THE ECONOMICS OF AQUACULTURE PRODUCTION AND CONSUMPTION EMPHASIZING THE NUTRITIONAL BENEFIT OF THE POOR IN BANGLADESH

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ZUSAMMENFASSUNG

Fisch ist eine wichtige Quelle für hochwertige Proteine und Mikronährstoffe für Menschen auf der ganzen Welt. Es ist die Hauptquelle für tierisches Eiweiß, das mehr als 60 Prozent des gesamten tierischen Eiweißkonsums in Entwicklungsländern ausmacht. Die wachsende Bevölkerung mit höherem Fischkonsum auf der ganzen Welt beeinflusst die globale Nachfrage nach Fisch. Infolgedessen ist in den letzten drei Jahrzehnten ein dramatischer Wandel in der Struktur von Angebot und Nachfrage mit einer steigenden Nachfrage nach Fisch auf nationalen und internationalen Märkten zu beobachten. Ein schnelles Produktionswachstum und ein zunehmender Handel halten mit der wachsenden Nachfrage nach Fisch weltweit Schritt. Durch die Bereitstellung von Fisch aus Fischerei- und Aquakulturquellen hat sich Asien zum Hauptanbieter dieser Expansion entwickelt. Obwohl das globale Angebot an Fangfischereien in den letzten 20 Jahren konstant geblieben ist, hat die Aquakultur den größten Teil zum jüngsten Wachstum der Fischproduktion und des Fischkonsums beigetragen. Darüber hinaus spielt die kleinbäuerliche Aquakultur auf Haushaltsebene eine sehr wichtige Rolle, insbesondere für die armen Haushalte, indem sie den Fischkonsum erhöht, die Nahrungsmittelversorgung durch zusätzliche Einkommen verbessert und Arbeitsplätze schafft.

Obwohl die Aquakultur viel dazu beiträgt, Mikronährstoffdefizite in Entwicklungsländern zu verringern, gibt es bisher nur wenige Studien, die die Produktion-, Konsum- und Ernährungszusammenhänge identifizieren. Darüber hinaus besteht ein reges Interesse der Geberorganisationen an der Förderung der Aquakultur, um den Zusammenhang zwischen Aquakultur und Armut zu ermitteln. Diese Arbeit leistet die folgenden Beiträge zur bestehenden Literatur über die Ökonomie der Aquakulturproduktion und des Konsums von Kleinbauern in Bangladesch. Erstens, durch die Disaggregation der Fischnachfrage auf Artenebene, identifiziert diese Arbeit Interventionen auf der Angebotsseite für spezielle Fischarten, um die Produktion von Fisch für die Armen zu erweitern. Zweitens wird durch Produktions-, Konsum- und Ernährungsbeziehungen, für die es bisher keine empirischen Untersuchungen gibt, ermittelt, wie die Aquakultur den Armen zugute kommen kann. Drittens fehlt es in der Literatur zur Aquakultur mangels vergleichbarer Mikrodaten an Längsschnittanalysen. Diese Lücke wurde geschlossen, indem Paneldaten von Kleinbauern in Bangladesch verwendet wurden, um den beobachteten und unbeobachteten Unterschied zwischen den Bauern zu identifizieren, die kommerzialisiert haben und denjenigen, die nicht kommerzialisiert haben. Viertens, methodisch zeigt diese Arbeit einen Schlüsselbeitrag zur empirischen Forschung durch die Anwendung eines zweistufigen endogenen Switching

Regressions (ESR)-Modells in einem korrelierten Random Effects (CRE)-Modell, um die Auswirkungen der Aquakulturvermarktung auf das Wohlergehen der Haushalte zu schätzen. Diese Analyse liefert einige Erkenntnisse über den Zusammenhang zwischen Aquakultur und Armut in Bangladesch.

Zu diesem Zweck zielt diese Arbeit darauf ab, die Ökonomie der Aquakulturproduktion und des Konsums in Bangladesch zu untersuchen, wobei der Ernährungsnutzen der armen Haushalte betont wird. Die spezifischen Forschungsziele sind: (i) das Fischverbrauchsmuster von Haushalten in Bangladesch zu untersuchen, indem die Veränderungen der Nachfrage nach Fischarten und Armutsgruppen analysiert werden; (ii) einen Zusammenhang zwischen Fischkonsum und Ernährungszustand herzustellen, indem die Auswirkungen der Aquakulturproduktion auf den Nahrungsmittelverbrauch und die Ernährungsvielfalt analysiert werden; und (iii) die von den armen Haushalten praktizierten Produktionssysteme der Aquakultur zu identifizieren und den Übergang vom Existenzminimum zu einem marktorientierteren Produktionsansatz zu analysieren, um den Beitrag der Aquakultur-Kleinbetriebe zum Wohlergehen der Haushalte in Entwicklungsländern wie Bangladesch zu verstehen.

Die in dieser Studie verwendeten Daten, die drei verschiedene Papiere umfassen, stammen aus drei verschiedenen Quellen. Das erste Papier untersucht das Fischkonsumverhalten der Haushalte in Bangladesch anhand von Haushaltsdaten auf Mikroebene, die aus den jüngsten verfügbaren Daten des Bangladesch National Household Income and Expenditure Survey (HIES), d.h. 2010-2011, stammen. HIES basiert auf einer landesweiten Umfrage unter einer national repräsentativen Anzahl von ländlichen und städtischen Haushalten. Das zweite Papier untersucht, ob das Einkommen aus der Heim-Aquakultur zu den Ernährungszuständen der Haushalte in Entwicklungsländern wie Bangladesch beiträgt. Diese Studie verwendet die Primärdaten aus der Haushaltserhebung "Fish Production, Consumption and Nutrition Linkages" der Universität Hannover und WorldFish, Penang, Malaysia, von Mai 2016 bis Juni 2016 in Bangladesch. Das dritte Papier untersucht die Möglichkeiten der kleinbäuerlichen Aquakulturzüchter in Entwicklungsländern, einen wirksameren Beitrag zur Fischproduktion zu leisten, indem sie sich von der Subsistenzwirtschaft der Heimteichproduzenten zu einem moderneren, kommerzialisierten Kleinaquakultursystem entwickeln. Diese Studie verwendet einen ausgewogenen zwei-Perioden Paneldatensatz, der aus Haushalten stammt, die in Bangladesch eine Heimteich-Aquakultur betreiben. Die erste Runde wurde 2011 durch eine Haushaltsumfrage mit dem Titel "Economics of the Homestead Pond Aquaculture System in

Bangladesh" von WorldFish, Bangladesh, im Rahmen des von USAID finanzierten CSISA-BD-Projekts erhoben, während die zweite Runde auf den Primärdaten basiert, die 2016 von der Universität Hannover und WorldFish, Penang, Malaysia, erhoben wurden.

Die Ergebnisse deuten darauf hin, dass der Fischkonsum zwischen armen und nicht armen Haushalten je nach Fischart nicht stark variiert. Arme Haushalte sind jedoch stärker auf Fisch als wichtigste Quelle für tierisches Eiweiß angewiesen. So sind beispielsweise Karpfen, die hauptsächlich aus Aquakultur, und kleine einheimische Fischarten, die hauptsächlich aus der Fischerei stammen, die am häufigsten konsumierten Fischarten für Haushalte in Bangladesch. Die Ergebnisse zeigen auch, dass die Aquakultur ein gutes Potenzial hat, den Rückgang des Fischangebots aus der Binnenfischerei auszugleichen.

Darüber hinaus zeigen die Ergebnisse, dass die Heimfischproduktion für viele Haushalte mit niedrigem Einkommen trotz des Aufkommens der kommerziellen Aquakultur in Bangladesch nach wie vor wichtig ist. Es generiert zusätzliche Einnahmen und stimuliert einen höheren Fischkonsum aus der heimischen Produktion. Infolgedessen erhöht es den Nahrungsverbrauch und verbessert die Ernährungsvielfalt auf Haushaltsebene. Außerdem trägt die heimische Fischproduktion dazu bei, die Qualität der Ernährung der Haushalte zu verbessern, indem mit zusätzlichem Einkommen mehr Kalorien am Markt nachgefragt werden können. Daher sollte das Fischereiministerium seine Ansicht über die Rolle der heimischen Fischproduktion überdenken und ihm mehr Anerkennung bei seinen politischen Aktivitäten verschaffen.

Weiterhin zeigen die Ergebnisse, dass die Kommerzialisierung unter den Subsistenzbauern weiter langsam voranschreitet. Die kommerzialisierten Haushalte haben ein höheres Pro-Kopf-Einkommen und eine geringere Armutsquote als diejenigen, die auf einem Existenzminimum mit niedriger Intensität stehen. Außerdem spezialisieren sich kommerzialisierte Haushalte über die Zeit. Bauern, die nicht transformiert haben, würden von der Kommerzialisierung sogar noch mehr profitieren als diejenigen, die es getan haben. Die Unterstützung durch Nichtregierungsorganisationen und Fischzüchterverbände auf Dorfebene spielt eine entscheidende Rolle, um den Kommerzialisierungsprozess in Bangladesch durch Informationen über Marktbedingungen und Preise zu erleichtern.

Daher kommt diese Arbeit zu dem Schluss, dass, während die Aquakultur schneller wächst als jeder andere Agrarsektor in Bangladesch, ein günstiges politisches Umfeld von der Regierung für das Wachstum der Aquakultur weiterhin erhalten bleiben, und die Fischerei weiterhin unterstützt werden muss. Ein besserer Marktzugang, verbesserte Infrastruktur und

angemessene Marktinformationen für Bauern können wirksame politische Instrumente für die langfristige Entwicklung und das nachhaltige Wachstum des Aquakultursektors in Bangladesch und vielen anderen Entwicklungsländern sein.

Stichworte: Aquakultur, Ernährung, Armut, Kommerzialisierung, Entwicklungsländer, Bangladesch.

ABSTRACT

Fish is an important source of high quality protein and micronutrients for people around the world. It is the primary source of animal protein providing more than 60 percent of total animal source protein consumed in developing countries. Rising population with higher fish consumption around the world is influencing the global demand for fish. As a result, a dramatic change has been observed for the last three decades in the structure of fish demand and supply with an increasing demand for fish in both domestic and international markets. A rapid growth in production and increased trade of fish are keeping pace together to meet the growing demand for fish worldwide. By providing fish from both capture fisheries and aquaculture sources, Asia has become the major contributor of this expansion. Although the global supply of capture fisheries has remained static for the last 20 years, aquaculture has contributed the major share in the recent growth of fish production and consumption. Moreover, smallholder aquaculture is playing a very significant role at the household level, especially for the poor households by increasing fish consumption, improving food supply through generating additional incomes, and creating employment opportunities.

Although aquaculture is contributing much for reducing micronutrient deficiencies in developing countries, little research has been done so far to identify production, consumption and nutrition linkages. Additionally, there has been active interest from the donor to promote aquaculture with a view to identifying the linkage between aquaculture and poverty. This thesis makes the following contributions to the existing literature on economics of smallholders' aquaculture production and consumption in Bangladesh. First, by disaggregating the fish demand at species level, this thesis has identified necessary species for poor households that need supply-side interventions designed from the government to expand the production of fish for the poor. Second, how aquaculture can benefit the poor is identified through production, consumption and nutrition linkages for which there is no empirical research so far. Third, due to lack of comparable micro-level data, there exists lack of longitudinal analysis in the literature of aquaculture. This gap has been fulfilled by using panel data collected from smallholder fish farmers in Bangladesh to identify the observed and unobserved difference between the farmers who did commercialize and who did not commercialize. Fourth, methodologically this thesis makes the key contribution to empirical research by applying a two-step endogenous switching regression (ESR) model in a correlated random effects (CRE) framework to estimate the impact of aquaculture commercialization on household welfare. This analysis will shed some lights on the link between aquaculture and poverty in Bangladesh.

To this end, this thesis aims to study the economics of aquaculture production and consumption in Bangladesh, emphasizing the nutritional benefit of the poor households. The specific research objectives are: (i) to examine the household fish consumption pattern in Bangladesh by analyzing the changes in demand for fish by species and by poverty groups; (ii) to establish a link between fish consumption and nutritional outcomes by analyzing the effect of aquaculture production on household food consumption and dietary diversity outcomes; and (iii) to find out the aquaculture production systems practiced by the poor households and analyze the transition from subsistence to more market oriented production approach to understand the contribution of smallholder aquaculture on household welfare in developing countries like Bangladesh.

The data used in this research, which includes three different papers, are from three different sources. The first paper examines the fish consumption pattern of households in Bangladesh using the micro level household data collected from the most recently available of the Bangladesh National Household Income and Expenditure Survey (HIES), i.e., 2010-2011. HIES is based on a countrywide survey of a nationally representative number of rural and urban households. The second paper examines whether income from homestead aquaculture contributes to household nutritional outcomes in developing countries like Bangladesh. This study uses the primary data collected from the household survey of 'Fish Production, Consumption and Nutrition Linkages' by University of Hannover, Germany, and WorldFish, Penang, Malaysia from May 2016 to June 2016 in Bangladesh. The third paper examines the possibilities of smallholder aquaculture farmers in developing countries to more effectively contribute to fish production by transforming from subsistence-type of home-pond producers towards a more modern, commercialized small-scale aquaculture system. This study uses a two-period balanced panel data collected from households who are engaged in homestead pond aquaculture in Bangladesh. The first round was collected in 2011 through a household survey titled as the 'Economics of the Homestead Pond Aquaculture System in Bangladesh' conducted by WorldFish, Bangladesh under the USAID-funded CSISA-BD project while the second round uses the primary data collected in 2016 by University of Hannover, Germany and WorldFish, Penang, Malaysia.

The results suggest that fish consumption does not vary much by types between poor and non-poor households. However, poor households rely more on fish as their primary source of animal protein. For example, carps mainly sourced from aquaculture, and small indigenous fish species mainly sourced from capture fisheries are the most frequently consumed fish species for the

households in Bangladesh. The results also find that aquaculture has good potential to compensate for the decline of fish supply from inland capture fisheries.

Furthermore, the results show that homestead fish production remains important for many low-income households in spite of the emergence of commercial aquaculture in Bangladesh. It generates additional cash income and stimulates higher fish consumption from home production. Consequently, it increases food consumption and improves dietary diversity at the household level. Moreover, home production of fish contributes to improve the quality of households' diet by purchasing more calories from the market with the additional income. Therefore, the Department of Fisheries should reconsider its view on the role of homestead pond production and give it more recognition in its extension activities.

Additionally, the results reveal that commercialization among subsistence homestead farmers continues to take place but at a slower pace. Households who commercialized have higher per capita income and lower rate of poverty headcount compared to those who remain in a low intensity subsistence scale. Also, commercialized households become specialized overtime. Moreover, farmer who did not transform would in fact benefit even more from commercialization than those who did. Support from non-government organizations, and fish farmers' associations at village level play a crucial role to facilitate the commercialization process in Bangladesh through providing information regarding market condition and prices.

Hence, this thesis concludes that while aquaculture is growing faster than any other agriculture sector in Bangladesh, a continued favorable policy environment needs to be maintained by the Government for the growth of aquaculture, however, continuing the support for capture fisheries. Better market access, improved infrastructure and appropriate market information for farmers may be effective policy instruments for the long-term development, and sustainable growth of aquaculture sector in Bangladesh and many other developing countries.

Keywords: Aquaculture, Nutrition, Poverty, Commercialization, Developing countries, Bangladesh.

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LIST OF ABBREVIATIONS

AHM	Agricultural Household Model
AME	Adult Male Equivalent
AIDS	Almost Ideal Demand System
ATT	Average Treatment Effect on Treated
ATU	Average Treatment Effect on Untreated
BBS	Bangladesh Bureau Of Statistics
CRE	Correlated Random Effects
CBN	Cost Of Basic Needs
DoF	Department of Fisheries
DDS	Dietary Diversity Score
DPDT	Directorate of Patent Design and Trademark
DFO	District Fisheries Office
ESR	Endogenous Switching Regression
FCS	Food Consumption Score
GI	Geographical Indication
GDP	Gross Domestic Product
HIES	Household Income and Expenditure Survey
IMR	Inverse Mills Ratio
MDG	Millennium Development Goals
NGOS	Non-Government Organizations
OLS	Ordinary Least Squares
PIGLOG	Price-Independent Generalized Logarithmic
PSU	Primary Sampling Units
SUR	Seemingly Unrelated Regressions
SIS	Small Indigenous Species
SDG	Sustainable Development Goal
3SLS	Three-Stage Least Squares
TH	Transitional Heterogeneity
2SLS	Two-Stage Least Squares
WFP	World Food Programme
WIPO	World Intellectual Property Organization

CHAPTER 1: INTRODUCTION

1.1 Background

Since about two decades, Bangladesh has experienced continuous economic growth resulting in structural transition of the economy (Zhang et al., 2013). The annual increase of GDP was instrumental for the decline in the poverty head count ratio from 31.5 in 2010 to 24.3 percent in 2016 (BBS, 2017). Growth has been largely ‘pro-poor’ as households below the 70^{th} percentile of the per-capita consumption distribution experienced the largest increases in per-capita consumption (WB, 2013, p. 12). Nevertheless, poverty reduction remains a challenge as many people remain vulnerable.

From the perspective of food security, caloric self-sufficiency has been attained in the country as the average per-capita calorie intake has exceeded the minimum requirement of 2,122 kcal in 2016 (BBS, 2017). Nevertheless, food and nutrition security of the people remains the key concern of the Government as one fourth of the population are food insecure and 7 percent are suffering from acute hunger (Osmani et al., 2016).

Adequate micronutrient intake is the primary requirement to defeat undernutrition and to ensure food and nutrition security (Ahmed et al., 2012). Inclusion of sufficient quantities of animal source food in the diet is an effective means to reduce micronutrient deficiencies. Traditionally fish is a source of animal foods widely consumed by the poor (FAO, 2014). It is the most important animal protein in Bangladesh contributing more than 60 percent of daily animal protein intake (FRSS, 2017; FAO & WHO, 2014). Additionally, fish provides essential fatty acids and a variety of micronutrients (Roos et al., 2007). Hence, in Bangladesh, fish is important in two prospects, i.e., (1) as a source of animal protein, and (2) as a nutrient rich food (Toufique, Farook & Belton, 2018, pp. 63) accounting the second highest share of food expenditures after rice (BBS, 2017).

Over the period from 2000 to 2010, annual per capita fish consumption has witnessed a 29 percent increase with a growth more than double in the urban areas as compared to the rural areas (Toufique, 2015). To meet the growing fish demand, the fisheries sector of Bangladesh has been going through a fundamental transformation. During the past, fish for household consumption was mostly supplied from capture fisheries. However, to date, culture fisheries provide the majority share of fish for household consumption. The aquaculture sector is growing at a rate of almost 10 percent per year in Bangladesh while it is only 3 percent for capture fisheries (ibid.). Following three decades of sustained growth, aquaculture sector is now contributing more than 56 percent of reported fish production in Bangladesh (DoF, 2017). While both production and consumption have increased over time, it is not known how the supply and demand patterns have changed in the country. Concerning the role of fish in reducing micronutrient deficiencies, it is necessary to understand household fish consumption patterns and species composition because the nutrition value of fish varies considerably across types (Bogard et al., 2015).

In case of supply, fish ponds play a crucial role as the main supplier of fish in domestic fish markets. It is estimated that there are over four million households engaged in fish production with own ponds near-by the homestead (Belton & Azad, 2012). There are almost 2 million homestead ponds in Bangladesh (Huda et al., 2010) contributing over 43 percent of the total recorded aquaculture production (DoF, 2016). Due to its contribution, homestead ponds are increasingly being recognized by the Department of Fisheries (DoF), which is the agency responsible for advising fish farmers. Production from homestead ponds are getting importance for two main reasons. First, it makes fish available to households on a regular basis and in easily accessible manner. Second, it offers the opportunity of selling surplus fish to the market and hereby, can generate additional household income. Therefore, analyzing the impact of homestead aquaculture on poverty reduction and household's food and nutrition security has become a major focus of many research projects (Belton & Azad, 2012; Bogard et al., 2015; Castine et al., 2017).

This thesis is an outcome of such a collaboration research project, which addresses these issues in the context of Bangladesh. The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) project "Aquaculture and the Poor: Improving Fish Production, Consumption and Nutrition Linkages" was financed by the Federal Ministry for Economic Cooperation and Development (BMZ), Germany from 2014-2017. The GIZ project aims to secure supplies of, and access to, fish that meets the food and nutrition requirements of poor and vulnerable consumers, particularly women and children. The purpose is to generate knowledge of fish consumption patterns amongst poor consumers, and to identify and communicate to key stakeholders, technology, institutional and policy innovations that support sustainable development of fish value chains and meet the present and future requirements of poor and vulnerable consumers.

This thesis contributes to the project outcomes by improving the understanding of production-consumption-nutrition linkages of fish in Bangladesh. Three essays have been formulated, each addressing a central question through which the overall objectives of this thesis will be achieved.

Essay 1: What are the necessary species frequently consumed and demanded by the poor in Bangladesh, and how the respective price and income elasticities of those species differ between different poverty groups?

Essay 2: Does income from homestead aquaculture contribute to household nutritional outcomes in developing countries like Bangladesh?

Essay 3: Is there any possibility of smallholder aquaculture farmers in developing countries to more effectively contribute to fish production by transforming from subsistence-type of home-pond producers towards a more modern, commercialized small-scale aquaculture system?

In the next section, the research objectives of this thesis are introduced, followed by the methodologies in section 3. Section 4 and 5 describes the data and summarizes the main results of this thesis. Section 6 concludes and provides some policy recommendations followed by future research in section 7. Finally, section 8 provides the outline of the overall thesis.

1.2 Research Objectives

The **first essay** examines the fish consumption pattern of households in Bangladesh. Following the most widely adopted systems approach consistent with demand theory, this essay identifies the fish demand patterns of the households living in Bangladesh. Three specific objectives have been addressed:

i. To identify the necessary species that are frequently consumed and demanded by the poor to shed some light on potential policy implications for supply-side interventions designed from the government;
ii. To identify the determinants of demand for fish in Bangladesh, and
iii. To calculate the respective price and income elasticities of fish demand in Bangladesh, disaggregating by different poverty groups, species groups, and sources.

The **second essay** examines whether income from homestead aquaculture contributes to household nutritional outcomes in developing countries like Bangladesh. Following the non-separable agricultural household model (AHM) to understand the behavior of a farm household, this essay evaluates whether and how homestead fish ponds contribute to a better nutritional status in Bangladesh. This essay has three specific objectives:

i. To examine whether higher share of aquaculture income results in higher food consumption at the household level;
ii. To investigate whether and to what extent aquaculture income contributes to ensure higher dietary diversity at the household level, and
iii. To see how additional income from aquaculture improves the quality of a households' diet by changing the structure of food consumption at the fishing households.

The **third essay** analyzes the possibilities of smallholder aquaculture farmers in developing countries to more effectively contribute to fish production by transforming from subsistence-type of home-pond producers towards a more modern, commercialized small-scale aquaculture system. The objectives of this paper are:

i. To analyze the extent and trend of commercialization among the homestead fish farmers in Bangladesh;
ii. To identify the factors that determine the extent of smallholder commercialization, and
iii. To assess the impact of smallholders' commercialization on household welfare overtime.

1.3 Methodology

To achieve the overall objectives, several theoretical models have been adopted to apply the empirical methodologies. The detail methodologies are explained below:

The **first essay** applies a utility function consistent with demand theory to estimate the disaggregated fish demand model for Bangladesh. The PIGLOG preference is used in the form of expenditure function to estimate the respected price and income elasticities under the framework of the Almost Ideal Demand System (AIDS) suggested by Deaton and Muellbauer (1980_a, 1980_b). The estimation strategy of the AIDS model follows a two-step procedure with limited dependent variables to solve the problem related to micro level household data (Heien & Wessells, 1990; Amemiya, 1974; Lee, 1981).

The **second essay** develops a non-separable agricultural household model (Benjamin, 1992; Bardhan & Udry, 1999; LaFave et al., 2016; Strauss, 1984) to assess the effect of aquaculture production on household consumption and nutritional outcomes. The empirical strategy follows two estimation techniques following Dillon et al. (2015) and LaFave et al. (2016). First, a two-stage least squares (2SLS) estimation technique to measure the effects of income from homestead aquaculture on households' consumption and nutritional outcomes. This technique solves the problem relating to the presence of unobserved heterogeneity in the model, which might influence the dependent and the explanatory variables of interest. Second, a simultaneous equations system to capture the effects of aquaculture income on caloric shares from different food groups to determine the improvement in the quality of the diet of fishing households.

Following Barrett (2008), Alene et al. (2008) and Boughton et al.'s (2007), the **third essay** uses the extended version of agricultural household model (AHM) in the context of endogenous prices and transactions costs to examine whether commercialization of aquaculture benefits the smallholders in developing countries. The empirical model follows a two-step endogenous switching regression (ESR) model in a correlated random effects (CRE) framework to estimate the impact of aquaculture commercialization on household welfare of smallholder fish farmers in Bangladesh. In the first step, farmers' market participation decision to commercialize is determined and estimated using a probit model. In the second step, a counterfactual analysis is implemented following Di Falco & Veronesi (2013), Teklewold et al. (2013) and Carter & Milon (2005) to estimate the impact from the expected welfare outcomes between two groups of farmers, i.e., who commercialize and who did not commercialize.

1.4 Data

The data used in this thesis, which includes three different papers, are from three different sources. The **first essay** used the micro level household data collected from the most recently available of the Bangladesh National Household Income and Expenditure Survey (HIES), i.e., 2010-2011. HIES is based on a countrywide survey of a nationally representative number of rural and urban households. Bangladesh Bureau of Statistics (BBS) carries out this survey at regular intervals of 5-years.

The HIES data was collected through a two-stage stratified random sampling technique over a one-year survey period from mid-2010 to mid-2011 reflecting the agricultural year. The first stage included selection of Primary Sampling Units (PSUs)[1] and second stage included

[1] The PSUs are defined as contiguous two or more enumeration areas with around 200 households in each PSU from the framework of Integrated Multipurpose Sample (IMPS) following the Population and Housing Census 2001. The IMPS divides the country into 1000 PSUs.

selection of households within each PSU. The survey strategy was to divide the year into 18 equal terms in order to be better able to capture the seasonal variations in income, expenditure and consumption pattern over the period of a year. During each term, a total of 34 PSUs were selected to collect data of 680 sampled households (i.e., 20 households per PSU). During the entire survey period, a total of 12,240 households were interviewed in 612 primary sampling units with 7840 and 4400 households from rural urban areas respectively. A standard household survey questionnaire was used to collect a wide range of information on household characteristics, economic activities such as wage and self-employment, agriculture and non-agricultural enterprises, asset and income, consumption expenditures, health and social safety net programs.

