semi-definite) if $\mathbf{B} = \mathbf{AA}^{`}$. Where **A** is a lower triangular squire matrix for which $\mathbf{A}_{ij} = 0$ for j >i. Maintaining this condition is necessary to impose convexity on the profit function.

$$\mathbf{AA}^{`} = \begin{bmatrix} a_{11} & 0 & 0 & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 & 0 & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} & 0 & 0 \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} & 0 \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & a_{66} \end{bmatrix} \begin{bmatrix} a_{11} & a_{21} & a_{31} & a_{41} & a_{51} & a_{61} \\ 0 & a_{22} & a_{32} & a_{42} & a_{52} & a_{62} \\ 0 & 0 & a_{33} & a_{43} & a_{53} & a_{63} \\ 0 & 0 & 0 & a_{44} & a_{54} & a_{64} \\ 0 & 0 & 0 & 0 & a_{55} & a_{65} \\ 0 & 0 & 0 & 0 & 0 & a_{66} \end{bmatrix}$$

$$= \begin{bmatrix} a_{11}^2 & & & & & \\ a_{21}a_{11} & a_{21}^2 + a_{22}^2 & & & & \\ a_{31}a_{11} & a_{21}a_{31} + a_{32}a_{22} & a_{31}^2 + a_{32}^2 + a_{33}^2 & & & \\ a_{41}a_{11} & a_{21}a_{41} + a_{42}a_{22} & a_{31}a_{41} + a_{32}a_{42} + a_{43}a_{33} & a_{41}^2 + a_{42}^2 + a_{43}^2 + a_{44}^2 & & \\ a_{51}a_{11} & a_{21}a_{51} + a_{52}a_{22} & a_{31}a_{51} + a_{32}a_{52} + a_{53}a_{33} & a_{41}a_{51} + a_{42}a_{52} + a_{43}a_{53} + a_{54}a_{44} & ..... & \\ a_{61}a_{11} & a_{21}a_{61} + a_{62}a_{22} & a_{31}a_{61} + a_{32}a_{62} + a_{63}a_{33} & a_{41}a_{61} + a_{42}a_{62} + a_{43}a_{63} + a_{64}a_{44} & ..... & ..... \end{bmatrix}$$

For a quadratic profit function the Hessian matrix **B** look like the following:

$$
\mathbf{B} = \begin{bmatrix}
\frac{\partial y_1}{\partial p_1} & & & & & \\
\frac{\partial y_2}{\partial p_1} & \frac{\partial y_2}{\partial p_2} & & & & \\
\frac{\partial y_3}{\partial p_1} & \frac{\partial y_3}{\partial p_2} & \frac{\partial y_3}{\partial p_3} & & & \\
\frac{\partial y_4}{\partial p_1} & \frac{\partial y_4}{\partial p_2} & \frac{\partial y_4}{\partial p_3} & \frac{\partial y_4}{\partial p_4} & & \\
\frac{\partial y_5}{\partial p_1} & \frac{\partial y_5}{\partial p_2} & \frac{\partial y_5}{\partial p_3} & \frac{\partial y_5}{\partial p_4} & \frac{\partial y_5}{\partial p_5} & \\
\frac{\partial y_6}{\partial p_1} & \frac{\partial y_6}{\partial p_2} & \frac{\partial y_6}{\partial p_3} & \frac{\partial y_6}{\partial p_4} & \frac{\partial y_6}{\partial p_5} & \frac{\partial y_6}{\partial p_6}
\end{bmatrix}
= \begin{bmatrix}
\beta_{11} & & & & & \\
\beta_{12} & \beta_{22} & & & & \\
\beta_{13} & \beta_{23} & \beta_{33} & & & \\
\beta_{14} & \beta_{24} & \beta_{34} & \beta_{44} & & \\
\beta_{15} & \beta_{25} & \beta_{35} & \beta_{45} & \beta_{55} & \\
\beta_{16} & \beta_{26} & \beta_{36} & \beta_{46} & \beta_{56} & \beta_{66}
\end{bmatrix}
$$

To impose convexity we need to estimate A_{ij} instead of B_{ij} using the relation $\mathbf{B} = \mathbf{AA}^{`}$, all elements of which is shown below:

$$
\begin{bmatrix}
\beta_{11} & & & & & \\
\beta_{12} & \beta_{22} & & & & \\
\beta_{13} & \beta_{23} & \beta_{33} & & & \\
\beta_{14} & \beta_{24} & \beta_{34} & \beta_{44} & & \\
\beta_{15} & \beta_{25} & \beta_{35} & \beta_{45} & \beta_{55} & \\
\beta_{16} & \beta_{26} & \beta_{36} & \beta_{46} & \beta_{56} & \beta_{66}
\end{bmatrix}
= \begin{bmatrix}
a_{11}^2 & & & & & \\
a_{21}a_{11} & a_{21}^2 + a_{22}^2 & & & & \\
a_{31}a_{11} & a_{21}a_{31} + a_{32}a_{22} & a_{31}^2 + a_{32}^2 + a_{33}^2 & & & \\
a_{41}a_{11} & a_{21}a_{41} + a_{42}a_{22} & a_{31}a_{41} + a_{32}a_{42} + a_{43}a_{33} & ..... & & \\
a_{51}a_{11} & a_{21}a_{51} + a_{52}a_{22} & a_{31}a_{51} + a_{32}a_{52} + a_{53}a_{33} & ..... & ..... & \\
a_{61}a_{11} & a_{21}a_{61} + a_{62}a_{22} & a_{31}a_{61} + a_{32}a_{62} + a_{63}a_{33} & ..... & ..... & .....
\end{bmatrix}
$$

D3 Flexible functional form

A primary objective of estimation of profit function is measurement of the economically relevant information that characterizes the profit maximizing behavior of economic agents. This information includes the value of the function (e.g. the level of profit), the gradient of the function (e.g. the output supply and input demand), and the Hessian (e.g. the matrix of elasticity). For any technology with n netput represented either by its primal or by dual form, there are ½(n+1)(n+2) economically relevant effects (Lau

1978). A profit function representation of technology of n netput has the following economic effects, after maintaining the property of homogeneity and symmetry:

Economic Effect	Formula	Number of distinct effect
The level of profit	$\pi = f(\mathbf{q}, z)$	1
Output supply and input demand	$y_i^*(\mathbf{q}, z) = \dfrac{\partial \pi(\mathbf{q}, z)}{\partial \mathbf{q}_i}$	n
Own price elasticity	$\varepsilon_{ii} = \dfrac{\partial^2 \pi(\mathbf{q}, z)}{\partial \mathbf{q}_i^2}$	n
Cross price elasticity	$\varepsilon_{ij} = \dfrac{\partial^2 \pi(\mathbf{q}, z)}{\partial \mathbf{q}_i \partial \mathbf{q}_j}$	½n(n-1)

A functional form is flexible if it does not impose a priory value to any of these ½(n+1)(n+2) parameters. The flexible form let the data determine these effects. Thus, a functional form in n variables should have at least ½(n+1)(n+2) parameters to be a flexible form. This is best demonstrated by a counter example. Cobb-Douglas production function in two inputs L and K; $y = aL^{\alpha}K^{\beta}$ has three parameters, whereas there are ½(3+1)(3+2)=10 distinct economic effects to be captured. Obviously the three parameters in Cobb-Douglas functional form cannot capture the 10 different effects. Cobb-Douglas function allows no flexibility with respect to own-price and cross price elasticity effects. It assumes elasticity of own (3 effects) and cross price (3 effects) as unity. Thus, Cobb-Douglas is not a flexible functional form. Therefore, in choosing a functional form, one rich enough in parameters to portray all of these effects should be the employed. In the past, empirical estimation of the parameters has been limited to those of rather simple algebraic form such as linear function, Cobb-Douglas function. Because of a general dissatisfaction with the restrictive implications of the simple functional form, there has been a proliferation of the new algebraic form of empirical work in recent years.