The **second essay** used the primary data collected from the household survey on 'Fish Production, Consumption and Nutrition Linkages' by University of Hannover, Germany and WorldFish, Penang, Malaysia from May 2016 to June 2016 in Bangladesh. The sample was selected from the survey of the 'Economics of the Homestead Pond Aquaculture System' under the United States Agency for International Development (USAID)-funded Cereal Systems Initiative for South Asia in Bangladesh (CSISA-BD) project implemented by WorldFish, Bangladesh in 2011 (WF, 2015). A purposive random sampling technique was used in the WorldFish survey following a multi-stage process to select the households practicing aquaculture (Jahan et al., 2015). In 2011, the WorldFish survey collected information of five major aquaculture production systems that has been practiced in Bangladesh (Figure 1.1).

Among these production systems, homestead pond aquaculture was the only non-commercial aquaculture production system and the only system where a major proportion of the aquaculture production was used for household's consumption. Therefore, to fulfill the objective of this essay, households practicing homestead pond-based aquaculture production system were selected from the CSISA-BD project, and resurveyed independently in 2016 through a household survey to collect necessary information. Finally, a total of 518 households' information was collected who engaged in homestead pond aquaculture technology.

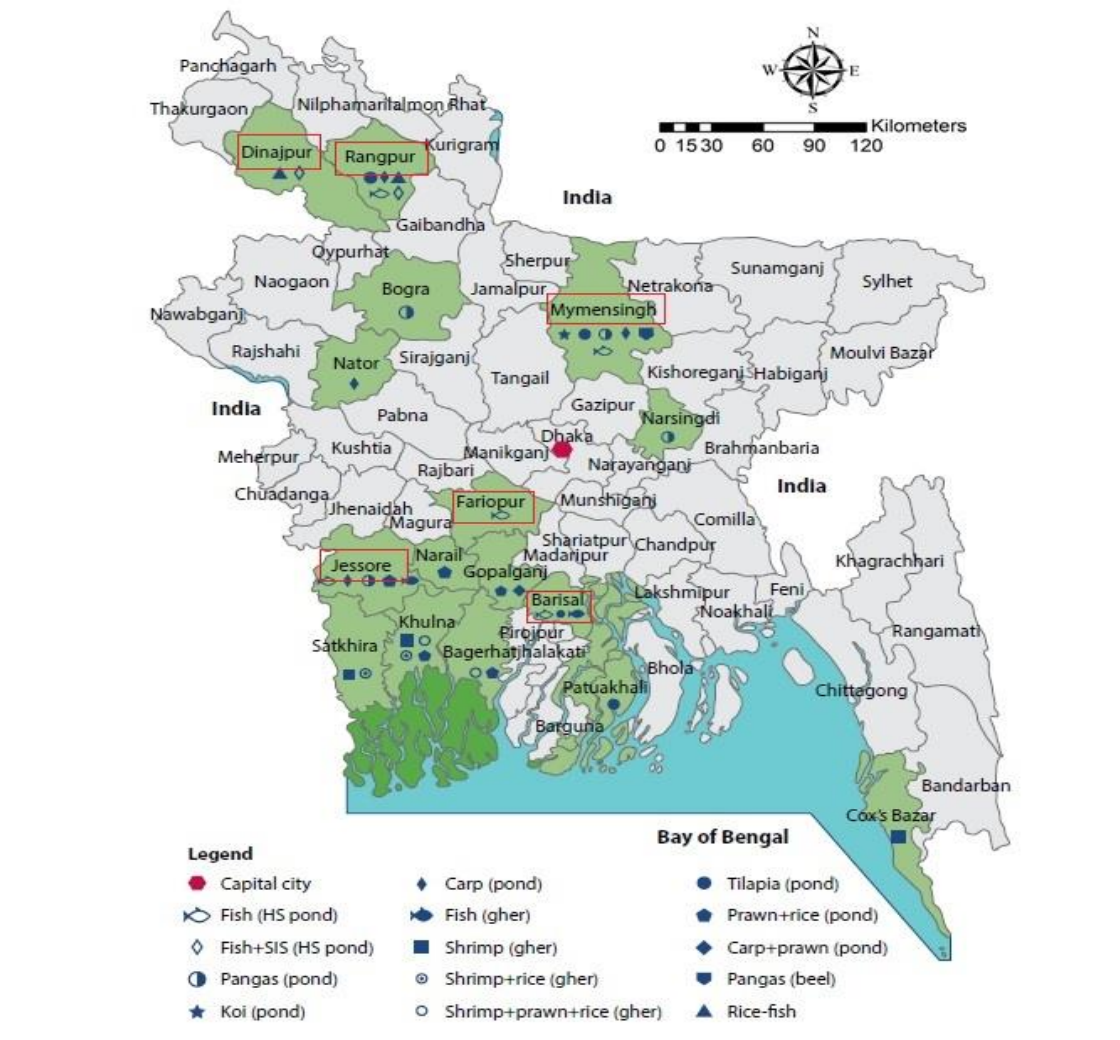

Figure 1.1: Study area in Bangladesh
Source: Jahan et al. (2015, p. 19).

A household survey questionnaire was used to generate information on household characteristics, income sources, asset endowments, aquaculture production, health and nutritional knowledge and practices, well-being and risk attitudes and consumption expenditures. Additionally, a village questionnaire was also administered to collect information regarding village demographic, socio-economic condition, infrastructure, local food prices and aquaculture production practices in the village.

The **third essay** used a two period panel data collected from households who engaged in homestead pond aquaculture in Bangladesh. The first round of data was collected from the household survey of ‘Economics of the Homestead Pond Aquaculture System in Bangladesh’ conducted by WorldFish, Bangladesh under the USAID-funded CSISA-BD project in year 2011. The second round of data was collected from the household survey conducted by

University of Hannover, Germany and WorldFish, Penang, Malaysia in 2016. Both round used the same sampling technique initially applied by the WorldFish in 2011 to select the households practicing different aquaculture technologies in Bangladesh.

The survey questionnaire of both rounds has been kept similar to generate necessary information on various aspects including household characteristics, income sources, expenditures, asset endowments, aquaculture production and practices. Finally, this essay used 932 observations of balanced panel data drawn from 466 households.

1.5 Results

The **first essay** shows that fish demand in Bangladesh differs between poor and non-poor households and varies substantially across fish types and species. Poor households consume less fish than non-poor households, although the share of fish as a primary animal source food is higher for the poor. The low-priced fish produced in aquaculture is mainly consumed by poor households. The fish species consumed in poor and non-poor households are largely similar, except for some species, e.g., hilsa.

The elasticity estimates show that income elasticity for most fish species is higher for the poor than for non-poor households originated from culture and capture sources. Fish demand of poor households is price-elastic for the majority of fish species and they have a high cross-price elasticity of fish demand, which implies that they respond more to changes in the price of substitutes. Most importantly, this essay indicates that the declining supply of capture fish can be compensated by increasing the production of aquaculture fish as most of the fish species from capture source have positive cross price elasticities with the fish from aquaculture source.

The results of the **second** essay first, show that aquaculture income from homestead ponds contributes to increased food consumption expenditures and calorie intake, and improves dietary diversity. Second, the gender of the household head is important for household food and nutrition security because households with female heads have lower food consumption and dietary diversity. Third, farm income from crop and livestock also plays an important role in the fish farming households. This implies that income from homestead aquaculture is a complementary to other sources of income, albeit its contribution is significant. Fourth, households with better market access derive more income from selling fish. Fifth, access to credit is important to enable fish farming households to move gradually from subsistence homestead production to a more a commercial type of aquaculture. Sixth, homestead fish production increases home consumption of fish and thereby its share in total calorie intake. Seventh, additional income from aquaculture helps to improve the quality of a households' diet by consumption of more calories from pulses, meat, eggs and fish. Therefore, the food consumption structure of poor farmers is diversified with high-quality protein and energy-dense food items.

The **third** essay shows that commercialization among subsistence homestead farmers continues to take place but at a slower pace. Households who commercialized have a higher per capita income and are less likely to be poor compared to those who continue to practice a low-intensity-subsistence production system. The counterfactual model suggests that farmer who did not transform from subsistence to commercial scale, would in fact benefit even more from commercialization than those who did. Support from non-government organizations, and fish farmer's associations at village level play a crucial role to facilitate the commercialization among small and medium-scale farmers in Bangladesh through providing information regarding market condition and prices. Moreover, distance to village market and access to credit are of the utmost importance to reduce the transaction cost and liquidity constraints of smallholders. The overall findings suggest that providing appropriate information to farmers and proper strategies to improve their efficiency level can be an effective policy instrument to induce households to commercialize in aquaculture activities.

1.6 Conclusion and Policy Implications

The empirical evidences presented in this thesis provide potentially important implication for nutrition, health and agricultural policy in Bangladesh, which also have relevance for other developing countries. Moreover, the results of this research can be helpful for the design of a sustainable aquaculture sector to fulfill the growing demand for fish.

Support for favorable public policy interventions

In Bangladesh, policies for open water resources are largely ignored by development planners and their partner organizations (Apu, 2014). Since fish is the most important animal source food for the poor, the government needs to maintain a continued favorable policy environment for aquaculture growth, and at the same time implement measures for the sustainability of capture fisheries. The following recommendations are made in this regard:

1. Facilitating the maintenance of homestead fish pond through better market access and improved infrastructure for the long-term development of the aquaculture sector.

Improved infrastructure lowers transaction costs by reducing distance and improves market access for produces and consumers. It offers farmers the possibility to develop their aquaculture enterprises.

2. Supporting the smallholder fish famers through providing high-quality fingerlings and expert training on modern and sustainable aquaculture techniques to cope with the potential challenges of price declines, production failure and investment risks.
3. Disseminating information, providing extension services, and formal credit from Department of Fisheries (DoF) to facilitate the implementation of commercialization strategies among smallholders.

Investments to facilitate changes of current aquaculture production systems

Considering the fact that capture fisheries is in constant decline (Toufique & Belton, 2014), poor consumers will lose some of the fish with high nutritional value. Therefore, changes are required to better enable current aquaculture production systems to grow more small indigenous species (SIS) in order to supplement the micronutrient supply among the poor (Bogard et al., 2015; Thilsted, 2012; Kohinoor, Sultana,WF & Hussain, 2007). The technology of combing SIS with existing polyculture system in Bangladesh is called as 'carp-SIS' polyculture, which is emerging and need support from the Government to promote it. and make it familiar among the farmers. Disseminating information and training on the technical knowledge of carp-SIS technology will make this technology familiar among the farmers and will encourage them to explore the carp-SIS technology in ponds.

Improve access to relevant information

Provision of relevant information is important for advancing aquaculture production of smallholders. An important source of technical information is fish farmers' associations. They are in the best position to provide technical information and training on sustainable aquaculture management practices. The Government should allocate more funds to fish farmers' associations in order for them to be able to hire qualified staff and provide information in an efficient and readily accessible manner for small-scale farmers.

To conclude, while there is an increasing trend of rural households to engage in non-farm income generating activities, proper support from the Government and implement measures to increase the productivity of smallholder fish farmers will ensure the food and nutrition security at the household level.

1.7 Future Research

The analyses in this thesis raise some issues that need further research for the growth of aquaculture sector in developing countries.

This thesis estimates the demand for fish disaggregated at species level using cross-sectional data. However, considering the recent changes in fish consumption, it would be interesting to see the changes in fish demand overtime in Bangladesh. For doing this, longitudinal study is required, which will provide the information of fish species that are getting increasingly scarce in Bangladesh, and the fish species are becoming more available to the consumers due to aquaculture growth.

Furthermore, aquaculture is contributing significantly to the country's rural economy though increasing farm incomes and creating on-and off-farm employment. However, little research has done so far on different aquaculture technologies practiced in Bangladesh. Now-a-days, varieties of new commercial technologies have been practicing in rural areas, which are mainly underreported (e.g., Jahan et al., 2015). This thesis only focuses on the non-commercial aquaculture technologies that have been identified and tries to see the changes and the role of these technologies for household food and nutrition security. However, a significant proportion of fish production comes from commercial aquaculture systems and there is the possibility that homestead pond farmers develop into commercial aquaculture schemes. Therefore, it would be interesting to see further the changes in commercial aquaculture production systems and their contribution to rural farm incomes, and employment creation. In this regard, creating a long-term panel data set including all the production system practiced would allow investigation into what extend changes occurs, and need to be adjusted in Bangladesh.

1.8 Thesis Outline

This thesis is structured into four chapters including three essays. The overview of these chapters is presented in Table 1.1 and the brief descriptions are presented below.

The second chapter presents the **first essay** titled as 'Is there a Difference between the Poor and Non-Poor? A Disaggregated Demand Analysis for Fish in Bangladesh'. In particularly, section 2.1 explains the justification of analyzing fish consumption pattern in developing countries, section 2.2 provides the detailed methodological framework of consumer demand and its estimation process. Section 2.3 explains the data used in this study with detailed analysis of how fish and poverty groups are disaggregated. Section 2.4 explains the results from the model and discusses the estimates of price and income elasticities. Section 2.5 concludes and provides some policy implications.

Chapter 3 explains the **second essay** titled as ‘The Role of Homestead Fish Ponds for Household Nutrition Security in Bangladesh’. This chapter is organized as follows. Section 3.1 explains the role of fish to combat micronutrient deficiencies in developing countries. Section 3.2 explains the link between homestead aquaculture, dietary diversity and household nutrition security. Section 3.3 provides the theoretical framework. Section 3.4 explains detail methodology for the empirical models. Section 3.5 explains the data and shows descriptive statistics of the household survey. The results from two empirical models are presented in section 3.6. Section 3.7 concludes the chapter and provides some policy recommendations.

Chapter 4 presents the **third essay** of this thesis titled as ‘The Blue Revolution in Bangladesh: What Can Smallholders Aquaculture Farmers Contribute?’. This chapter is organized as follows. Section 4.1 explains why commercialization of smallholder aquaculture is important in developing countries. Section 4.2 explains the implications of aquaculture commercialization on household welfare. Section 4.3 provides the theoretical framework. Section 4.4 explains detail estimation procedures. Section 4.5 explains the data and shows some descriptive statistics from the household survey. The results of the empirical models are presented in section 4.6. Section 4.7 concludes this chapter with some policy recommendations.

Table 1.1: Overview of the essays in the dissertation

No.	Title	Authors	History
Essay 1 (Chapter 2)	Is there a Difference between the Poor and Non-Poor?: A Disaggregated Demand Analysis for Fish in Bangladesh	Badrun Nessa Ahmed, Sven Genschick, Michael Phillips and Hermann Waibel	Submitted to: *Aquaculture Economics & Management* Earlier versions presented at: *The 3rd GlobalFood Symposium.* Organized by GlobalFood and Georg-August-Universität Göttingen. April 28-29, 2017, Göttingen, Germany
Essay 2 (Chapter 3)	The Role of Homestead Fish Ponds for Household Nutrition Security in Bangladesh	Badrun Nessa Ahmed and Hermann Waibel	Revised and resubmitted: *Food Security*
Essay 3 (Chapter 4)	The Blue Revolution in Bangladesh: What Can Smallholders Aquaculture Farmers Contribute?	Badrun Nessa Ahmed and Hermann Waibel	Published as a conference proceeding in the *Tropentag conference.* September 17-19, 2018, Ghent, Belgium. Earlier vesion presented at: *International conference on Research on Food Security, Natural Resource Management and Rural Development (Tropentag 2018).* Organized by the University of Ghent, KU Leuven, and Antwerp University. September 17-19, 2018, Ghent, Belgium.

Source: Author’s illustration

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CHAPTER 2: IS THERE A DIFFERENCE BETWEEN THE POOR AND NON-POOR? A DISAGGREGATED DEMAND ANALYSIS FOR FISH IN BANGLADESH

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Abstract

This study examines the fish consumption pattern of households in Bangladesh. Data from the national Household Income and Expenditure Survey (HIES) has been used to develop a demand model disaggregated by fish types and poverty groups. A two-step censored regression model is applied to estimate price and income elasticities. Results show that poor and non-poor households consume similar types of fish. However, poor households rely more on fish as their primary source of animal protein. As income increases, the fish consumption of the poor rises more than for the non-poor. Additionally, fish price increase will lead to a deterioration of their nutritional conditions. In terms of fish species, the study finds that carps, mainly sourced from aquaculture, and small indigenous fish species, mainly sourced from capture fisheries, are the most frequently consumed fish species for the households in Bangladesh. This research also finds that aquaculture has good potential to compensate for the decline of fish supply from inland capture fisheries.

Keywords: Demand elasticity, AIDS model, Seemingly Unrelated Regressions, Poverty, Nutrition, Bangladesh.

2.1 Introduction

Significant progress in monetary poverty reduction has been achieved in Bangladesh, i.e., the poverty rate declined from 57 percent in 1991 to 31.5 percent in 2010 (MoF, 2015). However, less progress has been made in other dimensions of poverty such as: anthropometric status, morbidity, mortality and education, which are only weakly, correlated with growth in income (Baulch & Masset, 2003; Günther & Klasen, 2009). Especially improvements in the nutritional status of the poor take more time to achieve (Haddad et al., 2003; Waibel & Hohfeld, 2016). More than six million children are chronically malnourished in Bangladesh (WFP, 2016; FAO & WHO, 2014; Save the Children, 2015). Inadequate micronutrient intake is a prime cause of undernutrition (Ahmed et al., 2012). Increasing the diversity of diets by inclusion of sufficient quantities of animal source food is an effective means to reduce micronutrient deficiencies, and traditionally fish has been a source of animal foods widely consumed by the poor (FAO, 2014). In Bangladesh, more than 60% of daily animal protein intake comes from fish (FRSS, 2017; FAO & WHO, 2014), which is considered as a low-cost source of animal protein for a majority of low-income households' (Ali, 2002). The comparatively high accessibility is due to the facts that fish is reasonably affordable and easily available in most of the developing countries (Kawarazuka & Béné, 2010).

During the last two decades, fish production in Bangladesh has increased. Between 2006 and 2015, the average growth in production has been estimated with 5.4 percent (Hossain, 2016). Moreover, average annual per capita fish consumption has increased by over 28 percent between 2000 and 2010 (BBS, 2011). While both production and consumption have increased over time, it is not known how the supply and demand patterns have changed in the country. With regards to the role of fish in reducing micronutrient deficiencies, it is necessary to understand household fish consumption patterns and species composition because the nutrition value of fish varies considerably across types (Bogard et al., 2015).

Fish demand studies are not new in developed and developing countries. Studies that have analyzed fish demand in developed countries considered fish as an aggregate commodity (Wellman, 1992; Eales et al., 1988; Cheng & Capps, 1988; Yen, Kan, & Su, 2002). In most of the previous studies in Bangladesh, a similar kind of aggregation can be found (Pitt, 1983; Goletti, 1992 as cited in Dey, Bose, & Alam, 2008; Ahmed & Shams, 1994; Hossain, 1988; Talukder, 1993). Only few studies have estimated a disaggregated fish demand model (i.e., Ali, 2002; Dey, 2000; Dey, Bose, & Alam, 2008; Dey, Alam, & Paraguas, 2011; Toufique, Farook,

& Belton, 2018). However, these studies classified households according to income quantiles, poverty groups and origin of production. Dey (2000) and Dey et al. (2011) have done demand analysis at disaggregated level based on fish types, but the data used was not representative for the scope of Bangladesh and dates back to the nineteen nineties, which means that elasticity coefficients are outdated and may no longer hold. The most important conclusion of these papers is that elasticity estimates varied across fish species and income groups justifying the need a disaggregated demand model. Using recent data, Toufique et al. (2018) show that elasticities of demand for fish vary by origin of production for poor and non-poor households. They recommend effective management policy for fish species from different sources with special attention to aquaculture and inland capture fisheries. Considering the fact that any intervention (e.g., poverty reduction strategy, fishery sector development and management policy) may not have the similar effect on the demand of each species originating from similar sources, this study looks at a more disaggregated species level to answer this question. The effectiveness of any policy depends on how successful it is in appropriate targeting. If the main target of an intervention is to provide fish at a reasonable price to boost consumption and nutrition among households, especially poor households, preference should be given to promote the production of species with the highest likelihood given its low price and high availability of being consumed by households living in poverty. This study identifies those necessary species for poor households and shed some light on potential policy implications for supply-side interventions designed from the government to expand the production of fish for development of fishery sector in Bangladesh.

This study is conducted through six major steps. First, following the HIES, fish is classified into 15 different groups based on species. Second, households are categorized into two broad poverty classes identifying as poor and non-poor. Third, household consumption is divided by adult male equivalents in the household to have a more accurate estimate of the adequacy of household food consumption. Fourth, the impact of location and divisions is added as demographic effects on the demand for fish in Bangladesh by considering six administrative divisions and two areas, i.e., rural and urban. Fifth, following a censored regression technique, the system approach is used to estimate the demand equations. Finally, the seemingly unrelated regressions (SUR) specification is applied to generate efficient estimates from the system of linear demand equations. This procedure helps to estimate fish demand elasticities by species group and by poverty class.

The estimated elasticities provide information regarding the demand for specific fish species group by poverty class as income and prices changes. In addition, the descriptive analysis shows us how much fish do poor households consume and what species do they consume. Considering the process of ‘blue revolution’ in aquaculture which makes more fish available at low prices (Toufique et al., 2018), results of this analysis are particularly helpful for the regulatory authority to develop a price stabilizing policy for the aquaculture and fisheries sector in Bangladesh to address the needs of the poor and to manage production and investment decisions that increase the market supply of fish to ensure food and nutrition security at the household level. In brief, results of this study show that poor households consume less fish than non-poor households, however, they rely more on fish as their primary source of animal protein. The fish species consumed in poor and non-poor households are similar. This study finds that poor households’ demand for fish is price elastic and hence, the nutritional conditions of the poor will deteriorate as fish prices rise. Finally, as expected this study finds that fish demand for the poor is income elastic and inelastic for the non-poor.

The remainder of this chapter is organized as follows: section 2 provides the detailed methodological framework of consumer demand and its estimation process. Section 3 explains the data used in this study with detailed analysis of how fish and poverty groups are disaggregated. In Section 4, the results from the model are explained with a discussion of the estimates of price and income elasticities. Section 5 concludes and provides some policy implications.

2.2 Methodology

There are different approaches in the literature to model the demand theory through single equation or system approaches. In recent empirical works, system approach is more prominent than single approach. The most widely adopted systems approach consistent with demand theory is Almost Ideal Demand System (AIDS) developed by Deaton and Muellbauer (1980a, 1980b). AIDS derives the Marshallian and Hicksian demand functions from a specific class of preferences known as the price-independent generalized logarithmic (PIGLOG) preferences. As utility is unobserved, consumer preference is captured by the cost or expenditure function which defines the minimum expenditure necessary to obtain a specific utility level at given prices (Deaton & Muellbauer, 1980_a, p. 313).

In this study, the AIDS specification has been applied to model the fish demand in Bangladesh. The modified version is used to incorporate the socio-demographic effects in the model. The full demand system is estimated in two-step using censored regression technique to solve the problem related to micro level data.

2.2.1 Specification of Almost Ideal Demand System (AIDS)

Following Deaton and Muellbauer (1980_a, 1980_b), the Almost Ideal Demand System (AIDS) has been defined from the PIGLOG preferences in the form of expenditure function as:

$$\log ex(p,u) = a(p) + ub(p) \qquad (1)$$

Where, $a(p) = \alpha_0 + \sum_{i=1}^{n} log\, p_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \log p_i \log p^j$

$$b(p) = \beta_0 \prod_{i=1}^{n} p_i^{\beta_i}$$

The utility (u) is expressed as a function of prices and expenditure as:

$$U = {\log X - \log P}\Big/{\beta_0 \prod_{i=1}^{n} p_i^{\beta_i}}$$

Where, $\log P = \alpha_0 + \sum_{i=1}^{n} \alpha_i \log\ p_i + \frac{1}{2}\sum_i \sum_j \gamma_{ij} \log\ p_i \log p_j$

The price derivative of the expenditure function yields the demand function, and after all substitutions, the AIDS model can be specified in the form of budget shares as:

$$w_i = \alpha_i + \sum_j \gamma_{ij} \log\ p_j + \beta_i log\left({X}/{P}\right) + u_i \qquad i, j=1, 2\ldots n \qquad (2)$$

Where, w_i is the budget (expenditure) share of the i^{th} good; X is the total expenditure of all fish categories; p_j is the nominal price of the j^{th} good; *P is the* aggregate *price* index; u_i is the error term in the i^{th} equation with mean zero and constant variance.

The slope coefficients β_i and γ_{ij} explain the effect of expenditure and prices on demand for *n* goods.

The aggregate price index 'P' is a translog price index used to normalize and deflate the total expenditure of the i^{th} household in equation (2). The price index specifies as:

$$\log P = \alpha_0 + \sum_i \alpha_i \log\ p_i + \frac{1}{2}\sum_i \sum_j \gamma_{ij} \log\ p_i \log p_j \qquad (3)$$

There are two basic functional forms of AIDS model, i.e., linear and quadratic based on the specification of price index in equation (3). The estimated results will be similar in two functional forms and the linear model will approximate the nonlinear one, provided that measurement errors are taken into account during the estimation process (Moschini, 1995; Moschini & Vissa, 1992). Therefore, the linear version of AIDS model has been chosen in this study for estimating the demand system.

For linearizing the model, the Laspeyres price index is used, which corrects the unit of measurement error by scaling the prices with their sample mean. The log-linear version of Laspeyres price index which is a geometrically weighted average of prices:

$$\log(P^L) = \sum_j \overline{w}_j \log(p_j) \qquad j=1, 2,\ldots n \tag{4}$$

Substituting the price index in equation (2), the main model is linearized as:

$$w_i = \alpha'_i + \sum_j \gamma_{ij} \log\, p_j + \beta_i\big(log(X) - \sum_j \overline{w}_j \log\big(p_j\big)\big) + u'_i \tag{5}$$

Although Stone’s price index is widely used to linearize the AIDS model, the problem of simultaneity (Eales & Unnevehr, 1988) and measurement error (Alston, Foster, & Green, 1994; Asche & Wessells, 1997; Moschini, 1995) remains. To deal with these problems, Laspeyres price index has been used, which is considered as superior among other price indexes for generating unbiased estimators of expenditure and price elasticities (Buse & Chan, 2000; Moschini, 1995).