D4 Second Order Taylor Approximation

A second order Taylor-series expansion about a point can approximate any true function, which has ½(n+1)(n+2) parameters. It is capable of providing a flexible functional form for the profit function. According to Diewert (1987), a function $G(y)$ is a second order approximation to a function $F(y)$ at y_0 if the first and second derivatives of the two functions are equal at y_0, that is,

$$G(y_0) = F(y_0)$$

$$\left[\frac{\partial G}{\partial y_i}\right]_{y=y_0} = \left[\frac{\partial F}{\partial y_j}\right]_{y=y_0}$$

$$\left[\frac{\partial^2 G}{\partial y_i \partial y_j}\right]_{y=y_0} = \left[\frac{\partial^2 F}{\partial y_i \partial y_j}\right]_{y=y_0}$$

Many properties of a function are not preserved when approximated by a Taylor's series expansion. The properties that are preserved are the values of the first and second derivatives at the point where the approximation is made. Consequently, at this point, the symmetry of the Hessian matrix, as well as the properties of monotonocity and convexity, is preserved. However, for points different from the point of approximation, while symmetry of the Hessian matrix is preserved, other properties are no longer preserved in general. So, care should be exercised in making inferences about the properties of the true function on the basis of properties of the approximating function. Moreover, if a flexible form is calibrated to provide a second order approximation at a point, then the approximation is of this order only, the higher order effects are neglected.

If a flexible form is fitted to observations over an extensive domain, then the fitted form will not in general be a second order approximation to the true function at any chosen point. As a result, the economic effects deduced from the approximation will bear perhaps misleading results to the corresponding effects for the true function. However, usually it does not need to extrapolate the results too far away from the sample data, where the function is approximated; values within a certain domain is relevant for most of the empirical work. Thus, for all practical purposes use of Taylor-series expansion to approximate a true function will suffice.

D5 Semi-Flexible Functional Form

As mentioned earlier, estimation of a flexible functional form requires ½(n+1)(n+) free parameters unless there are special restrictions. If n equals say 20, then a flexible functional form requires 231 parameters. However, most empirical work that utilizes annual time series data is based on data for, say, 20-30 years. This may preclude estimation due to lack of degrees of freedom. Thus, it may be impossible to estimate flexible functional forms in the context of economic models based on time series data involving a large number of goods. Empirical estimation of demand system often encounters a similar problem; the model becomes prohibitively demanding in terms of data as the number of goods being modeled increases. The number of parameters to be estimated increases quadratically as the number of goods increases. For a large demand system, this leads to a degree of freedom problem, which may seriously affect the statistical property of the estimated model. However, there are instances of estimating a large system of equation with many variables. Aradhyula (1989) estimated large system of commodity and factor demand equations consisting thirteen netput using time series agricultural data from Iowa.

Moschini (1998) argued a second reason to consider a restrictive version of the model arises from estimation considerations related to enforcement of convexity property of profit function. When estimation of the unrestricted model yields results that violate convexity, then estimation of the convex model imposing appropriate restrictions may be difficult. Violation of convexity means that some of the eigenvalues are negative. In such a case, estimation of the convex model will tend to drive the eigenvalues that are negative in the unrestricted model to a value close to zero. In other words, estimation under the restriction of convexity is likely to yield a substitution matrix of less than full rank. When this happens, estimation of the (otherwise unrestricted) convex model breaks down because the linearized version of the model entails a singular design matrix. Thus, when unrestricted parameter estimates violate convexity, considering a model with a substitution matrix of rank $k<n$ may be useful to achieve convergence of the parameters of the convex model. The current study suffered convergence problem because of this phenomenon. The problem was overcome following the procedure proposed by Diewert and Wales (1988). This procedure involves equating the symmetric Hessian matrix **B** of the profit function with a restricted version of $\mathbf{AA}^{`}$ matrix, which is as follows:

$$\mathbf{AA}`=\begin{bmatrix} a_{11} & 0 & 0 & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 & 0 & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} & 0 & 0 \\ a_{51} & a_{52} & a_{53} & a_{54} & 0 & 0 \\ a_{61} & a_{62} & a_{63} & a_{64} & 0 & 0 \end{bmatrix}\begin{bmatrix} a_{11} & a_{21} & a_{31} & a_{41} & a_{51} & a_{61} \\ 0 & a_{22} & a_{32} & a_{42} & a_{52} & a_{62} \\ 0 & 0 & a_{33} & a_{43} & a_{53} & a_{63} \\ 0 & 0 & 0 & a_{44} & a_{54} & a_{64} \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