Consumer demand theory imposes four general restricts on the parameters of equation (5). $\sum W_i = 1$, is called the adding up restriction which requires:

$$\sum_{i=1}^{n} \alpha_i = 1,\ \sum_{i=1}^{n} \gamma_{ij} = 0\ and \quad \sum_{i=1}^{n} \beta_i = 0 \tag{6}$$

Additionally, the demand functions are homogenous of degree zero in price and income:

$$\sum_{j=1}^{n} \gamma_{ij} = 0\ , \forall\ i \tag{7}$$

Slutsky symmetry implies the consistency of consumer’s choice:

$$\gamma_{ij} = \gamma_{ji}, \quad \forall\ i, j \tag{8}$$

Negativity has no parameter restriction. However, it requires the matrix of substitution to be negative semi-definite.

Once the model is set up, other factors apart from expenditures and prices are included that influence the demand for fish. It has been found that socio-demographic factors such as: accessibility of fish item, household composition and geographical location can influence the fish demand (Ray, 1980; Heien & Wessells, 1990; Ali, 2002; Ahmed & Shams, 1994). These factors can affect the price and thereby the expenditure pattern of the household. Hence, this study incorporated the socio-demographic variables in the AIDS model to capture the effect of other factors also.

2.2.2 Incorporation of Socio-Demographic Effects

Using a linear demographic translation (Pollak & Wales, 1981) in equation (5), the socio-demographic factors are incorporated in the AIDS model. Information relating to age-sex composition, parental education, household size, urbanization zone and administrative regions (e.g., divisions[2]) is included to capture the probable socio-demographic effects on household's consumption demand for fish. The modified vision of AIDS model follows as:

$$w_i = \alpha^*{}_i + \sum_k \delta_{ik} D_k + \sum_j \gamma_{ij} \log\, p_j + \beta_i\big(log(X) - \sum_j \overline{w}_j\, log(p_j)\big) + u''{}_i \qquad (9)$$

Where, $\alpha^*{}_i = \alpha'{}_i - \sum_k \delta_{ik} D_k$

The adding up restrictions upgrades to:

$\alpha^*{}_i$=1 and $\sum_k \delta_{ik} = 0$ k =1, 2……, m (10)

Where, *k* represents the number of socio-demographic variables considered in the model.

After incorporating the socio-demographic variables, the elasticities are estimated from equation (9).

2.2.3 Elasticities in the AIDS Model

Taking the derivatives of equation (9) with respect to $ln(x)$ and (p_j) , the income and price elasticity are generated (Green & Alston, 1990).

Price elasticity: Price elasticity explains the percentage change in quantity demand of fish due to percentage change in its price. There are two types of price elasticities, i.e., compensated and uncompensated. The compensated elasticities capture only the price effect while the uncompensated one captures both the price and income effect of a price change.

The 'Marshallian' or uncompensated own $(i = j)$ and cross $(i \neq j)$ price elasticities:

$$\eta_{ij} = -\delta_{ij} + \left(\frac{1}{w_i}\right)\left(\frac{\delta w_i}{\delta ln(p_j)}\right) = -\delta_{ij} + \left(\frac{\gamma_{ij}}{w_i}\right) - \left(\frac{\beta_i}{w_i}\right) w_j \;\forall i, j = 1,2 \ldots\ldots, n \qquad (11)$$

[2] Divisions are administrative regions in Bangladesh. Each division has the local government with certain fiscal and administrative powers over districts and sub-districts (i.e., union, municipalities, and city corporations) within its jurisdiction.

Where, δ_{ij} is the Kronecker delta that is equal to one if i=j and zero otherwise.

The 'Hicksian' or compensated own price elasticities at the normalization point:

$$\eta^*_{ij} = \eta_{ij} + \eta_i w_j = -\delta_{ij} + \left(\frac{\gamma_{ij}}{w_i}\right) + w_j \; \forall i, j = 1,2 \ldots\ldots, n \tag{12}$$

Where, δ_{ij} is the Kronecker delta that is equal to one if i=j and zero otherwise.

The proportionate rate of change in quantity demanded is measured through own and cross price elasticity. Own price elasticity gives the rate of change in quantity demanded caused by a rate of change in price of same good. On the other hand, cross price elasticity gives the rate of change in quantity demanded of good i in response to a rate of change in price of good j.

Income elasticity: The income (expenditure) elasticity explains the percentage change in quantity demand of fish due to percentage change in income (expenditure) of household. In AIDS model, only the expenditures of 15 fish species groups are used and hence, it doesn't provide the estimate of income elasticity directly. Therefore, an Engel function specification is applied to get the desired income elasticity using ordinary least squares (OLS) regression.
Differentiating equation (9) with respect to income, the expenditure elasticity is generated for fish category i as:

$$\eta_{ix} = 1 + \left(\frac{1}{w_i}\right)\left(\frac{\delta w_i}{\delta ln(x)}\right) = 1 + \frac{\beta_i}{w_i} \tag{13}$$

Therefore, the Engel function specification to get the income elasticity is:

$$\log(M) = \beta_0 + \beta_1 \log P^l + \beta_2 \log(Ex) + \textstyle\sum_k \delta_{ik} D_k + \varepsilon_i \tag{14}$$

Where, P^l is laspeyres price index, Ex is total annual consumption expenditure.

This study uses the consumption expenditure as a reflection of income. In developing countries, consumption is considered as a better indicator of household income as it is "less understated and comes closer to measuring permanent income" (WB, 2009, p. 9). It is also viewed as "the preferred welfare indicator, for practical reasons of reliability and because consumption is thought to better capture long-run welfare levels than current income" (WB, 2000, p. 17). This indicator is also used by both Bangladesh Bureau of Statistics (BBS) and World Bank to measure poverty.

Fish expenditure elasticity with respect to income is:

$$\varepsilon_f = \left(\frac{\delta \log M}{\delta ln(Ex)}\right) = \beta_2 \tag{15}$$

Finally, the income elasticity for fish category i is:

$$E_i = \eta_{ix}\ x\ \varepsilon_f \qquad (16)$$

2.2.4 Estimation of Seemingly Unrelated Regressions with Censored Regression Technique

The problem of zero expenditure is a major concern in demand analysis using micro level data (Salvanes & DeVoretz, 1997; Heien & Wessells, 1990). Zero expenditure arises from non-consumption or zero consumption of any commodity. The dependent variable is thus censored by some unobserved characteristics that are hidden behind a household's decision of not consuming a particular fish during the survey period. This study applies two-step estimation procedure with limited dependent variables to solve the problem related to micro level data (Heien & Wessells, 1990; Amemiya, 1974; Lee, 1981).

First-step: Probit analysis of decision to consume

The first step of estimation involves estimating an inverse Mills ratio (IMR) to determine the probability of a household's consuming particular types of fish. The decision to consume or not to consume is modeled as a *probit* for 15 different types of fish as:

$$Prob\ (Y_i = 1) = Prob\ (f(P_j, X, D_k) + u_{ik} > 0 \qquad (17)$$

Where,

$$\mathrm{Y_i} = \begin{cases} 1 \text{ if the household consumes ith fish item, i.e., } \mathrm{w_{ih}} > 0 \\ 0 \text{ if the household does not consume the item under consideration} \end{cases}$$

X= total expenditure

D_k= Socio-demographic variables

P_j=Price of *j*th fish category

IMR is then calculated using the following specifications for:

Who consumes: $\mathrm{IMR_i} = \frac{\theta(\mathrm{p,d,x})}{\Phi(\mathrm{p,d,x})}$ Does not consume: $\mathrm{IMR_i} = \frac{\theta(\mathrm{p,d,x})}{1-\Phi(\mathrm{p,d,x})}$ (18)

$\theta\ and\ \Phi$ in equation (15), represent the standard normal density and cumulative probability functions respectively

Second-step: The AIDS model with the IMR

The estimated IMR is used as an instrument and additional regressor in the AIDS model to correct the sample section bias. Therefore, equation (9) takes the form as follows after the final specification of the demand system:

$$w_i = \alpha^*{}_i + \sum_k \delta_{ik} D_k + \sum_j \gamma_{ij} \log\, p_j + \beta_i \big(log(X) - \sum_j \overline{w}_j \log(p_j)\big) + \delta_i IMR_i + u_i{'''} \quad (19)$$

IMR_i represents the inverse mills ratio of i^{th} fish category

The adding up restriction in equation (10) further upgrades to:

$$\alpha^*{}_i = 1 \text{ and } \sum_k \delta_{ik} = 0 \qquad \sum_{i=1}^{n} \delta_i\, IMR_i = 0 \qquad k = 1, 2\ldots\ldots, m \quad (20)$$

Inverse mills ratio can take any value and it is not possible to impose restriction like equation (20). The solution of the problem requires delete one equation from the system and then computes the parameters of that deleted equation residually. Therefore, equation (19) is applied only to the first $n-1$ demand relations to preserve the adding up property. The coefficients of the deleted equation are derived residually by imposing the adding up restrictions using the following specification:

$$w_n = \alpha^*{}_n + \sum_k \delta_{nk} D_k + \sum_j \gamma_{nj} \log\, p_j + \beta_n \big(log(X) - \sum_j \overline{w}_j \log(p_j)\big) - \sum_{j=1}^{n-1} \delta_j\, IMR_j + u_j{'''} \quad (21)$$

The estimates in equation (21) are completely invariant to which equation is dropped from the system (Pollak & Wales, 1969; Barten, 1969). Usually the least interested commodity is selected as the residual commodity. Therefore, the demand equation for ‘other fish’ type is dropped from the system to preserve the adding up property.[3]

The dependent variable in equation (19) satisfies the budget constraint but the error terms across the questions are correlated. Although ordinary least squares (OLS) estimate would be consistent and unbiased, the seemingly unrelated regressions (SUR) would be more efficient. Therefore, the SUR model for 15 fish demand equations has been applied incorporating the AIDS specification. The full demand system under the SUR specification follows as:

$$w_i(w_{1,}\, w_{2,} \ldots\ldots.. w_{15}) = \begin{cases} \alpha^*{}_1 + \sum_k \delta_{1k} D_k + \sum_j \gamma_{1j} \log\, p_j + \beta_1 \big(log(X) - \sum_j \overline{w}_1 \log(p_1)\big) + \delta_1 IMR_1 + u_1''' \\ \alpha^*{}_2 + \sum_k \delta_{2k} D_k + \sum_j \gamma_{2j} \log\, p_j + \beta_2 \big(log(X) - \sum_j \overline{w}_2 \log(p_2)\big) + \delta_2 IMR_2 + u_2''' \\ \vdots \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \vdots \\ \vdots \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \vdots \\ \vdots \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \vdots \\ \alpha^*{}_{15} + \sum_k \delta_{15k} D_{15} + \sum_j \gamma_{15j} \log\, p_j + \beta_{15} \big(log(X) - \sum_j \overline{w}_{15} \log(p_{15})\big) + \delta_{15} IMR_{15} + u_{15}''' \end{cases} \quad (22)$$

[3] The demand coefficients of the ‘other fish’ category are calculated residually from the parameters of the estimated equations using the adding up property.

To estimate the system in equation (22), the iterative Zellner procedure is applied here that specifies the SUR model to iterate until the parameter estimates converge to the maximum likelihood results (Zellner, 1962). This method produces efficient estimates from system of linear equations where errors are correlated across equations for an individual but uncorrelated across individuals (Cameron & Trivedi, 2010, p. 160). Finally, the completed demand system in equation (19) is estimated using the seemingly unrelated regressions (SUR) specification in equation (22) with the restrictions of economic theory presented by equation (6, 7 and 8).

Before the main estimation process, the theoretical restrictions in equation (6, 7 and 8) are checked for the consistency of the demand system with the assumptions of utility maximization (Appendix Table A1 and A2). The Wald test is used on the unrestricted SUR model to test the restriction of homogeneity and symmetry.[4] It is found that homogeneity holds only for 3 demand equations among the tested 14 equations and symmetry restrictions hold for majority of the cases (i.e., over 50 percent of the cases). The rejection of demand restrictions does not imply the rejection of consumer theory. Several plausible reasons such as presence of money illusion among the consumers, complexity in estimation process and short time period etc. can cause the rejection of homogeneity restriction in AIDS model (Deaton & Muellbauer, 1980_a).

2.3 Data

This study used the micro level household data from the most recent round (2010-2011) of the Bangladesh National Household Income and Expenditure Survey (HIES). HIES is based on a country-wide survey of a nationally representative number of rural and urban households. The survey is carried out at regular (5 yearly) intervals. This study uses the latest one available.

The survey provides micro data which has several advantages. First, it captures heterogeneity among consumer behavior and allows the treatment of exogenous preferences through incorporation of socio-demographic information (Yen, Kan, & Su, 2002). Second, micro data help to explain different consumer demand patterns based on detailed information of households' income and expenditures (Manchester, 1977; Blundell, Pashardes, & Weber, 1993).

[4] The results of Wald test statistics for the theoretical restrictions are available in the supplementary documents.

2.3.1 Sampling Design

The HIES data was collected through a two-stage stratified random sampling technique over a one-year survey period from mid-2010 to mid-2011 reflecting the agricultural year. The first stage included selection of Primary Sampling Units (PSUs)[5] and second stage included selection of households within each PSU. The survey strategy was to divide the year into 18 equal terms in order to be better able to capture the seasonal variations in income, expenditure and consumption pattern over the period of a year. During each term a total of 34 PSUs were selected to collect data of 680 sampled households (i.e., 20 households per PSU). During the entire survey period, a total of 12,240 households were interviewed in 612 primary sampling units with 392 in rural and 220 in urban areas.

A household survey questionnaire was used to collect a wide range of information on household characteristics, economic activities such as wage and self-employment, agriculture and non-agricultural enterprises, asset and income, consumption expenditures, health and social safety net programs. In addition, sub-modules on disability, credit access, migration and remittances as well as risks, shocks and coping measures were included in the questionnaire.

2.3.2 Information on Food and Fish Consumption

Information of food consumption was collected with a two-day recall period, which is administered on alternative days over 14 days. The food consumption module was divided into two parts of daily and weekly consumption. The food items such as: spices and condiments, which have small amount of daily consumption, considered to be collected on weekly basis to have precise information. Information of 194 daily food items as and 25 weekly food items was collected during the survey. Detailed data on the quantity, the value of food consumed with sources of receipts for various food items were collected.

[5] The PSUs are defined as contiguous two or more enumeration areas with around 200 households in each PSU from the framework of Integrated Multipurpose Sample (IMPS) following the Population and Housing Census 2001. The IMPS divides the country into a total of 1000 PSUs.

2.3.3 Disaggregation of Fish

Fish consumption information was collected from the consumption module. A large number of fish species was used in the consumption module to collect data on fish consumption patterns. Consumption information of 33 fish species was collected by aggregating into fifteen different groups of species (Table 2.1).

Table 2.1: Composition of species reported in HIES-2010

Fish species groups	Composition of species:		
	Local name	Scientific name	Average price (Taka/kilogram)
Hilsa	Hilsa	Tenualosa ilisha	234.10
Indigenous carp	Rohu Catla Mrigal Kalibaus	Labeo rohita Catla catla Cirrhinus cirrhosus Labeo calabasu	118.85
Exotic carp	Silver carp Grass carp Mirror carp	Hypophthalmichthys molitrix Ctenopharyngodon idella Cyprinus carpio var. Specularis	92.04
Large catfish	Pangus Boal Aior	Pangasius pangasius Wallago attu Mystus aor or Aorichthys aor	96.60
Medium catfish & Gourami	Baila Topshe	Awaous guamensis Sarotherodon melanotheron heudelotii	129.56
Small catfish & eels	Tengra Eel fish	Mystus tengara Eel fish	135.88
Live fish	Magur Shingi Khalisa	Clarias batrachus Hetropneustes fossilis Colisa spp.	198.84
Climbing perch	Koi	Anabus testudineus	177.28
Snakeheads	Shoal Gajar Taki	Channa striata Channa marulius Channa panctatus	108.09
Barbs & tilapia	Punti Big puti Tilapia Nilotica	Puntius chola Barbonymus gonionotus Oreochromis niloticus Nilotica	99.47
Small indigenous species	Mola-kachi Chala-Chapila	Amblypharyngodon mola Gonialosa manmina)	105.17
Shrimp	Shrimp	-	141.71

Dried fish	Dried fish	-	216.23
Sea fish	Sea fish	-	105.62
Other fish	Other types of fish	-	110.65

Note: Fish prices are obtained by dividing total expenditure by its quantity consumed. Missing prices are replaced by the estimated prices using the technique of regression imputation (Heien & Wessells, 1990; Wellman, 1992).

Source: Own calculation based on HIES data 2010

Fish species were grouped based on their biological type and commercial value (Figure 2.1). These fish groups fall under four major categories based on their origin (Taufique & Belton, 2014).

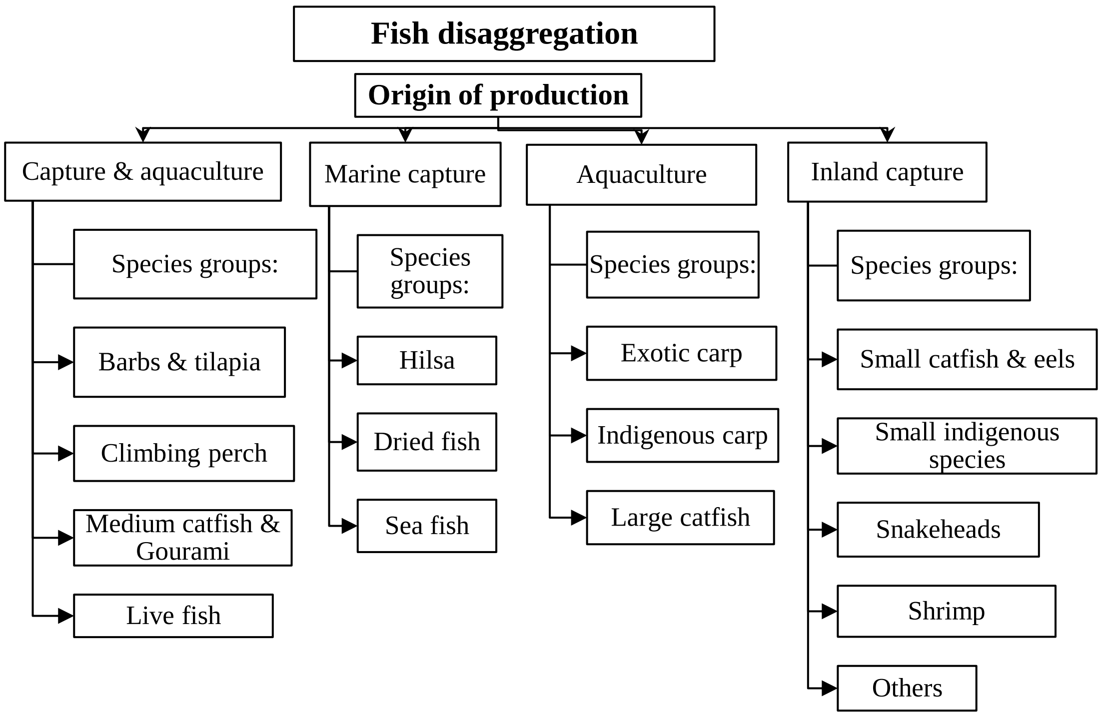

Figure 2.1: Disaggregation of fish in HIES 2010 (BBS, 2011)
Source: Author's illustration based on HIES data 2010

2.3.4 Identification of Poverty Groups

This study used the poverty line as a threshold to identify different poverty groups from Bangladesh based on the economic position of the households. The poverty line threshold is jointly used by the Bangladesh Bureau of Statistics (BBS) and World Bank, and considered as the 'official methodology' to determine the incidence of poverty (BBS, 2011, p. 181). The poverty estimates are based on the cost of basic needs (CBN) approach.[6] This method calculates the poverty line based on the average level of per-capita expenditure at which a household is expected to meet their basic needs (food and non-food items) (WB, 2008). Any household with per capita expenditure below the threshold is considered as poor and above as non-poor (Figure 2.2).

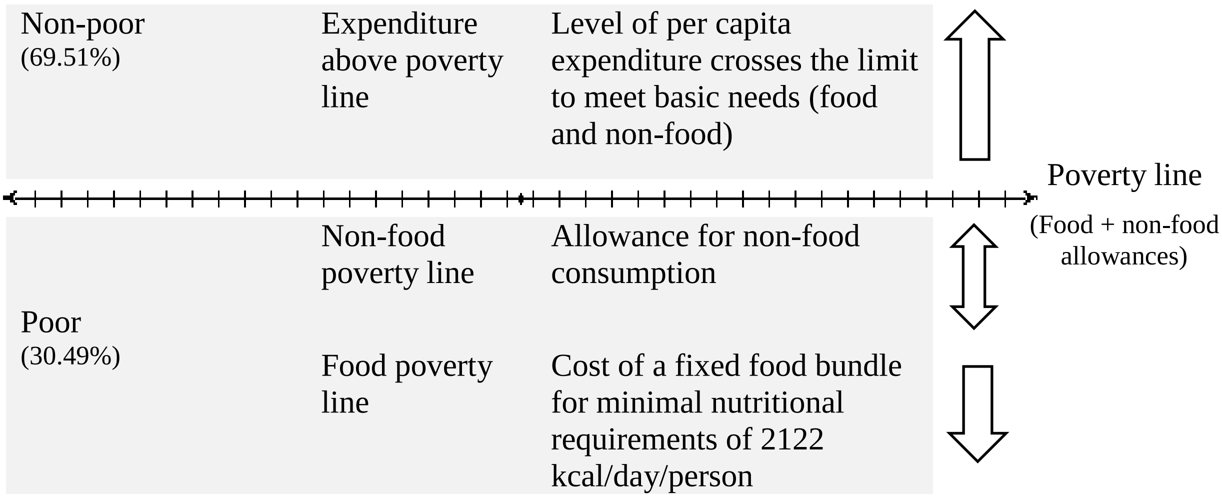

Figure 2.2: CBN method to calculate poverty line in Bangladesh
Source: Author's illustration based on Ravallion and Sen (1996)

In HIES data, 30 percent of the households fall below the estimated poverty line and 70 percent of the households' expenditure exceed the poverty line. Therefore, a total of 3732 and 8508 households were identified as poor and non-poor respectively.

2.3.5 Adjustment of the Adult Male Equivalent (AME)

Usually in demand studies household fish consumption is considered in per-capita terms. But a household with young children are expected to have lower energy intake compared to a household only with adults. The Adult Male Equivalent (AME) was developed following the methodology of FAO and the World Health Organization (WHO) to provide an expression of "household food intake that accounts for the composition of the household and allows the direct comparison of food or energy intakes of households of different sizes and compositions" (Weisell & Dop, 2012, p. S158). In AME, each family member is indicated as a fraction of an

[6] This method estimates a food poverty line at the cost of a fixed bundle of goods providing minimal nutrition requirements corresponding to 2122 kcal/day/person. This bundle consists of eleven food items: rice, wheat, pulses, milk, oil, meat, fresh water fish, potato, other vegetables, sugar, and fruits as recommended by Ravallion and Sen (1996). Then an 'allowance' for non-food consumption is estimated. The food and non-food allowances are added together to calculate the poverty line.

adult male equivalent consumption unit based on the energy requirements by gender and age. The AME for each of the households was computed using Table 2.2. After the computation, household size in equation (19) was replaced with adult equivalent household size and per capita expenditure was replaced with per capita adult equivalent expenditure.

Table 2.2: Adult male equivalent values for age and gender groups in Bangladesh

Age (year)	Females	Males	Age (year)	Females	Males
Below 1	0.20	0.22	12.0–12.9	0.75	0.83
1.0–1.9	0.29	0.32	13.0–13.9	0.78	0.90
2.0–2.9	0.36	0.39	14.0–14.9	0.80	0.96
3.0–3.9	0.40	0.43	15.0–15.9	0.81	1.00
4.0–4.9	0.44	0.47	16.0–16.9	0.82	1.04
5.0–5.9	0.47	0.51	17.0–17.9	0.82	1.07
6.0–6.9	0.51	0.55	18.0–18.9	0.83	1.08
7.0–7.9	0.55	0.59	19.0-29.9	0.78	1.02
8.0–8.9	0.59	0.64	30.0–59.9	0.80	1.00
9.0–9.9	0.64	0.69	Age ≥65	0.71	0.82
10.0–10.9	0.67	0.71	Lactation* (children<1)	0.04	
11.0–11.9	0.72	0.76	Lactation* (children 1.0–1.9)	0.03	

Note: * in addition to base requirement for age group
Source: Bogard et al. (2017).

2.4 Results and Discussion

This section presents the results and discusses the finding from the empirical model. First segment discusses fish demand patterns in Bangladesh to see how much fish is consumed by different households, and which species do they consume. Next segment describes the determinants of demand for fish in Bangladesh. Finally, the respective price and income elasticity of fish demand in Bangladesh are discussed.

2.4.1 Pattern of Fish Demand in Bangladesh

Table 2.3 shows that fish consumption varies by poverty groups among Bangladeshi consumers. The average value of the per capita consumption of fish in non-poor households was 2.2 times higher than that consumed in the poor implying non-poor households consume more fish than poor households.

Table 2.3: Per capita expenditure on fish and its share between different types of households

Types of households	Fish consumption (person/kg/year)	Fish expenditure (person/Tk./year)	Fish expenditure Share to food expenditure
Poor households	10.43	1098.54	11.09
Non-poor households	22.37	2789.77	14.50
Total sample	18.72	2250.24	13.80
Mean difference (Poor vs. Non-poor)	11.94*** (t= 52.49)	1691.23*** (t= 49.05)	-

Note: *** indicates t test is statistically significant at 1% level.
Source: Own calculation based on HIES data 2010

It is noted that the proportion of the expenditure on fish is 11 percent for poor and 14.5 percent for non-poor households. Moreover, it was 4.7 percent and 11.2 percent respectively for meat (Table 2.4). This result suggests that poor households tend to rely more on fish as their primary source of animal protein than do non-poor households.

Table 2.4: Share of major food items in households' food expenditure

Food item group	Total sample	Poor households	Non-poor households
Total food expenditure (Tk./month)	5883.05	4072.08	6677.43
Total food expenditure (percentage)			
Cereals	36.06	47.88	32.90
Pulses	2.56	2.35	2.61
Fish	13.80	11.09	14.50
Meat & eggs	9.85	4.68	11.24
Vegetables	7.90	9.13	7.70
Milk and milk product	3.77	1.49	3.49
Edible oil	4.35	4.55	4.29
Fruits	4.00	1.97	4.64
Sugar/molasses	1.36	0.89	1.78
Beverage/drink	0.73	0.29	0.85
Spices/betel leaf/chew goods	10.04	10.51	9.92
Tobacco & products	2.36	2.31	2.57
Miscellanies	3.20	2.76	3.50

Source: Own calculation based on HIES data 2010

Table 2.5 presents the per capita share of total expenditure of fish species groups. It is observed that the most popularly consumed fish species groups among the poor are barbs & tilapia, exotic carp, large catfish and small indigenous species. These four groups of fish species constituted 57 percent of fish expenditure and 62 percent of fish consumption share of the poor. Besides, they also consume a significant amount of indigenous carp and shrimp. Similar species composition is also popular among the non-poor; however, hilsa is an addition to their consumption item.[7]

Table 2.5: Share of fish expenditure and consumption by different fish species groups

Fish species groups	Share of total fish expenditure (%)			Share of total fish consumption (%)			Average price (Tk./kg)
	National	Poor	Non-poor	National	Poor	Non-poor	
A. Aquaculture fish	38	36	39	39	37	41	107
Exotic carp	12	14	11	11	14	11	92
Indigenous carp	14	09	16	13	8	16	119
Large catfish	12	13	12	14	14	13	97
B. Inland capture fish	23	26	22	25	33	22	118
Small catfish & eels	2	2	2	2	1	2	136
Small indigenous species	8	10	8	9	14	8	105
Snakeheads	4	5	4	4	5	4	108
Shrimp	5	5	5	7	9	5	142
Other fish	4	4	3	4	4	3	111
C. Marine fish	16	14	16	14	8	13	227
Hilsa	8	4	10	7	2	8	234
Dried fish	5	7	3	2	3	2	216
Sea fish	3	3	3	5	3	4	106
D. Capture & culture fish	23	24	23	22	22	24	108
Live fish	2	1	2	1	1	2	199
Climbing perch	2	2	2	3	1	3	177
Barbs & tilapia	18	20	18	18	20	19	99
Medium catfish & Gourami	1	1	1	1	1	1	130

Source: Own calculation based on HIES data 2010

The sources of production and supply show that among the most frequently consumed species, the cultured species occupied the highest share in fish expenditure (38 percent) and consumed in larger quantities (39 percent) than fish from any other sources. Fish from cultured sources are equally consumed among poor and non-poor households. Additionally, captured species occupy a large share of expenditure of poor households compared to non-poor households. Although, the expenditure share of marine fish is found almost similar between poor and non-poor, due to high price poor household consume a smaller amount of marine fish compare to

[7] Hilsa is most highly prized, culturally significant, and expensive fish in Bangladesh (Toufique, 2015). It is a marine fish but it migrates to inland for spawning for which no farmed substitute exists.

non-poor households. Hilsa is the most consumed marine species in non-poor households that is consumed less in poor households, expressed by the small consumption share of 2 percent. It is observed that low-priced fish are usually consumed by the poor than high-priced fish. Exotic carp and large catfish are cheaper and least expensive fish among all other species selling for Tk. 92 per kilogram and Tk. 97 per kilogram respectively. Other relatively inexpensive fish species are barbs and tilapia and small indigenous species, which together account for a larger share of consumption and expenditure (30 and 34 percent respectively) in poor households than in non-poor households (26 to 27 percent respectively). The cheaper fish is mainly produced by aquaculture compared to any other production sources.

To sum up, the results show that poor households consume less fish but rely more on fish as their primary source of animal protein than non-poor households. The most popular fish species consumed by poor households are low-priced fish, dominated by aquaculture species. Moreover, fish species consumed in poor and non-poor households are almost similar, however, the quantity varies.

2.4.2 The Determinants of Demand for Fish in Bangladesh

The parameter estimates from the AIDS model for all households in Bangladesh are presented in Table 2.6. The coefficients of per capita expenditure are statistically significant in all demand equations except for sea fish, indicating the effect of household wealth on the consumption demand of fish.

Table 2.6: Estimated parameters of the disaggregated fish demand system

Explanatory variable	Dependent Variable share in total expenditure of fish														
	(1) Hilsa	(2) Indigenous carp	(3) Large catfish	(4) Live fish	(5) Climbing perch	(6) Exotic carp	(7) Snakeheads	(8) Barbs & tilapia	(9) SIS	(10) Shrimp	(11) Dried fish	(12) Small catfish	(13) Sea fish	(14) Medium catfish	(15) Other fish
Fish prices :															
Ln(*P*_hilsa)	0.006	-0.025***	-0.002	0.003	-0.002	-0.015**	-0.006	0.007	0.003	0.022***	0.013***	0.010***	-0.014***	0.005*	-0.004
	(0.014)	(0.006)	(0.006)	(0.003)	(0.005)	(0.006)	(0.005)	(0.007)	(0.005)	(0.005)	(0.004)	(0.003)	(0.005)	(0.003)	
Ln(*P*_ carp)	-0.025***	-0.038**	0.005	0.001	0.013**	-0.005	0.006	0.018**	-0.006	0.011**	-0.009**	0.004	-0.001	0.006**	0.020
	(0.006)	(0.015)	(0.008)	(0.004)	(0.006)	(0.008)	(0.005)	(0.008)	(0.006)	(0.005)	(0.004)	(0.004)	(0.005)	(0.003)	
Ln(*P*_L. catfish)	-0.002	0.005	-0.012	0.002	-0.005	-0.019**	0.011**	-0.001	0.013**	-0.008**	-0.007*	0.005*	0.011***	0.006**	0.0001
	(0.006)	(0.008)	(0.013)	(0.004)	(0.006)	(0.009)	(0.004)	(0.007)	(0.005)	(0.004)	(0.004)	(0.003)	(0.004)	(0.003)	
Ln(*P*_ live)	0.003	0.001	0.002	-0.015	-0.004	0.000	0.004	-0.002	0.003	0.002	0.000	0.002	-0.010**	0.006*	0.008
	(0.003)	(0.004)	(0.004)	(0.015)	(0.006)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.002)	(0.003)	(0.004)	(0.003)	
Ln(*P*_ perch)	-0.002	0.013**	-0.005	-0.004	-0.017	-0.000	-0.001	-0.008*	0.001	0.000	0.003	0.004	0.001	0.004	0.012
	(0.005)	(0.006)	(0.006)	(0.006)	(0.019)	(0.005)	(0.006)	(0.004)	(0.004)	(0.004)	(0.002)	(0.005)	(0.005)	(0.005)	
Ln(*P*_ exotic)	-0.015**	-0.005	-0.019**	0.0002	-0.000	-0.056***	0.012**	0.025***	0.016**	0.007**	0.020***	0.004	0.025***	-0.005*	-0.009
	(0.006)	(0.008)	(0.009)	(0.004)	(0.005)	(0.016)	(0.005)	(0.007)	(0.007)	(0.003)	(0.004)	(0.004)	(0.006)	(0.003)	
Ln(*P*_ snakehead)	-0.006	0.006	0.011**	0.004	-0.001	0.012**	0.020	-0.018***	-0.018***	-0.018***	-0.004	-0.004	0.002	0.000	0.015
	(0.005)	(0.005)	(0.004)	(0.005)	(0.006)	(0.005)	(0.017)	(0.006)	(0.006)	(0.003)	(0.003)	(0.004)	(0.004)	(0.003)	
Ln(*P*_ barbs)	0.007	0.018**	-0.001	-0.002	-0.008*	0.025***	-0.018**	-0.029***	-0.001	-0.015**	0.005	-0.002	0.020***	0.004**	-0.002
	(0.007)	(0.008)	(0.007)	(0.003)	(0.004)	(0.007)	(0.006)	(0.010)	(0.007)	(0.006)	(0.004)	(0.003)	(0.006)	(0.002)	
Ln(*P*_ SIS)	0.003	-0.007	0.013**	0.003	0.001	0.016**	-0.018***	-0.001	-0.073***	0.004	-0.005	0.010***	0.010*	0.006***	0.037
	(0.005)	(0.006)	(0.005)	(0.003)	(0.004)	(0.005)	(0.005)	(0.007)	(0.010)	(0.005)	(0.004)	(0.004)	(0.005)	(0.002)	
Ln(*P*_ shrimp)	0.022***	0.011***	-0.008**	0.002	0.000	0.007	-0.018***	-0.015***	0.004	-0.007	0.016***	-0.015***	-0.006*	0.000	0.005
	(0.005)	(0.005)	(0.004)	(0.002)	(0.004)	(0.003)	(0.003)	(0.006)	(0.005)	(0.007)	(0.003)	(0.003)	(0.003)	(0.002)	
Ln(*P*_ dried)	0.013***	-0.009*	-0.007*	-0.000	0.002	0.020***	-0.004	0.004	-0.005	0.016***	-0.037***	0.003	0.003	-0.005***	0.005
	(0.004)	(0.004)	(0.004)	(0.002)	(0.002)	(0.004)	(0.003)	(0.004)	(0.004)	(0.003)	(0.005)	(0.002)	(0.004)	(0.001)	
Ln(*P*_S. catfish)	0.010***	0.004	0.005	0.002	0.004	0.004	-0.004	-0.002	0.010**	-0.015***	0.003	-0.018	-0.007**	-0.005	0.008
	(0.003)	(0.004)	(0.003)	(0.003)	(0.006)	(0.004)	(0.004)	(0.003)	(0.004)	(0.003)	(0.002)	(0.012)	(0.003)	(0.004)	
Ln(*P*_ sea)	-0.014**	-0.001	0.011**	-0.010**	0.001	0.025***	0.002	0.020***	0.010*	-0.006*	0.003	-0.007**	-0.056***	0.011***	0.013
	(0.005)	(0.005)	(0.004)	(0.004)	(0.005)	(0.006)	(0.005)	(0.005)	(0.005)	(0.003)	(0.004)	(0.003)	(0.012)	(0.003)	
Ln(*P*_ M. catfish)	0.005*	0.006**	0.006**	0.006*	0.004	-0.005	0.000	0.004**	0.006***	0.000	-0.005***	-0.005	0.011***	-0.033	-0.001
	(0.003)	(0.002)	(0.003)	(0.003)	(0.005)	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)	(0.001)	(0.004)	(0.003)	(0.020)	
Ln(*P*_ other)	-0.004	0.020	0.0001	0.008	0.012	-0.009	0.015	-0.002	0.037	0.005	0.005	0.008	0.013	-0.001	-0.107

Socio-economic status:															
Ln (family size)	0.018***	0.042***	0.024***	0.001	0.001	0.003	0.001	0.011*	0.018***	0.011***	0.032***	0.004**	0.000	0.004***	-
	(0.003)	(0.005)	(0.004)	(0.002)	(0.002)	(0.005)	(0.003)	(0.007)	(0.004)	(0.003)	(0.003)	(0.002)	(0.002)	(0.001)	
Ln (per capita expenditure/P)	0.039***	0.029***	0.014***	0.008***	0.014***	0.011***	0.007***	0.034***	0.021***	0.007*	0.049***	0.005***	0.002	0.003***	-
	(0.003)	(0.004)	(0.003)	(0.001)	(0.002)	(0.003)	(0.002)	(0.005)	(0.003)	(0.003)	(0.003)	(0.001)	(0.002)	(0.001)	
Poverty (poor=1)	-0.006*	-0.041***	0.010*	0.002	-0.007***	0.009**	0.010***	0.002	0.008*	-0.001	-0.003	0.0003	-0.006***	-0.00001	-
	(0.003)	(0.004)	(0.005)	(0.002)	(0.001)	(0.005)	(0.002)	(0.005)	(0.004)	(0.003)	(0.003)	(0.002)	(0.002)	(0.001)	
Urban consumer dummy (urban=1)	0.018***	0.008**	-0.026***	-0.002	0.003	-0.035***	-0.010***	0.003	-0.005	0.016***	-0.020***	0.001	0.023***	0.004	-
	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.004)	(0.002)	(0.004)	(0.003)	(0.003)	(0.002)	(0.002)	(0.003)	(0.003)	
Divisional dummy (yes=1):															
Barisal	0.050***	-0.048***	-0.108***	0.000	-0.002	-0.052***	0.031***	-0.093***	-0.017***	0.151***	-0.097***	-0.005*	0.073***	0.039***	-
	(0.007)	(0.007)	(0.009)	(0.002)	(0.004)	(0.010)	(0.005)	(0.008)	(0.006)	(0.010)	(0.009)	(0.003)	(0.007)	(0.004)	
Chittagong	-0.013**	-0.005	-0.042***	-0.006**	-0.015***	-0.034***	-0.024***	0.042***	-0.011***	0.041***	0.044***	-0.014***	0.113***	-0.012***	-
	(0.006)	(0.005)	(0.006)	(0.002)	(0.003)	(0.006)	(0.003)	(0.006)	(0.004)	(0.003)	(0.004)	(0.002)	(0.008)	(0.002)	
Khulna	0.008*	0.111***	-0.091***	-0.003	-0.002	0.030***	-0.001	0.054***	-0.096***	0.011***	-0.136***	0.001	0.019***	-0.003**	-
	(0.005)	(0.008)	(0.007)	(0.003)	(0.003)	(0.006)	(0.003)	(0.006)	(0.011)	(0.004)	(0.012)	(0.002)	(0.003)	(0.001)	
Rajshahi	0.007	0.062***	0.045***	0.004*	-0.007**	0.103***	-0.005	-0.068***	-0.039***	-0.040***	-0.110***	-0.008***	-0.034***	-0.019***	-
	(0.005)	(0.008)	(0.007)	(0.002)	(0.004)	(0.008)	(0.003)	(0.008)	(0.007)	(0.007)	(0.008)	(0.003)	(0.006)	(0.003)	
Rangpur	0.025***	0.048***	-0.098***	0.005*	-0.006**	0.067***	0.023***	0.025***	-0.027***	-0.044***	-0.032***	-0.011***	0.005**	-0.032***	-
	(0.006)	(0.008)	(0.008)	(0.003)	(0.004)	(0.007)	(0.004)	(0.009)	(0.007)	(0.09)	(0.005)	(0.003)	(0.002)	(0.005)	
Sylhet	-0.022***	-0.035***	-0.026***	0.003	-0.009***	-0.036***	-0.022***	-0.002	0.076***	0.008**	0.053***	0.024***	-0.026***	-0.021***	-
	(0.005)	(0.008)	(0.006)	(0.002)	(0.003)	(0.007)	(0.003)	(0.007)	(0.007)	(0.004)	(0.006)	(0.004)	(0.005)	(0.003)	
Inverse Mills ratio	-0.081***	0.043***	0.064***	-0.10*	-0.012**	-0.015***	0.024***	0.040**	0.013***	0.018***	0.038***	0.013***	0.031***	0.028***	-
	(0.006)	(0.011)	(0.0104)	(0.006)	(0.006)	(0.001)	(0.006)	(0.019)	(0.003)	(0.003)	(0.007)	(0.005)	(0.007)	(0.004)	
Constant	0.113	0.006	0.075	0.017	0.036	0.120	0.048	0.192	0.114	0.012	0.144	0.005	-0.034	-0.058	0.156
	(0.013)	(0.017)	(0.014)	(0.011)	(0.014)	(0.015)	(0.011)	(0.020)	(0.014)	(0.016)	(0.011)	(0.011)	(0.015)	(0.011)	
R^2	0.19	0.07	0.04	0.01	0.04	0.10	0.03	0.05	0.07	0.14	0.20	0.03	0.13	0.04	-
χ^2	2820.27	1028.25	626.32	155.13	488.90	1328.49	417.32	716.75	1011.96	2024.26	2962.31	377.99	1801.79	542.50	-
$Prob > \chi^2(26)$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-

Note: *Ln*=Natural logarithm. *P*=price. Base category is Dhaka division for divisional dummy. Inverse mills ratios are calculated from the *Probit* regression of households' choice of consuming specific fish category, which is different for each fish type, details of this calculation are in methodology section. ***, ** and * indicate statistically significant at 1%, 5% and 10% level. Standard errors are in parentheses obtained from bootstrap procedure. A total of 169 households are dropped from the estimation process for having no information regarding total fish expenditure. Significance level cannot be assessed for the coefficients of 'other fish' as derived residually by using the demand restrictions.

Source: Own calculation based on HIES data 2010

Household size is significant, and positively correlated with the budget shares of all fish species groups. This indicates that consumption decision of fish is influenced by household size. The more family members in a household, the higher is expenditure share of any fish species.

Most of the coefficients of divisional dummies are statistically significant but vary in their sign indicating fluctuation in expenditure share by area and type of fish. The urban dummy is found to be statistically significant in all the share equations except that of live fish, climbing perch, barb & tilapia, small indigenous species, small catfish and medium-sized catfish. The sign of this variable is positive in the demand equation of hilsa, indigenous carp, shrimp and sea fish, indicating higher share of expenditure of such species in urban areas. However, it is negative for large catfish, exotic carp, snakeheads and dried fish, suggesting expenditure share of these fish are higher in rural areas than in the urban areas. These results suggest that the demand for expensive fish items is higher in urban areas than in the rural. Moreover, dried fish is more commonly consumed among rural households, rather than urban households.

Most of the poverty dummy variable coefficients are statistically significant; however, the signs of these variables differ by fish species groups. The sign is positive for the large catfish, exotic carp, snakeheads and small indigenous species, indicating higher expenditure share of these species in poor households. However, the coefficients are negative for hilsa, indigenous carp, climbing perch and sea fish, indicating higher expenditure shares for these species in non-poor households than in poor households. These results suggest that expenditure shares of fish differ between poor and non-poor consumers, as expected. Moreover, the inverse Mills ratios are highly significant in all share equations. Therefore, inclusion of this variable minimizes the effect of sample selection bias caused by zero purchases.

In summary, the model used in this study is plausible with regards to the determinants of fish demand in Bangladesh showing differences by fish types and species. This underlines the value of a disaggregated demand analysis. Furthermore, the differences between poor and non-poor households suggest that demand elasticities should be estimated separately for the poor.

2.4.3 The Elasticities of Disaggregated Fish Demand Model

The parameters of the AIDS model are used to generate the respective price and income elasticities for various fish species group. Table 7 presents the compensated and uncompensated own price elasticities and Table 9 represents the income elasticities of the 15 different fish species groups considered in this study.

Price elasticities of fish demand

Table 2.7 shows that price elasticities vary across different fish species within the poor and non-poor households, justifying the need of estimating demand elasticities by fish types. The estimated elasticities also carry the expected negative sign, which indicates households will reduce the consumption of a particular fish in response to an increase in the price of that fish.

Table 2.7: Price elasticity of demand for different fish species groups in Bangladesh

Fish species groups by sources	National		Poor households		Non-poor households	
	Uncompensated elasticities	Compensated elasticities	Uncompensated elasticities	Compensated elasticities	Uncompensated elasticities	Compensated elasticities
A. Aquaculture fish	-0.94	-0.85	-0.91	-0.85	-0.82	-0.71
Exotic carp	-1.16	-1.05	-1.16	-1.13	-0.76	-0.67
Indigenous carp	-0.56	-0.53	-0.49	-0.41	-0.83	-0.64
Large catfish	-1.11	-1.07	-1.09	-1.02	-0.86	-0.84
B. Inland capture fish	-0.85	-0.79	-0.88	-0.75	-0.65	-0.61
Small catfish & eels	-0.59	-0.57	-0.65	-0.60	-0.59	-0.51
Small indigenous species	-1.17	-1.07	-1.16	-1.10	-1.07	-1.02
Snakeheads	-0.53	-0.49	-0.87	-0.81	-0.63	-0.67
Shrimp	-1.12	-1.01	-1.27	-1.23	-0.68	-0.63
C. Marine fish	-1.59	-1.54	-2.07	-2.04	-0.97	-0.91
Hilsa	-0.97	-0.85	-2.34	-2.30	-0.48	-0.32
Dried fish	-1.67	-1.67	-1.71	-1.70	-1.58	-1.58
Sea fish	-2.13	-2.10	-2.15	-2.12	-0.85	-0.83
D. Capture & culture fish	-0.79	-0.70	-0.65	-0.56	-0.89	-0.83
Live fish	-0.70	-0.68	-0.33	-0.30	-1.29	-1.22
Climbing perch	-0.95	-0.89	-0.47	-0.45	-1.36	-1.31
Barbs & tilapia	-1.12	-0.97	-1.14	-1.10	-0.69	-0.56
Medium catfish & gourami	-0.43	-0.42	-0.41	-0.41	-0.24	-0.23

Note: The restricted coefficients are derived residually for this demand equation and hence, elasticity values for other fish cannot be generated.

Source: Own calculation based on HIES 2010 data.

The statistics at the national level show that fish has a price inelastic demand for all sources except for marine fish. This result indicates that as the price of fish increases, demand for fish decreases at a lower rate for aquaculture, capture, capture & culture sources but at a higher rate for marine sources. Hence, increase in price has a larger impact on the consumption of fish from marine source than any other sources. Therefore, given an elastic demand, producers particularly in the aquaculture sector may encounter difficulties for their product as an increase in aggregate fish production will not result in a proportionate increase in revenue (Toufique, Farook, & Belton, 2018). However, at the disaggregated level, the results are more interesting with two broad findings.

First, the elasticity values of exotic carp, large catfish, small indigenous species, shrimp, hilsa, sea fish and barbs & tilapia are all greater one and exhibit a downward trend between poor and non-poor household. This result implies that demand for these fish species turn to be less elastic when households move above the poverty line as income increases. Therefore, poor consumers tend to respond more to changes in fish prices than non-poor consumers. This result has several interpretations. (1) Due to affordability, low-priced exotic carp, large catfish, small indigenous species, and barbs & tilapia are generally popular among the poorer households. Table 4 also confirms this statement by showing that the expenditure and the consumption shares of these fish are high among the poor households. Therefore, any further increase in price will encourage poor consumers to find for alternative substitute fish species (2) High-priced fish such as hilsa and sea fish are generally preferred among the non-poor consumers. Therefore, due to preferences, these fish species have a lower elasticity among those who can afford them. (3) Although the low-priced barbs & tilapia and large catfish exhibits a downward trend, the consumption and expenditure shares of these fish species are almost similar between the two poverty groups (poor and non-poor) (Table 2.5). Additionally, they capture the highest shares among all other fish species group. This implies that regardless of any socio-economic differences these fish species are equally popular among Bangladeshi households, however more preferred in non-poor households.

Second, the price elasticities of indigenous carp, live fish and climbing perch show an upward trend between the poor and non-poor households. This implies that consumer demand for these fish is more responsive to price changes in higher income households. Live fish and climbing perch are price inelastic for poor, however, elastic for non-poor households. On the other hand, elasticity value of indigenous carp is inelastic for both poor and non-poor households. This result is interpreted in two ways. (1) Live fish and climbing perch are high priced fish.

Therefore, the relatively wealthier households are responsive to price changes of fish as these fish are already expensive. (2) Indigenous carp has price inelastic demand. However, the magnitude is higher for non-poor households implying that non-poor households reduce the consumption of this fish stronger in response to an increase in the price of this fish. This fish is the most expensive fish among the fish produced by aquaculture sector.
Comparing compensated and uncompensated elasticity coefficients, this study find that in all cases the former are lower for both groups of households. This shows that price responsiveness of fish demand is dependent on income and hence, when income is held constant (i.e., not in the decision process) consumers tends to respond less to changes in fish prices.

The overall result shows that fish species usually consumed by the poor have high price elasticities. Therefore, price change or supply shock will reduce the consumption demand of fish by the poor.

Cross-price elasticity of fish demand

Table 2.8 presents the matrix of cross- price elasticities for both the poor and non-poor households. The diagonal values provide the own-price elasticities that come from table 6. The upper and the lower diagonal values of pairwise cross-price elasticities are the same and therefore, the lower diagonal values are provided for brevity.

The coefficients of cross-price elasticity carry both positive and negative signs. The positive sign indicates a substitute relationship while the negative implies complementary relationship. Approximately 96 percent of fish carry positive cross-price elasticities, for both the poor and non-poor households. This indicates that most of the fish are substitutes of each other's. However, the magnitudes are larger for poor than non-poor households, which imply that poor households respond more to changes in the price of substitutes. This is particularly true for all fish from aquaculture and most of the fish originated from other sources. Moreover, only a small proportion of the fish shows negative cross price elasticities that mostly belong to the fish from inland capture.