D6 Choice of functional form

The following three most popular functional forms can be considered as a second order Taylor-series expansion

$$\phi(\pi) = \alpha_0 + \mathbf{a}`\mathbf{p} + \tfrac{1}{2}\mathbf{p}`\mathbf{B}\mathbf{p} \qquad \mathbf{B}` = \mathbf{B}$$

with the following notational adjustments

Transcendental logarithmic:	$\phi(\pi) = \ln\pi$	$\mathbf{p}` = [\ln p_1,.....,\ln p_n]$
Generalized Leontief:	$\phi(\pi) = \pi$	$\mathbf{p}` = [\sqrt{p_1},.....,\sqrt{p_n}]$
Quadratic:	$\phi(\pi) = \pi$	$\mathbf{p}` = [p_1,.....,p_n]$

where **a** is a conformable vector and **B** a conformable matrix of parameters to be estimated. Any of these functional forms can be chosen for the profit function.

Thompson and Langworthy (1989) examine the effectiveness of several flexible functional forms such as Translog, Generalized Leontief, Quadratic and two less frequently used forms to approximate a profit function for which the underlying production function is known. They used two indicators to judge the effectiveness, the Allen Uzawa partial elasticity of substitution (AUES) and price elasticity. First they estimated the AUES and price elasticity from the known production function and then using the Monte Carlo simulation they estimated a series of the same result from the profit function of the underlying known production function approximated by flexible functional form. The comparison of results indicates that the relative performance of all five flexible functional forms to estimate AUES and price elasticity were very close. However, the Generalized Leontief demonstrated a little better performance on average.

Estimation of Normalized Quadratic flexible functional forms is attempted in this study because of its special convenience in estimation. The associated demand function of the Normalized Quadratic profit function is linear which is comparatively easier to estimate.

Appendix E: Seemingly Unrelated Regression

Zellner (1962) demonstrated that if the equations were estimated as a system, they would yield coefficient estimates asymptotically more efficiently than equation by equation least square estimates. This extra gain in efficiency is due to the use of the fact that many of the unexplained factors (accumulated in the error term) of individual equations may have some relationship. The multivariate generalized least square, which stacks all the equations into a single system, is capable of using the covariance of error terms among the equations. The equations are linked only by their error terms. Because of this fact this kind of generalized least squire is named as *seemingly unrelated regression*. Stacking m number of equations, k number of variables in each equation with n number of data points we get:

$$\begin{bmatrix} y_1 \\ y_2 \\ .. \\ .. \\ y_m \end{bmatrix}_{mn\times 1} = \begin{bmatrix} \tilde{p}_1 & 0 & & & 0 \\ 0 & \tilde{p}_2 & & & 0 \\ & & .. & & \\ & & & .. & \\ 0 & 0 & & & \tilde{p}_m \end{bmatrix}_{mn\times k} \begin{bmatrix} \beta_1 \\ \beta_2 \\ .. \\ .. \\ \beta_m \end{bmatrix}_{k\times 1} + \begin{bmatrix} \xi_1 \\ \xi_2 \\ .. \\ .. \\ \xi_m \end{bmatrix}_{mn\times 1}$$

$$\text{Or } y_{mn\times 1} = \tilde{p}_{mn\times k}\beta_{k\times 1} + \xi_{mn\times 1}$$

We can think of this formulation as a single equation. The variance-covariance matrix of the error term is $V = E(\xi\xi')$. In the context of cross sectional data it can be assumed that the variances of the error term are the same for all households for a particular equation and that there is no correlation between different households' error terms of a particular equation. Given these assumptions the variance covariance matrix can be written as $V = \Sigma_{m\times m} \otimes I_{n\times n}$, where

$$\Sigma = \begin{bmatrix} \sigma_{11} & \sigma_{12} & .. & .. & \sigma_{1m} \\ \sigma_{12} & \sigma_{22} & .. & .. & \sigma_{m2} \\ .. & .. & .. & .. & .. \\ .. & .. & .. & .. & .. \\ \sigma_{1m} & \sigma_{m2} & .. & .. & \sigma_{mm} \end{bmatrix}$$