Table 2.8: Cross-price elasticity of demand for different fish species groups in Bangladesh

Fish species groups by sources	Aquaculture fish			Inland capture fish				Marine fish			Capture & culture fish			
	Exotic carp	Indigenous carp	Large catfish	Small catfish	SIS	Snakeheads	S&P	Hilsa	Dried fish	Sea fish	Live fish	Climbing perch	B&T	Medium catfish
National														
A. Aquaculture fish														
Exotic carp	-1.05													
Indigenous carp	0.09	-0.53												
Large catfish	0.04	0.14	-1.07											
B. Inland Capture fish														
Small catfish	0.05	0.05	0.06	-0.57										
SIS	0.22	0.03	0.20	0.65	-1.07									
Snakeheads	0.14	0.09	0.13	-0.19	-0.18	-0.49								
S&P	0.11	0.15	-0.01	-0.77	0.10	-0.41	-1.01							
C. Marine fish														
Hilsa	-0.04	-0.11	0.07	0.62	0.12	0.08	0.49	-0.85						
Dried fish	0.22	0.01	0.007	0.22	0.01	0.06	0.35	0.21	-1.67					
Sea fish	0.23	0.02	0.11	0.37	0.15	0.09	0.08	0.15	0.10	-2.10				
D. Capture & culture fish														
Live fish	0.02	0.02	0.03	0.13	0.05	0.10	0.06	0.06	0.01	-0.36	-0.68			
Climbing perch	0.02	0.12	0.02	0.23	0.03	0.001	0.02	0.005	0.07	0.05	0.29	-0.89		
B&T	0.39	0.33	0.17	0.07	0.16	0.27	0.09	0.27	0.28	0.94	0.03	0.17	-0.97	
Medium catfish	0.04	0.05	0.06	0.25	0.08	0.003	0.01	0.07	0.08	0.42	0.44	0.18	0.03	-0.42
Poor households														
A. Aquaculture fish														
Exotic carp	-1.13													
Indigenous carp	0.19	-0.41												
Large catfish	0.11	0.24	-1.02											
B. Inland capture fish														
Small catfish	0.03	0.27	0.04	-0.60										
SIS	0.39	0.23	0.54	0.68	-1.10									
Snakeheads	0.26	0.42	0.03	-0.44	-0.05	-0.81								

S&P	0.16	0.42	0.07	-0.73	0.05	-0.32	-1.23							
C. Marine fish														
Hilsa	0.08	0.02	0.26	0.41	0.10	0.38	0.71	-2.30						
Dried fish	0.18	0.03	0.12	0.10	0.03	0.12	0.32	0.46	-1.70					
Sea fish	0.31	0.43	0.23	0.79	0.10	0.45	0.28	0.12	0.10	-2.12				
D. Capture & culture fish														
Live fish	0.02	0.03	0.04	0.01	0.005	0.002	0.04	0.45	0.06	0.11	-0.30			
Climbing perch	0.03	0.02	0.13	0.21	0.02	0.35	0.01	0.21	0.09	0.23	0.94	-0.45		
B&T	0.58	0.83	0.33	0.34	0.25	0.17	0.06	0.94	0.66	0.85	0.51	0.35	-1.10	
Medium catfish	0.01	0.19	0.03	0.22	0.12	0.04	0.06	0.35	0.01	0.24	0.82	0.48	0.04	-0.41
Non-poor households														
A. Aquaculture fish														
Exotic carp	-0.67													
Indigenous carp	0.07	-0.64												
Large catfish	0.09	0.15	-0.84											
B. Inland capture fish														
Small catfish	0.06	0.01	0.07	-0.51										
SIS	0.11	0.03	0.09	0.54	-1.02									
Snakeheads	0.07	0.03	0.15	-0.05	-0.23	-0.67								
S&P	0.10	0.08	0.02	-0.57	0.09	-0.37	-0.63							
C. Marine fish														
Hilsa	0.06	0.10	0.05	0.44	0.12	0.20	0.33	-0.32						
Dried fish	0.24	0.02	0.05	0.24	0.002	0.14	0.32	0.16	-1.58					
Sea fish	0.13	0.03	0.10	0.60	0.15	0.08	0.02	0.18	0.01	-0.83				
D. Capture & culture fish														
Live fish	0.01	0.02	0.05	0.12	0.07	0.07	0.11	0.02	0.06	0.38	-1.22			
Climbing perch	0.03	0.13	0.003	0.19	0.05	0.08	0.04	0.02	0.06	0.02	0.48	-1.31		
B&T	0.29	0.18	0.11	0.05	0.08	0.40	0.09	0.20	0.004	0.84	0.07	0.39	-0.56	
Medium catfish	0.06	0.03	0.06	0.34	0.06	0.09	0.0004	0.04	0.14	0.15	0.23	0.01	0.03	-0.23

Source: Own calculation based on HIES data 2010

Overall, the magnitudes of the cross-elasticities are mostly inelastic and less than one. This implies that demand for fish has a low response due to price change of other fish types. Therefore, a decline in price of one fish species will result in a less proportionate decline in the quantity demand of other substitute fish. This result has some insights. First, all fish originated from aquaculture, marine and culture & captures sources have positive cross price elasticities within the species and across the sources. Therefore, fish are substitute within sources and across sources. This implies that if the price of fish from a particular source increases, demand for other fish from similar or substitute sources increases. Second, fish from capture sources has positive cross-price elasticities with the fish from aquaculture, marine and culture & captures sources. However, some fish species within capture sources have negative cross price elasticity, for instance, snakeheads, small catfish, and small indigenous species. This implies that if price of any fish from capture sources increase, consumer will substitute their consumption with fish from aquaculture, marine or capture& culture sources. Moreover, price increase of any fish from inland capture will also reduce the consumption demand of other fish from inland capture.

These findings are true for all households in Bangladesh, irrespective of their poverty status. These results indicate that fish from inland capture can be compensated with the increasing production of fish from marine, aquaculture and capture & culture sources.

Income elasticities of fish demand

The estimated income elasticities are found to be positive for all types of fish included in this analysis suggesting fish is a normal good (Table 2.9). The coefficients have the expected positive signs. However, the magnitudes are mostly less than unity at the national level, indicating demand turns to be less elastic as consumer's income goes up. Therefore, increase in consumers' income has less than proportionate increase in the consumption demand for fish.

There are also clear differences in the magnitude between poor and non-poor households. Except for marine fish, all fish exhibit decreasing elasticities as income increases. Consumption of marine fish is only 8 percent of total consumption of the poor (see Table 2.5). Therefore, the effect on total fish consumption turns to be lower. The overall results suggest that as income increases, the potential for fish consumption among the poor is higher compared to the non-poor households.

Table 2.9: Income elasticity of different fish species groups in Bangladesh

Fish species groups by sources	National	Poor households	Non-poor households
A. Aquaculture fish	0.89	1.17	0.86
Exotic carp	0.73	1.02	0.70
Indigenous carp	1.05	1.19	1.04
Large catfish	0.90	1.31	0.85
B. Inland capture fish	0.82	1.10	0.75
Small catfish & eels	1.06	1.48	0.83
Small indigenous species	0.59	0.83	0.59
Snakeheads	0.91	1.16	0.84
Shrimp	0.72	0.93	0.72
C. Marine fish	0.88	0.66	0.90
Hilsa	1.21	1.23	1.63
Dried fish	0.47	0.36	0.43
Sea fish	0.81	0.47	0.79
D. Capture & culture fish	0.80	0.64	0.52
Live fish	0.84	0.77	0.74
Climbing perch	0.87	0.56	0.48
Barbs & tilapia	0.67	0.62	0.44
Medium catfish & gourami	0.84	0.63	0.41

Note: The restricted coefficients are derived residually for this demand equation and hence, elasticity values for 'other fish' cannot be generated.
Source: Own calculation based on HIES 2010 data.

With respect to individual fish species, the results found in this study have three observations. First, poor households' fish demand is income elastic (>1) for the fish originated from aquaculture and captured source except for fish species such as small indigenous species (SIS) and shrimp. SIS and shrimp have elasticity equal to 0.83 and 0.93, which are closer to one and are nearly elastic. However, fish is income inelastic (<1) for non-poor households from aquaculture and captured sources except for indigenous carp. These results suggest that fish in general is considered as a luxury-food commodity for poor households. Luxury food commodities have income elasticity of demand greater than unity. Therefore, income increase will have a greater impact on the consumption demand of fish in poor households compared to non-poor households. Second, income elasticity of hilsa is found to be highly elastic for both poor and non-poor households, which explains this species is considered as a luxury-food fish for all types of household in Bangladesh. As income increases all households would try to consume this fish more. Hilsa is a popular marine capture fish, which moves from the ocean to inland water bodies for reproduction. It is traditionally consumed during New Year but is expensive due its pronounced seasonality and high demand in the countries of Europe, the Middle East, and North America with a rapidly growing market where Bengali immigrants or migrants live (Rashid, Minot & Lemma, 2016). It is also very popular within Bangladesh and lately registered as the geographical indication (GI) product of Bangladesh.[8]

Third, in contrast, barbs & tilapia turns to be income inelastic for both poor and non-poor households. This fish captures 19 to 20 percent of total fish consumption among the poor and non-poor households. This result suggests that barbs & tilapia are normal necessities for all types of household in Bangladesh. Therefore, consumption demand increases less than proportionately as income increases.

The overall results suggest that household income is important for total fish consumption of the poor. As income increases, the potential for fish consumption among the poor is higher compared to the non-poor households. Poor households will increase their demand for fish particularly from inland capture and aquaculture sources.

Comparing the results from price and income elasticities, this study concludes that except for marine fish, poor households have high price and income elasticity for most types of fish compared to non-poor households. Therefore, in the context of increasing household income, a strategy to increase fish production (e.g., aquaculture sector) results in reducing fish price will benefit the poor most. For the last decades, this scenario prevails in Bangladesh where real prices of aquaculture fish are falling down with rising income as a result of large-scale aquaculture, especially tilapia and pangasius (Toufique & Belton, 2014), increasing the total fish consumption among the poor (Toufique, 2015). Moreover, the price elastic demand and income inelastic demand of marine fish by the poor implies that supply shocks will affect the fish demand of the poor most. However, the impact will be negligible on demand due to low amount of household consumption.

[8] According to the World Intellectual Property Organisation (WIPO), GI is a sign used on products that have a specific geographical origin and possess qualities or a reputation that are due to that origin. With this recognition, on 6 August 2017 Directorate of Patent, Design and Trademark (DPDT) under the Ministry of Industries, Bangladesh has declared the recognition of hilsa the second GI product of Bangladesh. Therefore, the countries that import hilsa will register this fish as the product of Bangladesh.

2.5 Conclusions and Policy Recommendations

In this study, a disaggregated demand model for fish in Bangladesh has been developed to estimate price and income elasticities for 15 fish species groups. A two-step censored regression technique has been used to calculate a system of demand equations using the seemingly unrelated regressions (SUR) technique. A cross section data of 12,240 households is used from the latest round of Bangladesh Household Income and Expenditure Survey (HIES).

Overall results show that fish demand in Bangladesh differs between poor and non-poor households and varies substantially across fish types and species. The main findings of the study are as follows. First, poor households consume less fish than non-poor households, although the share of fish as a primary animal source food is higher for the poor. Second, poor households mainly consume low-priced fish produced in aquaculture. Third, the species of fish consumed in poor and non-poor households are largely similar, except for some species, e.g., hilsa. Forth**,** income elasticity for most fish species is higher for the poor than for non-poor households for both sources of fish, i.e. culture and capture. Fifth, fish demand of poor households is price-elastic for the majority of fish species. Hence, price shocks as often caused for example by natural disasters may lead to the deterioration of the nutritional conditions of the poor when other low-cost sources of animal proteins cannot be made available. Sixth, the high cross-price elasticity of fish demand among the poor implies that they respond more to changes in the price of substitutes. Finally, the declining supply of capture fish can be compensated by increasing the production of aquaculture fish as most of the fish species from capture source have positive cross price elasticities with the fish from aquaculture source.

These findings have several policy implications. First, since fish is the most important animal source food for the poor, the government needs to maintain a continued favorable policy environment for aquaculture growth, however, continuing the support for the sustainability of capture fisheries. Second, price elasticity of fish among the poor is high and the price of fish is a determinant of nutrition poverty. Hence, measures to expand and stabilize the supply from some fish species from aquaculture production, namely exotic carp and large catfish will be most beneficial for poor households. Third, fish from inland capture and aquaculture is important for the poor. Considering the fact that capture fisheries is in constant decline (Toufique & Belton, 2014), which means that poor consumers will lose some of the fish with high nutritional value. A good example is small indigenous species (SIS), which is more popular among the poor, can be cultured in principal but require investments and changes of the current aquaculture production systems. The changes could be incorporating the culture of SIS within the current aquaculture production systems. The technology of combing SIS with existing polyculture system in Bangladesh is called as ‘carp-SIS’ polyculture, which is emerging and need support from the Government to promote it to supplement the micronutrient supply among the poor (Bogard et al., 2015; Thilsted, 2012; Kohinoor, Sultana, & Hussain, 2007).

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Appendix

Test statistics of theoretical restrictions in AIDS model

Table A 1: Test statistics for homogeneity restrictions

Homogeneity in	Wald test statistics	*p*-Value
Hilsa share equation	12.90	0.00
Indigenous carp share equation	75.33	0.00
Large catfishes share equation	86.82	0.00
Live fish share equation	6.18	0.01
Climbing perch share equation	3.85	0.05
Exotic carp share equation	6.24	0.01
Snakeheads share equation	35.00	0.00
Barbs & tilapia share equation	15.71	0.00
Small indigenous fishes share equation	70.57	0.00
Shrimp share equation	10.16	0.00
Dried fish share equation	0.43	0.65
Small catfishes & eels share equation	14.85	0.00
Sea fish share equation	6.43	0.01
Medium catfishes & gourami share equation	0.03	0.87

Source: Own calculation based on HIES 2010 data.

Table A 2: Test statistics for symmetry restrictions

Symmetry for	Hilsa	Indigenous carp	Large catfishes	Live fish	Climbing perch	Exotic carp	Snakeheads	Barb & tilapia	SIS	Shrimp	Dried fish	Small catfishes	Sea fish
Indigenous carp	2.20												
	(0.14)												
Large catfishes	6.96**	25.83***											
	(0.01)	(0.00)											
Live fish	0.75	25.92***	29.85***										
	(0.39)	(0.00)	(0.00)										
Climbing perch	0.55	13.43***	8.54***	7.97***									
	(0.46)	(0.00)	(0.00)	(0.00)									
Exotic carp	0.01	0.00	9.08***	3.68*	0.07								
	(0.92)	(0.95)	(0.00)	(0.06)	(0.79)								
Snakeheads	1.08	2.81	4.83**	7.07***	0.32	0.89							
	(0.30)	(0.10)	(0.03)	(0.01)	(0.57)	(0.35)							
Barbs & Tilapia	0.65	24.23**	9.80***	10.76***	6.60**	0.50	2.76						
	(0.42)	(0.00)	(0.00)	(0.00)	(0.01)	(0.48)	(0.10)						
Small indigenous	4.33*	16.05***	36.32***	0.81	1.40	28.29***	22.04***	0.11					
fishes	(0.06)	(0.00)	(0.00)	(0.37)	(0.24)	(0.00)	(0.00)	(0.75)					
Shrimp	6.22**	0.75	0.40	12.71***	8.63***	0.82	1.02	0.14	155.77***				
	(0.01)	(0.39)	(0.53)	(0.00)	(0.00)	(0.36)	(0.31)	(0.71)	(0.00)				
Dried fish	25.91**	1.61	21.42***	0.52	4.32**	41.39***	16.44**	94.57***	0.95	14.22***			
	(0.00)	(0.20)	(0.00)	(0.47)	(0.04)	(0.00)	(0.00)	(0.00)	(0.33)	(0.00)			
Small catfishes and	0.01	44.15 ***	3.54*	0.01	0.21	2.40	0.07	0.57	20.02***	19.68***	24.11***		
eels	(0.92)	(0.00)	(0.06)	(0.94)	(0.65)	(0.12)	(0.80)	(0.45)	(0.00)	(0.00)	(0.00)		
Sea fish	0.06	11.77***	13.96***	3.37*	8.98***	0.174	0.22	0.01	12.49***	2.45	30.47***	1.78	
	(0.81)	(0.00)	(0.00)	(0.07)	(0.00)	(0.71)	(0.64)	(0.92)	(0.00)	(0.12)	(0.00)	(0.18)	
Medium catfishes	1.22	0.69	7.43***	2.56	0.51	13.21***	1.73	2.43	72.08***	5.76**	36.75***	0.44	8.00***
	(0.27)	(0.41)	(0.00)	(0.11)	(0.48)	(0.00)	(0.19)	(0.12)	(0.00)	(0.02)	(0.00)	(0.51)	(0.00)

Note: Corresponding *p* values are in parentheses. ***, ** and * indicate statistically significant at 1%, 5% and 10% level.
Source: Own calculation based on HIES 2010 data.

CHAPTER 3: THE ROLE OF HOMESTEAD FISH PONDS FOR HOUSEHOLD NUTRITION SECURITY IN BANGLADESH

This chapter has been revised and resubmitted to *Food Security*

Abstract

This study examines whether income from homestead aquaculture contributes to household nutritional outcomes in developing countries. Using data from 518 homestead aquaculture producers in Bangladesh, this study applies a two-stage least squares (2SLS) as well as a three-stage least squares (3SLS) model in a simultaneous equations framework to estimate the effects of aquaculture income on household food consumption and dietary diversity. Results show that homestead aquaculture increases household food consumption and improves dietary diversity by generating additional cash income and stimulating higher fish consumption from home production. Moreover, aquaculture income helps the poor farmers to improve the quality of households' diet by purchasing more calories from the market associated with protein rich and energy-dense food items. The results of this study have important policy implications for countries with low dietary diversity. As the Governments tend to undervalue home production of the poor, this study emphasizes that homestead fish production remains important for many low-income households. Therefore, the Department of Fisheries should reconsider its view on the role of homestead pond production and give it more recognition in its extension activities.

Keywords: Aquaculture, Nutrition security, Agriculture household model, Two stages least squares, Simultaneous equations model, Developing country

3.1 Introduction

More than two billion people in the world are undernourished and are deficient in iron and vitamin A (Tulchinsky, 2010), increasing the susceptibility to diseases, especially among women and children (Caulfield et al., 2004). Therefore, one of the main objectives of the Millennium Development Goals (MDGs) has been to reduce the number of people suffering from an inadequate nutritional intake in countries where undernourishment is persistent (UN, 2012). However, this goal has been achieved partially in the developing countries due to reduction in the proportion of undernourished people only by half since 1990 to 2014-2016 (UN, 2015).

To combat micronutrient deficiencies, sufficient consumption of protein-rich food is necessary. Foods from animal sources are high in proteins and micronutrients (Murphy & Allen, 2003). However, affordability and availability make it difficult for the poor to consume adequate amounts of animal protein (Pachón et al., 2007). In many developing countries, fish is an important supplement to other animal sources providing more than 50 percent of total animal protein intake (FAO, 2016). Fish is rich in micronutrients and essential fatty acids (Roos et al., 2007). Moreover, many of the world's poorest people depend largely on fish for the supply of most of their daily animal protein (Beveridge et al., 2013). In addition, fish is reasonably affordable and easily available in most of the developing countries (Kawarazuka & Béné, 2010). However, fish production from capture sources i.e., ocean fisheries and inland open water bodies has been declining. Two decades ago, capture fisheries provided 74 percent of fish for human consumption. However, in 2016 culture fisheries produced 53 percent of all fish consumed by humans (FAO, 2018). Although aquaculture and commercial fish production is growing in the world, production in the homestead fish ponds still provide many advantages.

With the advancement of commercial aquaculture, consumers are benefitting from better market access and availability of fish. However, in many countries, this is a slow process and especially the poor who often do not have the cash to purchase fish from the market. For them home production of fish, even only in small ponds, remains an important source of nutrition. Furthermore, in many developing countries small-scale aquaculture has been recognized as a pathway to improve nutritional status and to ensure food security at the household level (Kawarazuka & Béné, 2010). It generates positive effects by increasing production, income from the sale of fish and employment.

Bangladesh is one of the countries where nutrition security is poor with more than six million children chronically malnourished (WFP, 2016; FAO & WHO, 2014; Save the Children, 2015). Inadequate micronutrient intake is a primary cause of undernutrition among women and children under five years of age (Ahmed et al., 2012). Fish is a major source of animal protein for consumers in Bangladesh providing about half of animal source of calorie and more than half of animal source of protein (BBS, 2011). There is a growing demand for fish in the country, which increases the annual per capita fish consumption by 29 per cent during last 10 years (BBS, 2011). The per capita income of the people is also rising over time. Income growth during the past ten years has enabled more and more middle-income consumers to buy fish from the market. However, most of the households in rural areas still rely on home production of fish by maintaining homestead fish ponds both as a source of fish consumption and for market sales of surplus production (Dey, Alam & Bose, 2010). It is estimated that there are over four million households own ponds near the homestead (Belton & Azad, 2012). The number of homestead ponds are approximately 1.95 million[9] (Huda et al., 2010) in Bangladesh contributing over 43 percent of the total recorded production (DoF, 2016). However, fish production from homestead ponds does not receive much attention from Government. The Department of Fisheries (DoF) which is the agency responsible for advising fish farmers has often labeled homestead ponds as inefficient (Alam et al., 2004). However, little research has been conducted on the role of homestead aquaculture for household nutrition Research on the topic in Bangladesh (Jahan et al., 2010; Belton & Azad, 2012; Bloomer, 2012) and Malawi (Dey et al., 2007) have demonstrated the contribution of homestead pond aquaculture to household income and fish consumption. However, overall there have only been few studies on this topic (Béné et al., 2015). What is particularly missing are studies with a rigorous econometric analysis that show the impact of homestead ponds on consumption, dietary diversity and nutritional status of poor households. Therefore, this study presents a quantitative analysis based on household data collected in 2016, which allows the formulation of an econometric model for estimating the consumption and market effects of homestead fish production in Bangladesh.

The main objective of this study is to evaluate whether and how homestead fish ponds contribute to a better nutritional status in Bangladesh. The production-nutrition relationship is explored through the effect of income from aquaculture on household nutrition as measured by

[9] A satellite survey is used for this estimate. The remote sensing technology excludes very small ponds (which account for a large portion of those found in rural Bangladesh) from the sample.

the households' food consumption and its dietary diversity. Using data from 518 fish producers with homestead ponds in 2016, a two-stage least squares (2SLS) estimation technique is applied for analyzing the effects of aquaculture income on household nutritional outcomes. Additionally, a simultaneous system of equations in a three-stage least squares (3SLS) framework is developed for analyzing the effects of aquaculture income on the quality of households' diet. The first model shows that household food consumption and dietary diversity increase as income from aquaculture rises. Per capita food consumption and per capita calorie intake both increase in fishing households. However, dietary diversity outcomes only improve marginally. The second model enables us to see the structure of food consumption at the household level. This study finds that household purchase more calories from the market associated with high quality diets, particularly protein rich and energy dense.

The remainder of this chapter is organized as follows. Section 2 explains the link between homestead aquaculture, dietary diversity and household nutrition security. Section 3 provides the theoretical framework. Section 4 explains in detail the methodology for empirical models. Section 5 introduces the data and presents relevant descriptive statistics of the household survey. In section 6, the results of two empirical models are presented and discussed. Section 7 concludes and provides some policy recommendations.

3.2 Homestead Aquaculture, Dietary Diversity and Households' Nutrition Security

This section provides a more detailed description on the role of homestead aquaculture production for household nutrition security based on the literature. At first, the pathways of how aquaculture can help to improve household nutrition security are elaborated, and then a description is provided on the nature of homestead aquaculture practiced in Bangladesh.

Homestead pond-based, small-scale aquaculture has been recognized as an important opportunity to improve households' calorie intake, dietary diversity and quality of diets in developing countries (Kent, 1997; Thorpe et al., 2005). Many studies show that household consumption of fish and total energy intake increases by investing in pond-based aquaculture (e.g., Prein & Ahmed, 2000; Kumar & Dey, 2006; Islam, 2007; Dey et al., 2007). Higher fish consumption has been reported in Malawi by households with fish ponds (Dey et al., 2007), while higher energy intake and lower levels of undernourishment have been found in Indian households with fish ponds (Kumar & Dey, 2006).

There are different pathways through which production from homestead aquaculture can contribute to households' nutritional security (Figure 3.1). The first and direct pathway is the nutritional contribution of fresh fish consumption. Households with homestead ponds have a cheap, regular and easily accessible source of animal protein and essential micronutrients (Roos et al., 2007, 2003, 2002). The second pathway is indirect and relates to increased purchasing power from selling fish. Income from selling fish enables households to purchase more food from the market, which improves the quality of their diet (Qaim, 2014; FAO, 1998). However, other important factors such as gender (Fischer & Qaim, 2012), health of children and household members (Iannotti et al., 2009), socio-economic factors (Keding et al., 2012), and farm and demographic factors (Jones et al., 2014; Pellegrini & Tasciotti, 2014) determine whether additional income contributes to increased dietary diversity and ensure nutrient security.

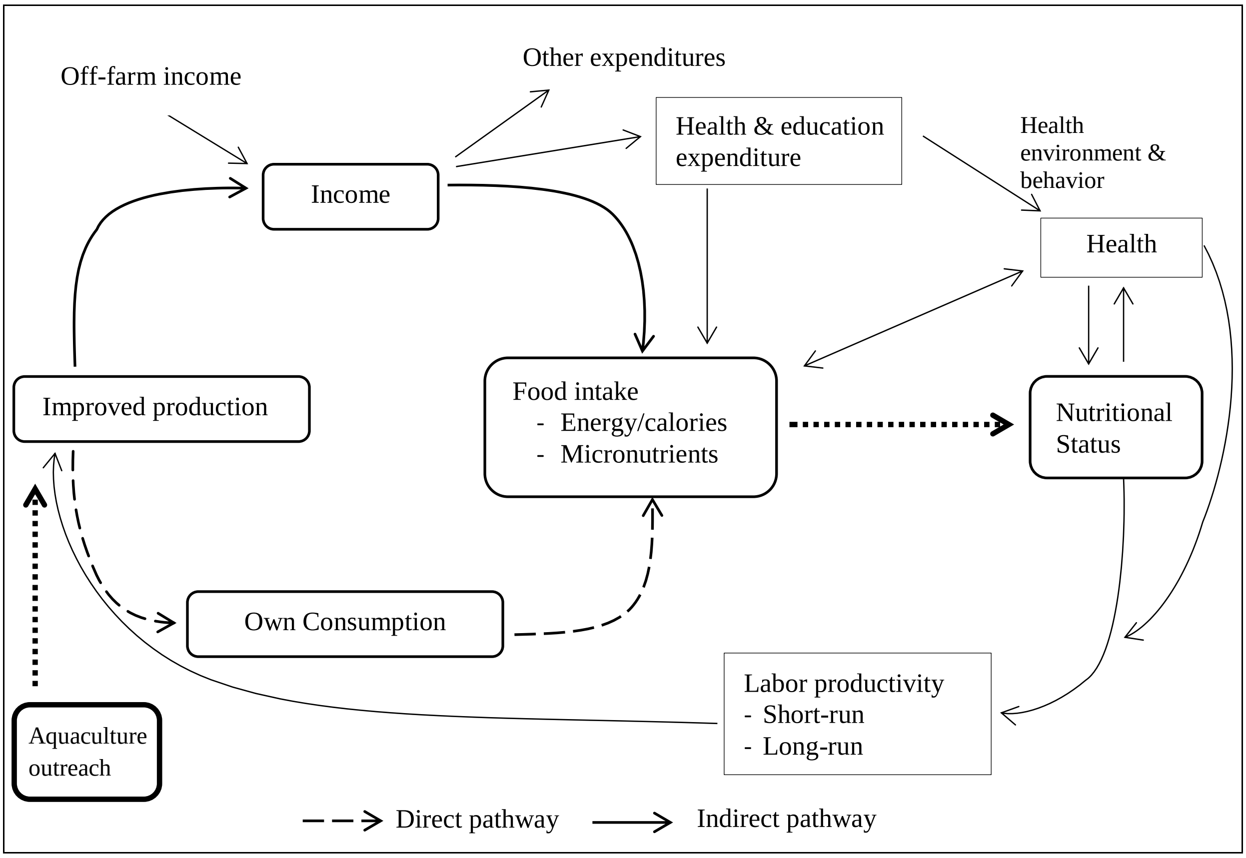

Figure 3.1: The pathway of aquaculture, dietary diversity and nutritional security
Source: Author's illustration based on Chung (2012, p. 4)

In Bangladesh, pond culture represents the mainstay of aquaculture, accounting for more than 80 percent of the total recorded production and over 55 percent of the area under culture in 2014-15 (Shamsuzzaman et al., 2017). Pond aquaculture includes commercial aquaculture and homestead ponds. The latter captures more than half of the total recorded aquaculture production (DoF, 2016). In rural Bangladesh, when an owner constructs a house, the basement of the house is made higher than the surrounding area to protect the house from flooding during the rainy season. Therefore, a large number of households have homestead area that includes a small or medium sized pond and ditches, which allow growing fish (Belton et al., 2011; WF 2015). Homestead ponds usually have multiple uses besides fish farming, including bathing, washing clothes, and growing crops like vegetables on the dikes. Hence, homestead fish production is a low external input system. Production mainly depends on the natural productivity of the water body for growing fish. Most of the inputs are farm by-products, e.g., rice bran, rice products and mustard oil cake as supplementary feed. The production system is polyculture with different large fish species (e.g. carps), together with a range of small indigenous species (SIS), which are especially rich in micronutrients (Castine et al., 2017). Most of the fish from homestead production is for home consumption and any surplus is supplied to the local markets. Fish (e.g., small fish species) for home consumption is considered as an important food item for low-income households during times when other sources of micronutrients are expensive (Islam, 2007).

To sum up, the available literature so far suggests that homestead aquaculture in developing countries can be important for two reasons. First, it makes fish available to households on a regular basis and in easily accessible manner. Second, it offers the opportunity of selling surplus fish to the market and hereby can generate additional household income. However, it remains unclear from the literature to what extent homestead aquaculture can contribute to nutrition security. The next section introduces a theoretical model to derive hypotheses of this study and then explains the methodology to test.

3.3 Theoretical Framework: A Household Model for Homestead Production

This study developed an agricultural household model to assess the effect of aquaculture production on household consumption and nutritional outcomes. The empirical specification of the econometric model follows the specification of the household model.

The joint production and consumption nature of homestead producers suggest the use of a household model for understanding the effect of aquaculture production on household nutritional outcomes (Singh et al., 1986). Households involved in homestead production consume a part of their harvested fish and sell the rest in the market. They also have alternative livelihood activity where they invest their time. This is the general picture of households in developing countries where a large fraction of the labor force is self-employed, and the majority of who run a small business alongside wage labor jobs (Gollin, 2008). Therefore, to build a model, it is necessary to allow the households to utilize both labor and other factors as potential producers, and allow them to choose to sell or hire these factors in factor markets. Therefore, this study adopts a non-separable agricultural household model (AHM) to understand the behavior of a household where production and consumption decisions are jointly determined (Benjamin, 1992; Bardhan & Udry, 1999; LaFave et al., 2016; Strauss, 1984).

In the AHM, the household acts both as a consumption unit to maximize utility over consumption and ‘leisure’ and as a production unit to decide how to allocate factors of production to its farm or business. The model presented here captures the situation of a farming household engaged in crop production, off-farm activity and homestead aquaculture production. Households maximize the utility given the cash income constraint (CI), time constraint (T) and production constraint (Q) (Singh et al., 1986). The household problem is to choose produced agricultural commodities (X_a), market purchased goods (X_m) and leisure (X_l) to maximize utility based on the observed (Z_o) and unobserved (Z_u) household characteristics:

$$Max\ U = U(X_a, X_m, X_l; Z_o, Z_u) \quad (1)$$

Subject to:

The cash income constraint: $CI = P_m P_a = P_a(Q_a - X_a) - w(L - F) - P_v V + E,$ (2)

Time constraint: $T = X_l + F\ (F^F, F^o),$ (3)

Production constraint: $Q_a = Q(L, V, A, K).$ (4)

Where, P_a and P_m are the prices of agricultural commodities and market-purchased goods, respectively. Q_a is the household's production of agricultural commodity, and (Q_a-X_a) is the surplus supplied to the market. w is the market wage, L is total labor input, and F is family labor input ($L – F>0$ is hired labor, and $L – F<0$ is off-farm labor supply). V is variable inputs such as seed and fertilizer, and P_v is the price of variable inputs. E is other income (non-labor, non-farm income etc.). T is the total stock of household time. A, and K are the household's fixed quantity of land and capital, respectively.

Equation (2) is the standard cash income constraint. Equation (3) is the time endowment of the household that is distributed between leisure (X_l), farm (F^F) and off-farm labor (F^o). Equation (4) is the production constraint that explains the relationship between input and output.

The three constraints on household behavior can be set into a single constraint by substituting one into the other as follows:

$$P_m X_m + P_a X_a + w X_l = wT + \pi + E \quad (5)$$

Where, $\pi = P_a Q_a(L, V, A, K) - wL - P_v V - P_A A$, which is farm's profit function.

The left-hand side of equation (5) is the household's total expenditure on three items, i.e., market-purchased goods, the household's purchase of its output, and time in the form of leisure. The right-hand side is the household's profit (π) and the value of the stock of time (wT), which is defined as the value of a household's full income when profits have been maximized with the appropriate choice of labor input.

In a separable household model, the solution of equation (1), for maximizing the utility subject to the constraints in equation (5) yields the standard demand curves:

$$X_i = X_i(P_m, P_a, w, \pi(P_a, P_v, P_v V, P_A A); Z_o, Z_u) \qquad \text{i=m, a, l} \qquad (6)$$

Equation (6) shows that demand depends on the prices and income, as well as on the profit that is determined by the household's production activities. Factors that affect production will also affect the household's profit (π) and thereby consumption behavior. Thus, the consumption behavior of a household is not independent of its production behavior.

In most developing countries, due to market imperfections (e.g., risk in production, absence of labor market) the separation property does not apply (Bardhan & Udry, 1999). Therefore, in the non-separable formulation, when markets are incomplete, production factors (i.e., input prices) influence the household's consumption decision. Consequently, the assumption that consumption is only influenced by income ceases to apply. Therefore, the consumption demand equation includes not only variables that affect household income but also variables that affect a household's production decisions. Therefore, the non-separable household demand equation turns to be:

$$X_i = X_i(P_m, P_a, w, \pi(P_a, P_v, P_v V, P_a A), P_a, P_v, P_v V, P_a A; Z_o, Z_u) \qquad i=m, a, l \qquad (7)$$

The identification strategy, therefore, for equation (7) follows a two-step procedure (Dillon et al., 2015; LaFave et al., 2016). The next section explains the procedure to model the theoretical framework.

3.4 Methodology

Combining the conceptual framework and the corresponding literature review, the theoretical model allows establishing three hypotheses. First, the higher the share of income from aquaculture, the higher is a household's food consumption. Second, higher aquaculture income shares cause higher dietary diversity. Third, additional income from aquaculture improves the quality of a households' diet.

Based on these hypotheses, the empirical strategy follows two estimation techniques to address the objectives of this study. First, a two-stage least squares (2SLS) estimation technique to measure the effects of income from homestead aquaculture on households' consumption and nutritional outcomes. This technique solves the problem relating to the presence of unobserved heterogeneity in the model, which might influence the dependent and the explanatory variables in this study. Second, the technique establishes a simultaneous equations system to capture the effects of aquaculture income on caloric shares from different food groups to determine the improvement in the quality of the diet of fishing households.

Model 1: Effect of aquaculture income on household nutritional outcomes

The effect of aquaculture income from homestead production on household's food consumption and dietary diversity outcomes is measured by a two-stage least squares (2SLS) model, controlling the household's wealth, demographic and district-level characteristics (Dillon et al., 2015). In the first stage, homestead production is determined by input prices, instruments (i.e., the value of fishing capital, number of fisheries officers per household) and household demographic characteristics such as household size and composition, which affect a household's consumption decision. The second stage identifies the relationship between production and dietary diversity at the household level. The specification of the model is:

$$ln\, E_h = \beta_0 + \beta_1 P_v + \beta_2\, P_m + \beta_3\, P_A + \beta_4 F_h + \beta_5 X_h + + e_h \qquad (8)$$

$$\ln Y_{j,h} = \alpha_0 + \alpha_1 P_v + \alpha_2 P_m + \alpha_3 X_h + \alpha_4 \ln E_h + \varepsilon_h \qquad j = 1,2,3,4 \qquad (9)$$

Where, E is the share of aquaculture income representing the household's involvement in aquaculture. P_v is different input prices, and P_m is market price of different foods. X is the vector of household characteristics including the household size. P_A is the value of fishing capital. F_h is number of fisheries officers per household, and Y is the household's food consumption or nutritional outcomes. *J* represents four outcome indicators; food expenditures, calorie consumption per capita, food consumption score and Simpson dietary diversity index. h represents household, and ε & e are the error terms.

As income from aquaculture *(E)* is endogenous, it is instrumented with the value of the fishing capital and the district level number of fishery officers per household[10]. The instruments are correlated with aquaculture production, however expected to be uncorrelated with household nutrition outcomes.[11] The test statistics showed that the chosen instruments are strongly correlated with the endogenous variable with a significant F-statistic for all four specifications of equation (9). The specifications also passed the standard tests for endogeneity (see Table 3 for more details). Therefore, the chosen instruments for this study did not affect the consumption or the nutritional outcomes directly, but indirectly through aquaculture production.

Model 2: Effect of aquaculture income on the quality of household diet

The three-stage least squares model was used to identify the effect of aquaculture income on the structure of individual food groups (Benfica & Kilic, 2016). This model combined the two-stage least squares (2SLS) model with a seemingly unrelated regression (SUR) (Zellner & Theil, 1962). A system of equations with endogenous variables (part of 2SLS) and correlated error terms (part of SUR) was the reason for adopting the 3SLS. Efficient estimation requires accounting for cross-equation error correlations in the estimation process. For this analysis, the calorie intake from different foods is decomposed into 11 groups to identify the effect of aquaculture income not only on dietary diversity but also on the quality of diet improvement. The model is expressed with the complete system as:

$$\ln SCal_{h,i} = \alpha_{0i} + \alpha_{1i}P_v + \alpha_{2i}P_m + \alpha_{3i}X_h + \alpha_{4i}\ln E_h + \varepsilon_{h,i} \qquad (10)$$

For each food group i, the calorie shares are defined as:

$$SCal_i(SCal_1, SCal_2, ..SCal_{11}) = \begin{cases} \alpha_1 + \alpha_{1,1}P_k + \alpha_{2,1}X_h + \alpha_{3,1}E_h + \eta_{h,1} \\ \alpha_2 + \alpha_{1,2}P_k + \alpha_{2,2}X_h + \alpha_{3,2}E_h + \eta_{h,2} \\ \vdots \qquad\qquad\qquad\qquad \vdots \\ \vdots \qquad\qquad\qquad\qquad \vdots \\ \vdots \qquad\qquad\qquad\qquad \vdots \\ \alpha_{11} + \alpha_{1,11}P_k + \alpha_{2,11}X_h + \alpha_{3,11}E_h + \eta_{h,11} \end{cases} \qquad (11)$$

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[10] District level data was collected directly from the records of the District Fisheries Office (DFO) in Bangladesh. DFO is governed by the Ministry of Fisheries and Livestock, Government of the People's Republic of Bangladesh.

[11] Previous studies also used agricultural capital (Dillon et al., 2015) and number of district agriculture officers (Benfica & Kilic, 2016) as instrument to control endogeneity of agriculture income. Considering the context of this study, aquaculture capital and number of district fisheries officers are used to control for the endogeneity of aquaculture income.

$$ln\ E_h = \beta_0 + \beta_1 P_v + \beta_2\ P_m + \beta_3\ P_A + \beta_4 F_h + \beta_5 X_h + +e_h \quad (12)$$

where, $SCal$ are the calories shares from different food groups, and i is the food groups. P_v is different input prices, and P_m is the market price of different foods. X is a vector of demographic variables, and E is the share of aquaculture income representing the household's involvement in aquaculture. P_A is the value of fishing capital, and F_h is the number of fisheries officers per household. h represents the household, and $\varepsilon, e\ and\ \eta$ are the error terms.

Definition of variables: Income, consumption and dietary diversity indicators

This study used five outcome variables to determine household nutritional status. The outcome variables were food expenditures per capita, caloric intake per capita, food consumption score, Simpson dietary diversity index and shares of caloric intake attributed to different food groups. The first four outcome variables were used for 2SLS estimation, and calorie shares were used for the process of 3SLS estimation. The variables are specified as:

Aquaculture income ($\mathbf{E_h}$): The household's income from homestead aquaculture is defined as the share of aquaculture income to total household income (Benfica & Kilic, 2016). For calculating aquaculture income, we have used farmer estimates of the total harvest value for each fish (Dillon et al., 2015), which includes the value of home consumption and market sales.[12] Thus, the variable captures the relative weight of returns from aquaculture. The variable is calculated as:

$$E_h = \frac{IncAq_h}{TotInc_h} \quad (13)$$

where, $IncAq$ is the household's income from homestead aquaculture production; $TotInc$ is the total household income, and h represents the household.

Food consumption indicators ($\mathbf{Y_1}$ and $\mathbf{Y_2}$): The household's food consumption was calculated both in terms of the value of the food consumed and the corresponding intake of calories from those food items.

[12] It has been found that on average household sold almost 39 percent of their harvested fish while consuming 54 percent and using 7 percent for other purposes. However, considering the harvest value of each fish will allow us to capture the value of different fish species produced in the homestead pond and therefore, reduces the risk of over estimating the value of total fish production.

- Per capita food consumption (Y_1) is the total value of food consumed in a household divided by its household size. It is measured in annual terms and in monetary value, which is expressed as follows:

$$Y_{1,pc,h} = \frac{1}{HS_h} \sum_{i=1}^{n} EXP_{h,i} \quad (14)$$

  Where, EXP is the value of the household's annual food consumption; HS is the household size; i represents the commodity, and h represents the household.

- The calorie intake per capita per day (Y_2) is calculated by converting the quantities of the food items consumed to calories using standard conversion factors suggested by FAO.[13] The sum of the calories across all food items is divided by the household size and 365 days to determine the daily per capita calorie consumption. This indicator was included in the model to assess the food insecurity in the fishing community to design appropriate policy interventions (Smith & Subandoro, 2007). It was measured in annual terms and is expressed as follows:

$$Y_{2,pcd,h} = \frac{1}{365 \times HS_h} \sum_{i=1}^{n} KCal_{h,i} \quad (15)$$

  Where, $KCal$ is the calories consumed from different food items; HS is the household size; i represents the commodity, and h represents the household.

Dietary diversity indicators (Y_3 and Y_4): The dietary diversity score (DDS) was calculated from the number of different foods or food groups consumed by a household within a specific reference period (Hoddinott & Yohannes, 2002; Swindale & Bilinsky, 2006; FAO, 2010). The households' economic ability to consume a set of nutritionally diverse food items is measured by DDS. However, DDS is only a qualitative figure and thus, to capture nutrition intake accurately, the World Food Programme (WFP) suggests using the food consumption score (FCS). The FCS captures both the household's dietary diversity and the consumption frequency of different foods (WFP, 2008). It assigns a weight to each food item to determine the richness of the consumed food groups, which is important for determining the quality of the household DDS. In this study, two indicators of dietary diversity are used to captures the richness of consumed food items in the fishing households.

- The food consumption score (Y_3) is a composite score based on the household's dietary diversity, the frequency of food consumption, and the relative nutritional importance of the

[13] The FAO/INFOODS food composition table (FCT) (Shaheen et al., 2013) and FAO/INFOODS density database- 2012 (Charrondiere et al., 2012) has been used to convert food intake data into energy (kilocalories).

different food groups. To calculate FCS, food items consumed by a household were categorized into nine different groups (appendix Table A1). The consumption frequency of each food group was then multiplied by the assigned nutrient-based weights proposed by the WFP (2008)[14]. All the values of each food group were then summed to generate the FCS, which is expressed as:

$$Y_{3,h} = \sum_{i=1}^{9} f_{h,i} \times W_i \qquad (16)$$

where, $f_{h,i}$ is households' frequency of consumption of food group i, W_i is the weight attributed to each food group, i represents the food group and h represents the household.

- The Simpson-Index of dietary diversity[15] (Y_4) is a measure of dietary diversity that considers not only whether a particular food item is consumed but also the relative importance of the food consumed, as expressed by calories consumption shares (Parappurathu et al., 2015; Drescher et al., 2007; Katanoda et al., 2006; Stewart & Harris, 2005). The index is estimated using the following formula:

$$Y_{4,h} = 1 - \sum_{i=1}^{n} SCal_{h,i}^2 \qquad (17)$$

Where, $SCal_{h,i}$ is the share of the i^{th} food item's calories in total calorie consumption of household h, n is the total number of food groups, i represents the food group, and h represents the household.

The calorie shares in the index assign more weight to a food item having larger shares. The index ranges from 0 to 1, where 0 indicates no diversity (when share=1) and 1 indicates more diversity (when share=0). When more food items are consumed, the index value increases to indicate more dietary diversity.

Calorie shares ($\mathbf{SCal_{h,i}}$): The calorie shares for different food groups are estimated as follows:

$$SCal_{h,i} = \frac{Cal_{h,i}}{\sum_{i=1}^{n} Cal_{h,i}} \qquad (18)$$

where, $Cal_{h,i}$ is the calorie share of food group i, n is the total number of food groups, i represents the food group, and h represents the household.

[14] The FCS score determines households' food consumptions status based on three thresholds, i.e. poor with a score of 0 to 21, borderline with 21.5 to 35 and acceptable food consumption with a score above 35. A score less than 35 is classified as inadequate consumption by WFP. However, the alternate cut-offs of 28 and 42 are more appropriate for poor and borderline category for populations with high frequency of consumption of sugar and oil. The maximum value of FCS can be 112, if the households consumed all food groups in each day.

[15] The Simpson-Index used in this study is popularly known as the Berry-Index. This index was applied mainly in economic food diversity studies (Stewart & Harris, 2005; Katanoda et al., 2006). Recently, it has been applied in nutritional studies to measure dietary diversity and its annual changes in different countries (Drescher et al., 2007).

3.5 Data and Descriptive statistics

3.5.1 Data

For this study, a household survey was conducted from May 2016 to June 2016 in Bangladesh. The survey was conducted jointly by University of Hannover, Germany and WorldFish, Penang, Malaysia through a household survey titled as ‘Fish Production, Consumption and Nutrition Linkages in Bangladesh’. During the survey, information from 518 households was collected who engaged in homestead pond culture.

The sample for the survey was selected from the survey of the ‘Economics of the Homestead Pond Aquaculture System’ under the United States Agency for International Development (USAID)-funded Cereal Systems Initiative for South Asia in Bangladesh (CSISA-BD) project implemented by WorldFish, Bangladesh in 2011 (WF, 2015). A purposive random sampling technique was used in this survey following a multi-stage process to select the households practicing aquaculture (Jahan et al., 2015). The first stage included identifying the most important aquaculture systems present in each hub. The location with the highest concentration of farmers was selected in the second stage. Once the farming systems and the location were identified, the study villages were selected at random from a list of all villages. During the third stage, a village profile was developed, and a census was conducted to identify the location of each individual aquaculture producer. Finally, the sampled households were selected randomly from the list of census households.

In 2011, the WorldFish survey collected information of five major aquaculture production systems containing 14 aquaculture technologies in Bangladesh from 2678 households. Among the production systems, homestead pond aquaculture was the only non-commercial aquaculture production system and the only system where a major proportion of the aquaculture production was used for household’s consumption. Under this system, households apply two technologies, i.e., fish polyculture without, and fish polyculture with small indigenous species covering five geographical hubs[16]. Thus, to fulfill the objective of this study, households practicing homestead pond-based aquaculture production system were selected from the CSISA-BD

[16] Geographical hubs are the aquaculture clusters in Bangladesh that consist of groups of districts with similar agroecology. The main technologies practised in each hub were identified through a process of rapid appraisal with local key informants.

project and resurveyed independently in 2016 through a household survey to collect necessary information.[17]

A household survey questionnaire was used to generate information on household characteristics, income sources, asset endowments, aquaculture production, health and nutritional knowledge and practices, well-being and risk attitudes and consumption expenditures. A village questionnaire was also administered to collect information regarding village demographic, socio-economic condition, infrastructure, local food prices and aquaculture production practices in the village.

3.5.2 Descriptive Statistics

Table 3.1 describes the variables used in the econometric analysis. The total landholding refers to the area of land under possession by a household. It includes all types of operating land for the purpose of farming, fishery and habitation. The value of fishing capital refers to the total value of fishing assets that are used to harvest fish and the current value of the fish stock that provides harvestable fish. Chronically sick household members are those members who are suffering from diseases that are persistent and exist longer than one year. The ratio of chronically sick household members to total household members was taken to generate the share of chronically sick adults in a household. The variable of whether households have income from agricultural sources refers to the income generated from crop production, livestock rearing, nursery and gardening, etc. However, it did not include the income from aquaculture production. Total calorie intake was derived from total consumption of different food on a per capita per day basis.

Additionally, distance to the village market, and off-farm income were used as proxies for market access. Households located near the market realized higher income from the increased trade opportunities that were utilized for increasing dietary diversity from purchased foods from the market. Non-farm employment opportunities generated additional cash income, which allowed greater access to food from the market (FAO, 1998). The off-farm income was defined as the income generated from non-farm self-employment activities, wage-paying activities and other services.

[17] A two-year panel data was prepared based on the data collected from households who engaged in homestead pond aquaculture in Bangladesh. The first round of data was collected in year 2011 for CSISA-BD project while the second round was collected in year 2016 only for this study using the same sampling procedures. However, for this study the data from 2011 cannot be used for not collecting information regarding household consumption expenditure.

Table 3.1: Descriptive statistics of the variables used in the estimation process

Variables	Definition and description	Mean	Std. deviation
Nutritional outcomes:			
Food expenditure	Per capita food expenditure in taka per year	16812.720	5732.295
Intake of calories	Calorie intake per capita per day	2017.629	471.233
Food consumption score	Food consumption score	54.970	17.815
Simpson index	Simpson dietary diversity index	0.485	0.107
Calorie shares:	Share of calorie consumption from different food groups (%)		
Grains		0.730	0.078
Pulses		0.022	0.022
Vegetables		0.038	0.020
Fruits		0.014	0.013
Milk		0.022	0.021
Sweets		0.023	0.016
Oils		0.102	0.041
Eggs		0.006	0.005
Meat		0.014	0.012
Fish		0.029	0.015
Beverages		0.001	0.002
Production and input cost:			
Aquaculture income share (%)	Aquaculture income as a share of total household income	0.129	0.429
Labor wage	Cost of hiring the labor for aquaculture activity in taka per hour	25.59	3.91
Price of fry	Price of fry in taka per kilogram	1870.41	254.069
Price of fingerling	Price in taka per kilogram	188.152	123.105
Cost of homemade feed	Cost of making feed at home. Price in taka per kilogram	19.746	7.014
Price of purchased feed	Price of feed ingredients from market in taka per kilogram	35.138	17.589
Value of fishing capital	Value of fishing asset and current value of fish stock in taka	8027.363	14732.41
Fisheries officers	Number of fisheries officers per household at district level	0.042	0.009
Diversification, credit and market access:			
Farm income	If the household has income from sale of crop, livestock and farm related goods (yes = 1 and no = 0)	0.886	0.319
Off-farm income	If the household has income from non-farm self-employment activities, wage paying activities and other services (yes = 1 and no = 0)	0.835	0.371
Distance to village market	Distance to nearest village market in kilometer	1.889	0.759

Borrowed loan	If the household borrowed loan for fish production in the pond. (yes = 1 and no = 0)	0.008	0.09
Household characteristics:			
Age of head	Age of the household head in years	49.892	13.106
Age square	Square of household head's age	2660.602	1330.339
Gender of head	Gender of household head (female-0 and male=1)	0.955	0.205
Education of head	Completed years of schooling of the household head	5.301	4.284
Number of children	Total number of children aged from 0 to 14 years	1.236	1.069
Number of adults	Total number of member aged from 15 to 64 years	3.504	1.558
Number of old adults	Total number of member aged from 65 and above	0.319	0.542
Wealth and productivity indicators:			
Landholding	Area of land under possession by a household in decimal	142.169	134.755
Share of sick adults	Ratio of chronically sick household members (longer than 1 year) to total household members	0.066	0.130
Regional information:			
Local food prices	Market price of different foods in taka per kilogram or liter or piece (at district level)		
Price of grains	Taka per kilogram	28.393	5.020
Price of pulses	Taka per kilogram	97.509	30.249
Price of vegetables	Taka per kilogram	18.023	4.746
Price of fruits	Taka per kilogram	71.418	44.660
Price of milk	Taka per liter	71.167	40.516
Price of sweets	Taka per kilogram	53.503	4.843
Price of oils	Taka per liter	94.893	15.644
Price of egg	Taka per piece	8.712	4.561
Price of meat	Taka per kilogram	268.036	112.327
Price of fish	Taka per kilogram	176.324	97.1308
Price of beverages	Taka per liter	59.975	8.186
Sample size	Number of households	518	-

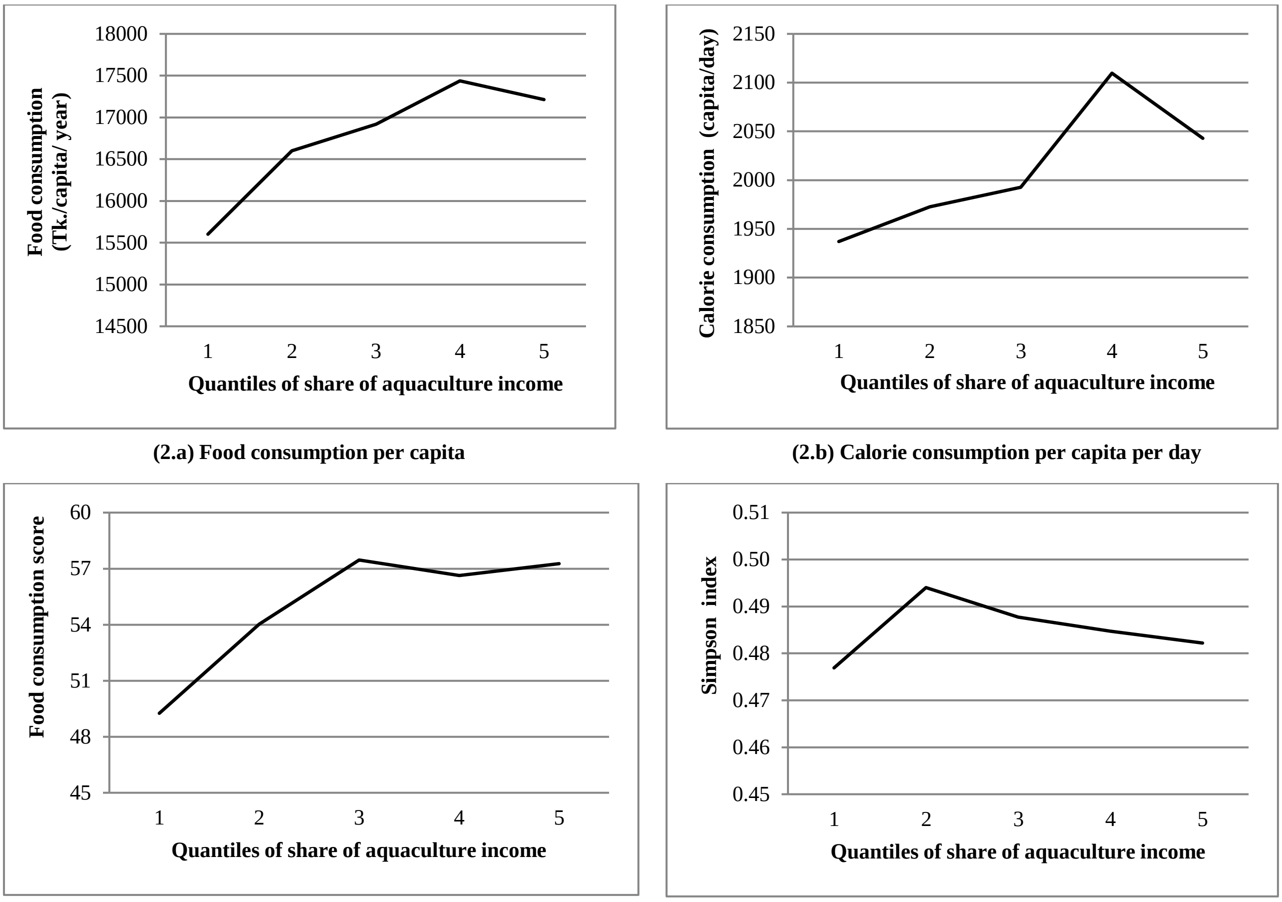
Note: A decimal is a unit of area approximately equal to 1/100 acre (40.46 m²).
Source: Own calculation based on household survey 2016

The summary statistics show that the average calorie intake was 2017.63 kilocalorie (kcal) per capita per day in the sampled households, which is below the international threshold of 2122 kilocalories (kcal/capita/day)[18]. More than half of the households in the sample are below the caloric threshold and therefore, can be considered as food insecure. On average, food grains provided 73 percent of calories, whereas fish constituted approximately three percent of total caloric intake with meat and egg contributing negligible amounts.