Although we formulated the system of equation as a single equation, we cannot apply the ordinary least square (OLS) directly, because OLS assumes that the diagonal elements of the variance-covariance matrix is constant (homocedasticity) and the off diagonal elements are zero (no autocorrelation). Which mean the variance-covariance matrix of OLS is in the form of $\sigma^2 I$. However, it is possible to apply Aitken's generalized least-squares, where the original variables of stacked equations are transformed through pre-multiplying by a matrix $T_{m\times m}$ such that:

$$T_{mn\times mn} y_{mn\times 1} = T_{mn\times mn} \tilde{p}_{mn\times k} \beta_{k\times 1} + T_{mn\times mn} \xi_{mn\times 1} \quad => \underset{mn\times 1}{y^m} = \underset{mn\times k}{\tilde{p}^m} \underset{k\times 1}{\beta} + \underset{k\times 1}{\xi^m}$$

The expectation of the variance covariance matrix of the error term of transformed model, $E(\xi^m \xi^{m'}) = E(T\xi(`T`) = TE(\xi E`)T` = TVT` = I$, is an identity matrix that satisfies the usual assumptions of the least-squares model. Note that for a symmetric squire matrix such as $V_{mn\times mn}$ it is true that TVT = I. Applying OLS to the transformed model we can get

$$\hat{\beta}_{GLS} = (\tilde{p}` V^{-1} \tilde{p})^{-1} \tilde{p}` V^{-1} y$$

$$Var(\hat{\beta}_{GLS}) = \sigma^2 (\tilde{p}` V^{-1} \tilde{p})^{-1}$$

Here $V_{mn\times mn}$ is a very large matrix (recall n is the number of observations and m is the number of equations), which is difficult to invert; but we can eliminate that difficulty by using the relation $V = \Sigma_{m\times m} \otimes I_{n\times n}$.

$$\hat{\beta}_{GLS} = (\tilde{p}`\Sigma^{-1} \otimes I\tilde{p})^{-1}\tilde{p}`\Sigma^{-1} \otimes Iy$$

$$Var(\hat{\beta}_{GLS}) = \sigma^2(\tilde{p}`\Sigma^{-1} \otimes I\tilde{p})^{-1}$$

Inverting a small matrix $\Sigma_{m\times m}$ will suffice. But the problem remains, we do not know $\Sigma_{m\times m}$. However, we can get an estimate of it $(\hat{\Sigma}_{m\times m})$ by applying ordinary least square equation by equation with the assumption that the error terms are not correlated. This method is known as feasible GLS. Substituting $\Sigma_{m\times m}$ with its estimate $\hat{\Sigma}_{m\times m}$ we get the SUR estimates.

$$\hat{\beta}_{FGLS} = \hat{\beta}_{SUR} = (\tilde{p}`\hat{\Sigma}^{-1} \otimes I\tilde{p})^{-1}\tilde{p}`\hat{\Sigma}^{-1} \otimes Iy$$

$$Var(\hat{\beta}_{FGLS}) = Var(\hat{\beta}_{SUR}) = \hat{\sigma}^2(\tilde{p}`\hat{\Sigma}^{-1} \otimes I\tilde{p})^{-1}$$

Appendix F: Glossary

Aus	Pre-monsoon summer rice: traditionally planted during the pre-monsoon rains
Aman	Monsoon rice: planted exclusively at the beginning of the monsoon season
Bill	Vast natural depression
Boro	Post-monsoon rice: planted in the flooded areas, irrigated during the dry winter season
CARE	CARE International, a non-profit organization
Comilla	Name of an administrative district
FFW	Food for work
Grameen Bank	Non-profit organization in Bangladesh, known for its micro-credit program
Haor	Vast natural depression flooded most part of the year, bigger and deeper than *bill*
HYV	High yielding variety
IFFD	Integrated Food For Development
IRR	Internal rate of return
NGO	Non-government organization
Pan	Certain kind of leaves eaten with spices
SIFAD	Strengthening the Institution for Food Assisted Development
Sundarban	The biggest mangrove forest in Bangladesh

Taka	Name of currency of Bangladesh
Thana	Sub-district administrative head quarter
USAID	United States agency of international development

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