The indicator of dietary diversity indicated that the average food consumption score was 54.97 for the fishing households. Although the level was in the acceptable diet cluster (see footnote 14), approximately 30 percent (i.e., 4.22 percent in poor and 24.50 percent in borderline) of the households remained in inadequate consumption clusters. It was observed that the Simpson dietary diversity index value was 0.485, which indicates a low level of dietary diversity at the household level. Therefore, it is possible to increase the dietary diversity by consuming or adding more diversified food items to the households' food baskets.

The bivariate relationship (without controlling for wealth, demographic and socio-economic factors) between aquaculture income and household nutritional outcomes are presented in Figure 3.2. It was observed that the higher the levels of aquaculture income, the higher the levels of food consumption, per capita calorie intake and food consumption score. However, after reaching quantile four, aquaculture income contributed less to household nutritional status as households may expend more on non-food items.

[18] The international threshold of 2122 kilocalories (kcal/capita/day) is recommended by the UN Food and Agricultural Organization (FAO) for the South Asian region.



(2.a) Food consumption per capita **(2.b) Calorie consumption per capita per day**

(2.c) Food consumption score **(2.d) Simpson index**

Figure 3.2: Comparison of aquaculture income with nutritional outcomes
Source: Own calculation based on household survey 2016

This study found that the shares of calories from food such as pulses, sweets, milk, oils, meat, fish and beverages increased at higher aquaculture income quantiles. Except fish, other food items were frequently purchased from the market. This finding reflects that households with higher shares of aquaculture income acquired more calories from the market sources. The calorie shares of fish increased with the increased share of aquaculture income (Table 3.2).

Table 3.2: Relationship between aquaculture income and shares of calorie consumption

Shares of calorie consumption (Percent)	Share of aquaculture income (Quantiles)				
Food groups	First	Second	Third	Forth	Fifth
Grains	73.684	72.173	72.059	71.23	69.199
Pulses	1.718	2.524	2.576	2.651	2.995
Vegetables	3.798	3.719	3.839	3.717	3.707
Fruits	1.371	1.215	1.265	1.101	1.105
Milk & milk product	2.071	2.099	2.139	2.265	2.295
Sweets & sweet product	2.13	2.299	2.305	2.299	2.415
Oils	10.828	10.986	10.391	11.21	11.734
Eggs	0.682	0.647	0.661	0.682	0.635
Meat	1.193	1.646	1.671	2.256	2.325
Fish	2.447	2.582	2.964	3.299	3.382
Beverages	0.078	0.108	0.151	0.19	0.247
Total	100	100	100	100	100

Source: Own calculation based on household survey 2016

Table 3.3 examines the descriptive link between size of aquaculture production with household income, farm characteristics and basic household characteristics. Average farm size is calculated by own land plus rented in/leased in minus rented/leased out (Palash, 2015).

Table 3.3: Aquaculture production and farm characteristics

Items	Size of aquaculture production (Quantiles of harvest value)				
	First	Second	Third	Forth	Fifth
Household size (number)	4.840	5.194	5.426	4.892	4.978
Farm size (decimal)	132.644	152.205	152.527	153.794	208.914
Pond Are (decimal)	19.170	23.799	17.373	19.795	40.544
Household income (Capita/month)	1823.681	27763.303	3369.86	3283.086	4116.819
Total Harvest value (Tk./year)	3870.460	13154.808	17112.965	27824.205	68927.167
Fish Yield (kg/year)	51.707	105.795	137.674	219.068	554.522
Sold (kg/year)	9.414	25.795	28.814	101.136	409.022
Consumption (kg/year)	42.293	80.000	108.861	117.932	147.135
Percentage sold (%)	18.206	24.382	20.929	46.166	73.761
Cost of production (Tk./kg)	60.370	49.777	36.795	34.919	24.286
Income from homestead production (Tk./year)	3870.459	13154.807	17112.965	27824.204	68927.167
Net income from homestead production (Tk./year)	1044.862	7154.124	12287.35	20266.64	48707.420

***Source*:** Own calculation based on household survey 2016

The average farm size of the homestead fish farmers was 161 decimal (0.651 hectare)[19] and it increases with the size of aquaculture production. Figure 3.3 also reveals that 62 percent of the homestead famers were small-scale farmers and marginal farmers.

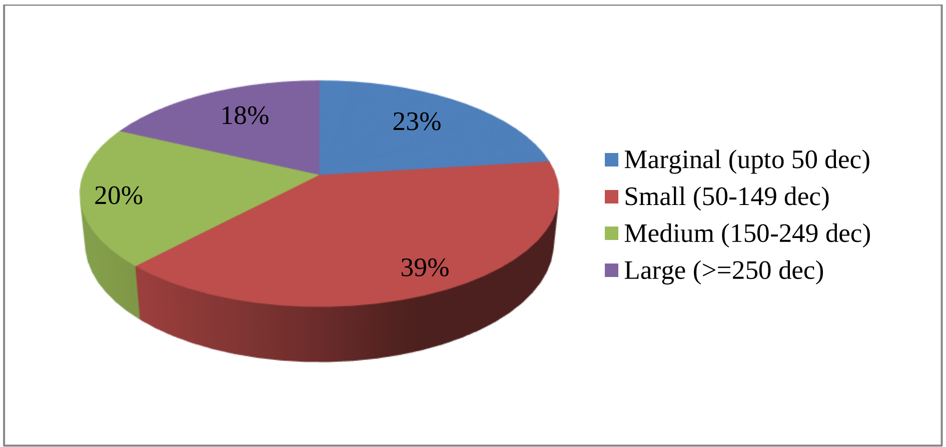


Figure 3.3: Distribution of average farm size of the homestead fish farmers
Note: A decimal is a unit of area approximately equal to 1/100 acre (40.46 m²)
Source: Own calculation based on household survey 2016

[19] Own calculation based on survey data 2016.

Moreover, household with higher aquaculture production cultured fish in largest pond area and reported to have higher per-capita income (Table 3.3). Other statistics shows that on an average, households' amount of fish sold in the market increases with the size of production. The net income was highest in the upper quantiles of production due to reduction in the cost of production per kilogram. This implies that farmers are generating higher revenue with minimum production costs when size of production increases.

Furthermore, it was found that household net income from aquaculture production increases with rising aquaculture production. It was observed that households' fish consumption and proportion of sold both increases with the increasing fish production; however, the rate of increase in consumption is not proportional to the rate of increase in sale. Despite the fact that homestead based pond aquaculture was mainly targeted to increase household consumption, farmers showed greater interest in selling fish with increased production. This implies that with increasing production, fish farming households will integrate themselves more with the market to sell the generated surplus.

The above explanation is from the bivariate relationship. The true assessment requires controlling for household and location characteristics along with addressing the potential endogeneity of aquaculture income. The next section explains the results from the econometric analysis addressing the issues mentioned above.

3.6 Model Results and Discussion

3.6.1 Homestead Aquaculture, Households' Consumption and Dietary Diversity Outcomes

Table 3.4 presents results from the 2SLS estimation following equations (8) and (9). The first column shows the results from the first stage regression establishing the relationship between the instruments (i.e., fishing capital, district fisheries officers) and the share of aquaculture income. These show that a significant correlation exists between aquaculture income and the chosen instruments, which is a prerequisite for the adequacy of instruments. The results also show that the higher value of fishing capital and more fisheries officer at district level are associated with generating higher aquaculture revenue. The fisheries officers play an important role for patrolling and helping the farmers for maintaining aquaculture activities. They provide appropriate guidelines and suggestions for aquaculture production including selection of species, use of appropriate fertilizer and issues related to fish diseases. Presence of more fisheries officers leads to a large production of fish and higher aquaculture income through their providing appropriate guidelines and suggestions. There are several other important factors strongly associated with the share of aquaculture income. For instance, a higher cost of input prices (i.e., labor wage and cost of fingerling and purchased feed) results in lower income from aquaculture activity, and households with income from off-farm activities (e.g., wage-earning or self-employment activity) have less involvement in aquaculture. Most importantly, distance to the village market was found to be negatively correlated, while the interaction term between distance and aquaculture income was positive and significant. This finding implies that households located closer to the village market have higher income opportunities from increased trade, and therefore, aquaculture income is higher in areas with better market access. This study also finds that access to credit positively and significantly correlated with aquaculture income share.

Table 3.4: Aquaculture income, food consumption and dietary diversity outcomes

Explanatory variables	Effects of aquaculture income on consumption and dietary diversity outcomes (Two-stage least squares estimates)				
	IV-1st stage:	IV- 2nd stage: log of household level outcomes			
	Log share of aquaculture income	Food consumption measures		Dietary diversity measures	
		Food expenditure (Tk./capita/ year)	Consumption of calories (Person/day)	Food consumption score	Simpson Index
	(1)	(2)	(3)	(4)	(5)
Aquaculture income:					
Share of aquaculture income (log)		0.147***	0.117***	0.182***	0.033***
		(0.053)	(0.047)	(0.059)	(0.005)
Household characteristics:					
Age of head	-0.024	0.009*	0.010**	0.012**	0.003
	(0.017)	(0.005)	(0.005)	(0.005)	(0.004)
Age squared	0.0002	-0.0001	-0.0001**	-0.0001**	-0.00001
	(0.0002)	(0.0001)	(0.00004)	(0.0001)	(0.0004)
Gender of head (male=1)	0.014	0.168**	0.166**	0.146**	0.040
	(0.196)	(0.080)	(0.075)	(0.074)	(0.058)
Education of head	-0.005	0.006**	0.003	0.007**	0.009***
	(0.009)	(0.003)	(0.003)	(0.003)	(0.002)
Number of children	-0.069*	-0.109***	-0.093***	-0.061***	-0.025**
	(0.038)	(0.013)	(0.012)	(0.013)	(0.011)
Number of adults	-0.037	-0.065***	-0.046***	-0.068***	-0.030***
	(0.025)	(0.009)	(0.008)	(0.009)	(0.008)
Number of old adults	-0.179**	-0.107***	-0.057**	-0.034	-0.059**
	(0.089)	(0.029)	(0.028)	(0.031)	(0.025)
Input cost:					
Log labor wage	-0.490**	-0.059	-0.022	-0.036	-0.027
	(0.195)	(0.068)	(0.068)	(0.083)	(0.071)
Input prices (at various districts level):					
Log price of fry	-0.167	-0.040	-0.009	-0.014	-0.014
	(0.304)	(0.056)	(0.049)	(0.049)	(0.042)
Log price of fingerling	-0.117	-0.011	-0.045	-0.030	-0.048*
	(0.099)	(0.035)	(0.030)	(0.036)	(0.027)
Log price of homemade	-0.025	-0.001	-0.009	-0.005	-0.018
feed	(0.099)	(0.030)	(0.025)	(0.028)	(0.021)
Log price of purchased	-0.165*	-0.001	-0.007	-0.005	-0.021
feed	(0.101)	(0.043)	(0.042)	(0.047)	(0.031)
Diversification, market and credit access:					
Have farm income?	0.190	0.089*	0.043	0.126***	0.072*
(yes=1)	(0.124)	(0.047)	(0.039)	(0.047)	(0.039)
Have off-farm income?	-0.447***	0.031	0.012	0.065	0.043
(yes=1)	(0.112)	(0.043)	(0.038)	(0.043)	(0.034)
Distance to village market	-0.386***	-0.119***	-0.027	-0.133***	-0.099***
	(0.121)	(0.041)	(0.033)	(0.047)	(0.033)

(Distance X aquaculture income)	0.668***	-0.088*	-0.070*	-0.117**	-0.067**
	(0.202)	(0.048)	(0.038)	(0.061)	(0.039)
Borrowed loan? (yes=1)	0.925***	-0.007	-0.121	-0.077	-0.011
	(0.198)	(0.083)	(0.099)	(0.128)	(0.090)
Wealth and productivity factors:					
Log land holding	0.017	0.093***	0.035**	0.103**	0.075***
	(0.052)	(0.017)	(0.016)	(0.019)	(0.015)
Share of sick adults	-0.430	-0.155*	-0.052	-0.252**	-0.156**
	(0.262)	(0.095)	(0.072)	(0.112)	(0.080)
Instrumental variables:					
Log value of fishing capital	0.041***	-	-	-	-
	(0.009)				
Log district fisheries officers per household	0.499**	-	-	-	-
	(0.217)				
Constant	4.176	5.101***	6.796***	1.242	1.435*
	(3.441)	(1.073)	(0.874)	(1.043)	(0.764)
Endogeneity test:+					
Durbin-Wu-Hausman Score: chi^2		10.810***	5.351**	13.801***	3.973**
F-statistics (1,474)		10.318***	5.051**	13.254***	3.739*
Over-identification test:++					
Sargan (score): chi^2		0.968	0.015	0.041	0.615
Basmann: chi^2		0.907	0.014	0.038	0.574

Note: Significance level: ***p<0.01, ** p <0.05 and *p<0.10. Robust standard errors are in parentheses. +H_o: Share of aquaculture income is exogenous; ++ H_o: One or more IVs are valid. Estimates for local food prices were omitted for brevity. In our initial estimation model, a dummy variable for remittances was included to see the role of remittances in the economy of rural households but it turned out to be insignificant in our two-stage least square technique. Therefore, we dropped this variable in the final estimation process for brevity.

Source: Own calculation based on household survey 2016.

Columns 2 to 5 show the results from the second stage of the least squares estimation. The results show that the effect of aquaculture income on households' food consumption and calories intake and on dietary diversity outcomes (i.e., food consumption score and Simpson diversity index of food types) remained positive and statistically significant. The results also show that controlling for all other factors, such as the household's socio-demographic characteristics, wealth and region-specific fixed effects, an increase in the share of aquaculture income by 10 per cent led to an increase in food consumption per capita by 1.5 per cent (Tk. 252 per capita per year). It also increased the total calorie intake per capita per day by 1.2 percent (24 calories per person per day) with a small improvement in dietary diversity outcomes, resulting from an increase of 1.8 percent and 0.33 percent in the food consumption score and Simpson diversity index, respectively.

The household's characteristics considered in the models also had a significant association with the household's food and calorie consumption and dietary diversity outcomes. As a well-known factor, gender plays an important role in determining household food and nutrition security (e.g., Sraboni et al., 2014). The gender of the household head was found to have a positive and statistically significant effect on the household's food and calorie consumption, which implies households with male heads are more likely to have higher per capita expenditure with high-calorie intake per capita. Besides, male-headed households have significantly higher food consumption score compared to female-headed households, which ensures the richness of the consumed food items at the male-headed households with better quality of dietary diversity. This result implies that female- headed households are nutritionally more insecure than male-headed households, which highlight the challenge faced by women in general, and to female-headed households in particular, in playing a more active role in ensuring food and nutrition security at the household level. These challenges include inadequate access to and control over productive resources (i.e., land, labor, and capital), lack of access to appropriate and efficient technologies and/or inputs to raise productivity, institutional barriers, cultural and social constraints in the form of gender-biased customs and conventions, obstacles for credit and extension advice etc. (FAO, 2010; Kebede, 2009; Ogunlela & Mukhtar, 2009). These constraints have consequences for women's productivity and efficiency and therefore, affect the overall role of woman at the household level. In fishing communities, women contribute significantly to the overall well-being of the households. However, they get very little in return due to deep-rooted gender disparities in social, cultural and economic spheres (Weeratunge-Starkloff & Pant, 2011, p. 2). Besides, in the transfer of aquaculture technology women are often bypassed and remain excluded from large-scale production (ibid.). Furthermore, the role of women in decision-making related to fishing is low at all levels from household to community, regional to national (WF, 2010; Weeratunge-Starkloff & Pant, 2011).

In addition, the number of household members belonging to different age groups (i.e., number of children, adults and old adults) was statistically significant and negatively associated with food consumption and dietary diversity outcomes. This result implies that more household members in a family reduce the per capita food expenditure and thereby per capita calorie intake. Thus, having less diversified food in their diet. Additionally, households having more land holding were more likely to have a diverse diet while diversity was low in households having more chronically sick members.

Farm and off-farm income generating activities had positive effect on dietary diversity outcomes. However, the magnitude of off-farm effect on dietary diversity outcomes was not statistically significant. This finding implies farm income is important for higher dietary diversity in fish farming households. Households with income from off-farm activities had less involvement in aquaculture. Therefore, the effect was negative on aquaculture income and less correlated to dietary diversity outcomes.

The coefficient of distance to village market is negative for household food consumption and the dietary diversity outcomes implying that fish farming households have greater dietary diversity from increased trade opportunities when they are located closer to the village markets. The interaction between aquaculture income and distance to village market was also statistically significant, explaining the significant effect of aquaculture income on household dietary diversity with better market access.

In each of the estimation processes, the exogeneity of the main explanatory variable (i.e., aquaculture income share) was rejected, which justifies the need for an instrumental variable approach. The chosen instruments were strongly correlated with the endogenous variable with a significant F-statistic for all four specifications. The specifications also passed the standard tests for endogeneity (i.e., Durbin-Wu-Hausman) and overidentifying restrictions (i.e., Sargan and Bassmann) justifying the correction of endogeneity of aquaculture revenue share.

Overall, the model results suggest that aquaculture income has positive and significant effects on household nutritional outcomes. Aquaculture income increases the purchasing power of households and thereby increases the access of other foods items and improves overall dietary intake. Although the effect on dietary diversity outcome is relatively small, it is significant and precisely estimated.

3.6.2 Homestead Aquaculture and the Structure of Household Consumption

Table 3.5 provides the results from the 3SLS for assessing the structure of consumption of the fishing households. For the three-stage least squares estimation process, the food items were disaggregated into 11 groups to determine the effect of aquaculture income on diversified food items. The disaggregated groups were the followings: grains, pulses, vegetables, fruits, milk, sweets, oils, eggs, meat, fish and beverages. In this estimation process, the calorie consumption shares from different food groups were the dependent variables, and the share of aquaculture income was the independent variable. The specification of simultaneous equation system passed all tests related to the instrumental variable approach.

The results show that aquaculture income has the highest effect on the consumption of pulses, which are low fat but energy-dense and protein-rich. A one percent increase in the share of aquaculture income increased the calories intake of pulses by 1.4 percent. A positive and statistically significant correlation was also observed between aquaculture income with the calorie shares of meat, fish and eggs. These food items have the highest quality protein among the other food groups, with energy dense fat and easily absorbable micronutrients (see appendix Table A1). Even with a small increase in the quantity consumed, improvements in the quality of diet are large. The estimates indicate that a one percent increase in the share of aquaculture income results in the increase of 0.38, 0.46 and 0.36 percent of more calories intake from egg, meat, and fish, respectively. Other food items have a statistically insignificant correlation with aquaculture income.

Summarizing the model results, the higher the share of aquaculture income, the greater is the share of calories intake from pulses, meat, eggs and fish. Fish is the food item mainly sourced from home production and others food items (i.e., meat, eggs and pulses) are mainly market purchased. Therefore, homestead aquaculture enables higher nutritional status in fish-farming households resulting from direct consumption of farmed fish and additional cash generated by selling the fish. Furthermore, aquaculture enterprises enable households to purchase other types of nutrient-rich food from the market such as meat, pulses and egg. Overall, homestead aquaculture helps the poor household to diversify food consumption by replacing low-quality food items (i.e., rice, wheat, sugar, oil) with high-quality protein and energy-dense food items.

Table 3.5: Aquaculture income and the structure of fishing households' food consumption

Explanatory variables	3SLS system of equations: log share of calories of food groups in total calories consumption										
	Grains	Pulses	Vegetables	Fruits	Milk	Sweets	Oils	Eggs	Meat	Fish	Beverages
Aquaculture income:											
Share of aquaculture	-0.025	1.434***	0.031	-0.129	0.445	0.101	0.154	0.375**	0.458**	0.358***	-0.176
income (log)	(0.017)	(0.398)	(0.135)	(0.185)	(0.309)	(0.218)	(0.212)	(0.164)	(0.240)	(0.136)	(0.224)
Household characteristics:											
Age of head	0.002	0.078	-0.025	-0.023	0.041	-0.007	-0.008	-0.028	0.017	0.003	0.023
	(0.002)	(0.051)	(0.017)	(0.024)	(0.039)	(0.028)	(0.027)	(0.0201)	(0.032)	(0.018)	(0.029)
Age squared	-0.000	-0.001	0.0003	0.0002	-0.0003	0.0001	0.0001	0.0003	-0.0002	-0.0002	-0.0002
	(0.000)	(0.001)	(0.0002)	(0.0002)	(0.0004)	(0.0003)	(0.0003)	(0.0002)	(0.0003)	(0.0002)	(0.0003)
Gender of head (male=1)	0.045**	-0.107	-0.083	0.087	0.363	0.656**	-0.310	0.469**	-0.106	0.368**	-0.190
	(0.022)	(0.532)	(0.181)	(0.248)	(0.414)	(0.293)	(0.284)	(0.219)	(0.332)	(0.184)	(0.299)
Education of head	-0.006***	0.0595**	0.001	0.003	0.088***	0.030*	0.025	0.038***	0.049***	0.014	0.020
	(0.001)	(0.030)	(0.010)	(0.014)	(0.023)	(0.016)	(0.016)	(0.012)	(0.018)	(0.010)	(0.017)
Number of children	0.013***	-0.147	-0.057	-0.099*	0.189**	-0.018	-0.123**	-0.038	0.048	-0.032	0.069
	(0.005)	(0.110)	(0.037)	(0.051)	(0.086)	(0.061)	(0.059)	(0.045)	(0.069)	(0.038)	(0.062)
Number of adults	0.014***	-0.067	-0.019	-0.097***	0.034	-0.035	-0.070*	-0.004	0.074	-0.009	0.031
	(0.003)	(0.080)	(0.027)	(0.037)	(0.062)	(0.044)	(0.042)	(0.033)	(0.049)	(0.028)	(0.045)
Number of old adults	0.032***	0.013	-0.045	-0.140	-0.178	-0.098	-0.213	-0.053	-0.074	-0.035	-0.072
	(0.010)	(0.251)	(0.086)	(0.117)	(0.196)	(0.138)	(0.134)	(0.104)	(0.157)	(0.087)	(0.141)
Input cost:											
Log Wage of labor	-0.009	-0.348	-0.041	-0.184	-0.100	-0.273	-0.199	-0.038	-0.025	-0.095	-0.322
	(0.031)	(0.753)	(0.256)	(0.350)	(0.586)	(0.414)	(0.402)	(0.311)	(0.469)	(0.260)	(0.424)
Input prices (at various districts level)											
Log price of fry	-0.003	-0.423	-0.164	-0.318	-0.023	-0.030	-0.065	-0.067	-0.498	-0.185	-0.540
	(0.029)	(0.705)	(0.240)	(0.328)	(0.549)	(0.388)	(0.377)	(0.291)	(0.439)	(0.244)	(0.397)
Log price of fingerling	-0.013	-0.278	-0.021	-0.078	-0.091	-0.082	-0.049	-0.004	-0.028	-0.248**	-0.158
	(0.012)	(0.295)	(0.100)	(0.137)	(0.229)	(0.162)	(0.157)	(0.122)	(0.184)	(0.102)	(0.167)
Log price of homemade	-0.006	-0.453*	-0.008	-0.447***	-0.330*	-0.277*	-0.027	-0.074	-0.134	-0.140	-0.051
feed	(0.011)	(0.270)	(0.092)	(0.126)	(0.210)	(0.149)	(0.144)	(0.112)	(0.168)	(0.095)	(0.152)
Log price of purchased	-0.013	-0.026	-0.012	-0.159	-0.559**	-0.088	-0.375**	-0.050	-0.154	-0.032	-0.058
feed	(0.015)	(0.352)	(0.120)	(0.164)	(0.274)	(0.194)	(0.188)	(0.145)	(0.219)	(0.122)	(0.198)

Diversification, market and credit access:											
Have farm income?	0.028	1.319***	0.054	-0.242	0.576*	-0.493**	-0.224	0.411**	0.619**	-0.200	-0.140
(yes=1)	(0.018)	(0.425)	(0.145)	(0.198)	(0.331)	(0.234)	(0.227)	(0.75	(0.2695)	(0.147)	(0.239)
Have farm off-income?	-0.037**	1.411***	-0.019	-0.137	0.279	0.067	0.325	0.166	0.395*	0.105	-0.003
(yes=1)	(0.016)	(0.386)	(0.1313)	(0.180)	(0.300)	(0.212)	(0.206)	(0.159)	(0.241)	(0.135)	(0.217)
Distance to village market	-0.035***	-1.075***	0.059	0.021	-0.403*	-0.062	-0.107	-0.260**	-0.216	-0.017	-0.180
	(0.012)	(0.286)	(0.097)	(0.133)	(0.223)	(0.157)	(0.153)	(0.117)	(0.178)	(0.099)	(0.161)
(Distance X aquaculture	0.007	-0.397**	0.053	0.013	-0.306**	-0.111	0.015	-0.114*	-0.122	-0.048	-0.059
income)	(0.006)	(0.157)	(0.054)	(0.0743)	(0.122)	(0.087)	(0.084)	(0.063)	(0.098)	(0.054)	(0.089)
Borrowed loan? (yes=1)	0.020	-0.241	0.051	0.058	-0.317	-1.747**	-0.320	0.049	0.012	-0.246	1.523**
	(0.054)	(1.305)	(0.444)	(0.607)	(1.015)	(0.718)	(0.6972)	(0.538)	(0.813)	(0.451)	(0.734)
Wealth and productivity factors:											
Log landholding	0.026***	-0.121	0.030	0.280***	0.304**	0.266***	0.088	0.023	0.218**	0.010	0.187**
	(0.007)	(0.174)	(0.060)	(0.0813)	(0.136)	(0.096)	(0.093)	(0.072)	(0.109)	(0.0570)	(0.098)
Share of sick adults	-0.087**	-1.532*	-0.031	-0.451	-0.787	-0.724	-0.143	-0.341	-0.763	-0.225	-0.682
	(0.035)	(0.844)	(0.287)	(0.393)	(0.656)	(0.464)	(0.450)	(0.348)	(0.525)	(0.292)	(0.474)
Instrumental variables:											
Log value of fishing capital	0.043***										
	(0.009)										
Log district fisheries	0.225**										
officers per household	(0.115)										
Over-identification test:$^{+}$											
Sargan- Hansen (score):	14.733										
chi^2	(p= 0.256)										
Constant	0.150	21.519**	0.897	11.045**	13.261*	-7.898	5.283	4.367	11.141*	5.521*	15.672***
	(0.415)	(9.939)	(3.385)	(4.624)	(7.733)	(5.466)	(5.304)	(4.099)	(6.189)	(3.437)	(5.591)

Note: Robust standard errors are in parentheses. Significance level: ***p<0.01, ** p <0.05 and *p<0.10. $^{+}$ H_o: One or more IVs are valid. Results of instrumental variable and over-identification test come from first stage of the three-stage least squares estimation technique. Estimates for local food prices were omitted for brevity.

Source: Own calculation based on household survey 2016.

3.7 Conclusions and Policy Recommendations

In this study, the link between homestead aquaculture income and household nutritional outcomes is analyzed using primary data from 518 households who engaged in homestead fish farming in Bangladesh. The study examines whether involvement in aquaculture improved household nutrition condition and dietary diversity. For methodology, due to the presence of unobserved heterogeneity, a two-stage least squares estimation technique is applied for analyzing the effect of aquaculture income on nutritional outcomes. Additionally, a simultaneous system of equations is also applied in a three-stage least squares framework for analyzing the effect on the quality of a household's diet.

This study has important implications for nutrition, health and agricultural policy in Bangladesh and other developing countries. First, aquaculture income from homestead ponds contributes to increased food consumption expenditures and calorie intake, and improves dietary diversity. Second, the gender of the household head is important for household food and nutrition security because households with female heads have lower food consumption and dietary diversity. Third, farm income from crop and livestock also plays an important role in the fish farming households. This implies that income from homestead aquaculture is a complementary to other sources of income, albeit its contribution is significant. Fourth, households with better market access derive more income from selling fish. Fifth, access to credit is important to enable fish farming households to move gradually from subsistence homestead production to a more a commercial type of aquaculture. Sixth, homestead fish production increases home consumption of fish and thereby its share in total calorie intake. In this regards, our findings are similar to the results to earlier studies by Gomna and Rana (2007) and Dey et al. (2005) who reported higher fish consumption in fishing households compared to other households. Seventh, additional income from aquaculture helps to improve the quality of a households' diet by consumption of more calories from pulses, meat, eggs and fish. Therefore, the food consumption structure of poor farmers is diversified with high-quality protein and energy-dense food items.

Results of this study suggest that homestead pond aquaculture remains an important source of protein and micronutrients in spite of the emergence and spread of large-scale, commercial aquaculture in Bangladesh. In homestead fish production, farmers integrate different species of micronutrient-rich fish for easy access of the household. Therefore, this study recommends that the Department of Fisheries should reconsider its view on the role of homestead pond production and give homestead ponds more recognition in its extension activities. Moreover, better market access and improved infrastructure are needed if more homestead fish producers are to gradually develop into a semi- or fully commercial small-scale aquaculture production systems.

To conclude, while there is an increasing trend of rural households to engage in non-farm income generating activities in Bangladesh and other developing countries, this study submits that for small and marginal farmers homestead fish ponds will remain important for many years to come.

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Appendix

Table A1: Food items, assigned groups and their nutritional attributes

Food groups	Weight	Food items	Nutritional attributes
Main staples	2	Rice, wheat, maize, bread, flour	Energy dense, protein content lower and poorer quality than legumes, micro-nutrients
Pulses	3	Beans, peas, groundnuts, cashew nuts	Energy dense, high amounts of protein but of lower quality than meats, micro-nutrients, low fat
Vegetables	1	Vegetables, leaves	Low energy, low protein, no fat, micronutrients
Fruit	1	Fruits	Low energy, low protein, no fat, micro-nutrients
Meat and fish	4	Beef, goat, poultry, duck, pigeon, eggs, fish	Highest quality protein, easily absorbable micronutrients, energy dense, fat. Even with small amount of consumption, improvements to the quality of diet are large.
Milk	4	Milk, yogurt, sweets, other diary	Highest quality protein, micro-nutrients, vitamin A, energy
Sugar	0.5	Sugar and sugar products, honey, dates	Zero calories
Oil	0.5	Oils, fats, butter	Energy dense, no micro-nutrients
Condiments	0	spices, tea, coffee, salt	Eaten in very small quantities, no impact on overall diet.

***Source*:** WFP (2008) adjusted for Bangladesh survey data of 'Fish Production, Consumption and Nutrition Linkages-2016'.

CHAPTER 4: THE BLUE REVOLUTION IN BANGLADESH: WHAT CAN SMALLHOLDERS AQUACULTURE FARMERS CONTRIBUTE?

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Abstract

This study examines the possibilities of smallholder aquaculture farmers in developing countries to more effectively contribute to fish production when transforming from subsistence-type of home-pond producers towards a more modern, commercialized small-scale aquaculture system. Using panel data from 518 homestead aquaculture producers in Bangladesh, this study assesses the impacts of commercialization on household welfare of smallholders. A binary endogenous switching regression model is applied in a correlated random effects framework, along with a counterfactual analysis to estimate the effect of commercialization. Results show that commercialization among subsistence homestead farmers continues to take place but at a slower pace. Households who commercialized have a higher per capita income and are less likely to be poor compared to those who continue to practice a low-intensity-subsistence production system. Using a switching-regression, counterfactual model suggests that farmer who did not transform from subsistence to commercial scale, would in fact benefit even more from commercialization than those who did. Support from non-government organizations, and fish farmer's associations at village level play a crucial role to facilitate the commercialization process through providing information regarding market condition and prices. Moreover, distance to village market and access to credit are of the utmost importance to reduce the transaction cost and liquidity constraints of smallholders. Therefore, the overall results suggest that providing appropriate information to farmers, and proper strategies to improve their efficiency level can be an effective policy instrument to induce households to commercialize in aquaculture activities.

Keywords: Commercialization, Household Welfare, Endogenous Switching Regression, Correlated random effect, Bangladesh, Developing countries

4.1 Introduction

Demand for fish has been continuously increasing in the world due to rapid population growth and rising incomes. Since capture fish resources are declining, fish production from aquaculture has been gaining importance. In recent period, aquaculture has become the fastest growing food-producing sector in the world with an annual growth rate of 5.8 percent in 2016 and accounting over 50 percent of total fish consumed globally (FAO, 2018a, 2018b). Growth of fish production in developing countries exceeded those in developed countries. In 2017, the share of developing countries export of fish and fish products was 59 percent in quantity terms and 54 percent in value terms (FAO, 2018a, p. 57). Smallholders dominate fish production in developing countries with important employment effects for the rural population (Phillips et al., 2011).

Most of smallholder aquaculture in developing countries is for subsistence and fish adds to a households' diverse livelihood activities. Over time, smallholders transform from pure subsistence to partially commercialized selling their surplus production to the market. Growing demand for aquaculture products is creating opportunities for rural smallholders to improve their livelihoods standards through increasing income and diversifying income sources (Phillips et al., 2011). Household level subsistence fish production mainly supports family nutrition (Bogard et al., 2015; Thilsted, 2012). Additionally, it contributes to household income once production becomes market-oriented and helps the households move out of poverty (Castine et al., 2017).

Due to favorable agro-climatic conditions and availability of resources, Bangladesh is considered as one of the most suitable countries for small-scale aquaculture development (Ahmed, Rab, & Gupta, 1995). In Bangladesh, aquaculture is expanding more rapidly than any other area of rural sector (Ali & Haque, 2011). This expansion is facilitated by the promotion of integrated agriculture-aquaculture systems to be practiced by small-scale farmers (FAO, 2007). Smallholders aquaculture in Bangladesh is mainly homestead pond based fish culture, which is just one component of a diversified farming system. Homestead fish ponds have multiple uses including bathing, washing and watering livestock. In most cases, homestead ponds are constructed when households excavate the soil to raise the basement of houses to avoid flooding. As a result, many households in Bangladesh hold a small pond near their homestead area (Huda et al., 2010; Kränzlin, 2000; Little et al., 2007).

Homestead pond culture produces over 43 percent of the total recorded aquaculture production in Bangladesh (DoF, 2016; Shamsuzzaman et al., 2017). On the other hand, homestead fish farming is an extensive system mainly for home consumption, which works as a food safety net of the poor making fish available year the round and makes farmers less vulnerable to fluctuation in fish supply and prices (Kawarazuka & Béné, 2010; Béné et al., 2016; Castine et al., 2017). Only in case of surplus production, fish is produced in homestead ponds sold in the market, thus complementing cash income of the poor (Edwards, 1999). Homestead fish farming is labor intensive but low intensive in external input use such as fish feeds. (Jahan et al., 2015). More recently, small-scale homestead ponds are gradually transforming into more commercial type enterprises (Sarker et al., 2017). Better-off farmers expand the pond area and intensify production by use of external inputs and increasing the stocking density.

Although pond based aquaculture has been widely practiced in Bangladesh, there is little research that has established its contribution to nutrition and food security and its potential to transform into more commercial scale of fish production by means of rigorous quantitative analysis. Therefore, the main objective of this study is to better understand the factors that foster the transformation of homestead fish farmers from a subsistence to a more market-oriented system. The specific objectives are, to first, analyze the extent and trend of commercialization among the homestead fish farmers in Bangladesh, second, to identify the factors that determine the extent of smallholder commercialization, and to third, assess the impact of smallholder commercialization on household welfare overtime.

To fulfill the objectives, this study uses a two-period panel data (i.e., 2011 and 2016) of farm households who engaged in homestead pond aquaculture in Bangladesh. Two groups of smallholder farmers are compared, namely those that are engaged in market production and those that remain dominantly subsistence-oriented. A two-step endogenous switching regression (ESR) model is applied in a correlated random effects (CRE) framework to estimate the impact of aquaculture commercialization on household welfare. In the first step, farmers' market participation decision to commercialize is determined and estimated using a probit model. In the second step, a counterfactual analysis is implemented to estimate the impact from the expected welfare outcomes between two groups of farmers.

Results show that commercialization among homestead fish farmers between 2001 and 2016 has increased. Generally, commercialization has led to welfare gains at household level. Farmers who commercialized have more income and are less likely to be poor. Moreover, commercialization also promotes income diversification among the non-commercialized household, and thereby, reduces the vulnerability of rural livelihoods.

The remainder of this chapter is organized as follows. Section 2 explains the implications of aquaculture commercialization on household welfare. Section 3 provides the theoretical framework. Section 4 explains details of the estimation procedures. Section 5 explains the data and shows some descriptive statistics from the household survey. In section 6, the results of the empirical models are presented and discussed. Section 7 concludes and offers some policy recommendations.

4.2 Aquaculture Commercialization and Its Implication for Household Welfare

Commercialization means the progressive shift of production at the household level from home-consumption to sales in accessible markets. Such a shift requires production and input decisions of households to be better in line with profit maximization principle, and participate in output and input markets (Olwande et al., 2015). Following the framework suggested by Pingali and Rosegrant (1995), in the process of commercialization, households go through a sequence of transformations from subsistence to semi-commercial, and finally to a fully commercialized production system (see Table 4.1).

Table 4.1: Production system with increasing commercialization

Level of market orientation	Farmers objective	Input sources	Product mix	Income sources
Subsistence system	Food self-sufficiency	Household generated (non-traded)	Wide range	Predominantly agricultural
Semi-commercial systems	Surplus generation	Mix of traded and non-traded inputs	Moderately specialized	Agricultural and non-agricultural
Commercial systems	Profit maximization	Predominantly traded inputs	Highly specialized	Predominantly non-agricultural

Source: Pingali and Rosegrant (1995, p. 172)

In many developing countries, smallholder commercialization is central of an inclusive development process, which is considered as an effective way to bring the welfare benefits of market-based economies to them (Arias et al., 2013; WDR, 2008). To date, there are rarely complete subsistence producers. Instead, production of smallholders is mostly semi-commercial, practiced in a kind of low-input and low-productivity system. Yet such systems are important for poverty alleviation (Olwande et al., 2015). Therefore, understanding the extent and the contributing factors of smallholders' commercialization is important for the design of effective agricultural policies in developing countries. Bye and large, smallholder commercialization has been considered as the major way of increasing farmers' income and a way-out of reducing rural poverty (WDR, 2008; Timmer, 1997; Pingali & Rosegrant, 1995) and ensuring food security at the household level (Pingali, 1997).

However, the literature remains diverse in its findings regarding the impacts of smallholder agricultural commercialization on the welfare of the poor (Binswanger & Braun, 1991). Based on the data from developing countries, studies carried out by IFPRI at household level show that agricultural commercialization significantly increases household income and welfare (Braun & Kennedy, 1994). Additionally, there is a positive impact of commercialization on household incomes that have been reported in many developing countries including Kenya (Muriithi & Matz, 2015), Malawi (Poulton, Kydd, & Dorward, 2006), Botswana (Timan et al., 2004) and Zimbabwe (Govereh & Jayne, 2003). In contrast, smallholder commercialization has been criticized by Pingali and Rosegrant (1995), and Pingali, Khwaja, and Meijer (2005) for widening the income inequalities among the poorest farmers. Therefore, it is recommended to go for further empirical research on the impact of agricultural commercialization on household welfare to find more convincing results (Zhou, Minde, & Mtigwe, 2013).

While many papers have been written on agriculture commercialization and its welfare impact, very little can be found so far for the case of commercialization in aquaculture. Although, aquaculture has attracted considerable interest as a vehicle for reducing poverty and food insecurity in many developing countries like Bangladesh (Toufique, 2015; Jahan, Ahmed, & Belton, 2010; Béné et al., 2016), few studies have rigorously analyzed aquaculture commercialization and its welfare impact on smallholder farmers.

The next section will proceed with the theoretical framework of modeling the impact of aquaculture commercialized on household welfare.

4.3 Theoretical Model of Households Market Participation Decision to Commercialize

Considering the heterogeneity nature of homestead fish farmers in Bangladesh, the non-separable agricultural household model (AHM) is adopted to explain households' market participation behavior of selling fish to commercialize aquaculture given that prices are endogenous to decision-making and determined by transactions costs (Barrett, 2008; Alene et al., 2008; Boughton et al., 2007; Bellemare & Barrett 2006).

Following Barrett (2008), Alene et al. (2008) and Boughton et al.'s (2007) application of the AHM, households' market-related decisions of whether or not to participate in the market as a seller is expressed as, M^{cs}. M^{cs} takes a value of one if the household enters into the market for selling a crop, and zero otherwise based on farmer's decision that depend on observed market prices and the vector of crop and household specific transaction costs. Similarly, the decisions of whether or not to participation in the market as a buyer is defined as, M^{cb}, which takes value one if the household elect to buy any crop and zero otherwise.[20]

Household's decision to participate in the market is expressed as the optimization problem as:

$$Max\ U(F^c, T) \tag{1}$$

Subject to:

Cash budget constraint

$$P^T T + \sum_{c=1}^{C} M^{cb} P^{c*} F^c = \sum_{c=1}^{C} M^{cs} P^{c*} \int^c (K^c, S) + O_f \tag{2}$$

Asset allocation constraint

$$K = \sum_{c=1}^{C} K^c \tag{3}$$

$$(1 - M^{cb}) F^c \leq \int^c (K^c, S) \qquad \forall\ c = 1,2,3 \ldots \ldots \ldots . C \tag{4}$$

Where, F^c (c=1, 2, 3,……..,C) is the consumption of vector of agricultural commodities; T is the Hicksian composite of other tradable goods; C is the production of goods and services from farm sources that are consumed at home and possibly sold in the market; O_f is off-farm sources; $f_c(K^c, S)$ is crop specific production technology, which is a function of quasi-fixed assets (K^c) and public goods and services (S); P^m is the parametric market price for each crop (c); $\tau^c(H, S, K, O_f)$ is household and crop specific transactions costs that depend on public goods

[20] In this simple model, transaction costs create a price wedge and so there exists a complementary slackness condition when $M^{cb}.M^{cs} = 0$ at any optimum. Therefore, households will not buy and sell the same crop simultaneously (Barrett, 2008)

and services (S), household-specific characteristics (H) , household assets. (K), and liquidity from off-farm income sources (O_f).

Household's net market position determines each household specific crop price as:

$$P^{c*} = P^{cm} + \tau^{c}(H, S, K, O_f) \qquad \text{if } c > \int^{c} \qquad (5)$$

$$P^{c*} = P^{cm} - \tau^{c}(H, S, K, O_f) \qquad \text{if } c < \int^{c} \qquad (6)$$

$$P^{c*} = P^{a} \qquad \text{if } c = \int^{c} \qquad (7)$$

Where, P^{a} is the autarkic (i.e., non-tradable) shadow price, which exactly equates household demand and supply.

In the non-separable household model, the transactions costs of market participation is defined by market prices plus and minus those costs, reflecting the net prices for buyers and sellers, respectively (De Janvry, Fafchamps, & Sadoulet, 1991). Therefore, solution of this optimization problem in equation (1) requires choosing the optimal choices of F^{c}, T, and K^{c} and the associated utility level under the feasible combination of M^{cb} and M^{cs} to identify the market participation vector as a buyer and seller $\{M^{cb}, M^{cs}\}$, which yields maximum welfare for each household (Key, Sadoulet, & Janvry, 2000; Stephens & Barrett, 2011). The structural model therefore, can be expressed in reduced form as a function of exogenous variables as follows:

$$M_i = M_i\left(P, H, K, S, O_f\right) \qquad (8)$$

Where, M_i indicates the decision to sell fish or not by a household, (i). P is observed market price of fish. H represents household characterizes and demographics. K is the value of household assets as well as ownership of household-specific assets such as: mobile, transport equipment that influence transaction costs. S is public services facility representing market infrastructure such as: distance, travel time to market etc.

The identification strategy for equation (8) follows a two-step procedure to determine homestead farmers market participation decision, and its welfare impact. The first stage requires modeling household market participation decision to sell fish based on the specification of equation (8), and the second stage requires estimating the impact from the expected welfare outcomes conditioned on household market participation decision defined in the first stage. In next section, the empirical strategy is explained in detail to do the impact analysis based on the discussed agricultural household model.

4.4 Estimation Strategy

In this section, at first the empirical model is explained based on the specification of the agricultural household model defined in section 4.3. The second part explains the detailed methodology to undertake the counterfactual analysis based on the effect of commercialization on household who participate (i.e., treated) and who do not participate (i.e., untreated) in the market, and the last part defines the main indicator variables used in the model.

4.4.1 Modeling Commercialization Decision to Assess Welfare Impact on Smallholders

Impact analysis using non-experimental data is challenging for establishing a counterfactual against which impact is going to be assessed. It is not easy in non-experimental data to observe the effect of the treatment outcome on the treated group had it not been treated. This problem is addressed in experimental studies by randomly assigning the treatment to a given sample (Kassie, Jaleta, & Mattei, 2014). However, problem arises when the treatment is not randomly assigned and the observed outcome on the treated and untreated groups is likely to be influenced by observed and unobserved characteristics. Therefore, this study faces several challenges while assessing impacts of commercialization. First, is the treatment is not randomly assigned as households self-select themselves to be commercialized and non-commercialized. This introduces a self-selection bias in the outcome variable. The self-selection bias causes a systematic difference between the treated and untreated groups that influence the treatment decision to be commercialized and therefore, the outcome variable in the model. Second, the impact of commercialization on household welfare could be different for the treated and untreated households for the structural difference in household and farm characteristics (Kassie et al., 2014; Shiferaw et al., 2014). Third, the treatment variable (e.g., aquaculture commercialization) is potentially endogenous.

To address these problems, this study generates a counterfactual group following a two-step modeling framework. The first step estimates a probit selection equation to find out the determinates of commercialization. Then a selection bias correction terms is calculated from the first step probit model, and added as a generated regressor in the outcome equation. The second step implemented a counterfactual analysis based on the outcome equation by calculating the average treatment effects on the treated and the untreated group to estimate the impact of commercialization on household welfare. Following Di Falco and Veronesi (2013), Di Falco, Veronesi, and Yesuf (2011) and Teklewold et al. (2013), the selection bias corrected regression is defined as an endogenous switching regression model (ESR). This model not only helps to correct for self-selection bias but also controls for both observed and unobserved heterogeneity between different commercialization strategies (Mansur, Mendelsohn, & Morrison, 2008).

Step 1: Probit selection equation to estimate determinants of commercialization

The theoretical model explains that farmers' choice to participate or not to participate in the market to sell fish depends on expected utility (Bellemare & Barrett 2006; Boughton et al., 2007; Alene et al., 2008), which depends on observed (X_{it}) and unobservable characteristics (U_{it}). As utility is unobservable, it can be expressed as a function of observable household characteristics (X_{it}) and the error terms (η_{it}) in the form of a latent variable model as follows:

$$C_{it} = \alpha_{it} X_{it} + \eta_{it} \qquad \text{Where, } P_{it} = \begin{cases} 1 \; if \; C^*{}_{it} > 0 \\ 0 \text{ otherwise} \end{cases} \tag{9}$$

In equation (9), C_{it} is the binary indicator variable for commercialization which equals to 1 if a household is commercialized and 0 if otherwise, αit is vector of parameters, $\mathrm{X_{it}}$ is vector of observable explanatory variables and η_{it} is the error term.

In this stage, the ESR model is estimated using the outcome functions conditional on the commercialization decision to evaluate the impact of commercialization on welfare following Kassie et al. (2014), Shiferaw et al. (2014) and Lokshin and Sajaia (2004) as follows:

$$W_{1it} = \beta_1 X_{1it} + \varepsilon_{1it} \qquad \text{if } C_{it} = 1 \tag{10a}$$

$$W_{0it} = \beta_0 X_{0it} + \varepsilon_{0it} \qquad \text{if } C_{it} = 0 \tag{10b}$$

Where, W_{1it} and W_{0it} are outcome variables, representing households' welfare indicators such as: household income, poverty and income diversification for commercialize and non-commercialize households respectively at time period t, X represents observed vectors of covariates, which determines outcome variable for commercialized and non-commercialized households respectively, at time period t, β is the vectors of parameters, and ε is the error terms that are normally distributed with zero mean and constant variance.

The ESR model to be identified, at least one selection instrument needs to be incorporated in the section model without the X_{it} variables. This instrument should be added to those automatically generated by the process due to non-linearity of the selection model (Kassie et al., 2014; Shiferaw et al., 2014). The validity of the selection equation requires the chosen instrumental variable should influence households' commercialization decision but not the outcome variables of interest (Wooldridge, 2010). Based on this requirement, this study chooses distance to village market and member of fish farmers association as instruments.

The justification for choosing the selected instruments is that in most of the developing countries, fish farmers' associations are an important source of information at the grass root level to provide technical support, facilitate market access, encourage better management practices, extend credit for members and facilitate knowledge sharing among the farmers (FAO, 2016; Mosher, 1966). Additionally, distance to village market greatly influences the price and the availability of inputs for aquaculture production. These variables have been commonly used in the previous studies to instrument household commercialization decision (Olwande & Smale, 2014; Boughton et al., 2007; Muricho et al., 2017; Mazengia, 2016; Abafita, Atkinson, & Kim, 2016). Therefore, this study hypothesizes that selected variables are valid to instrument the commercialization decision of the farmers although they are subjected to test to ascertain their validity. The validity is tested by applying the falsification test based on the assumption that these variables affect household commercialization decision in the probit section equation but do not affect the welfare outcome of the households that did not commercialize (Di Falco et al., 2011).

As the expected values of the error terms in equation (10a) and (10b) are non-zero conditional on the section equation, using OLS to estimate β_0 and β_1 will lead to biased estimates. The error terms $\eta, \varepsilon_1, \varepsilon_0$are assumed to have a trivariate normal distribution with zero mean and covariance matrix as follows:

$$\boldsymbol{Cov}(\eta, \varepsilon_1, \varepsilon_0) = \begin{bmatrix} \sigma_\eta^2 & \sigma_{\eta\varepsilon_1} & \sigma_{\eta\varepsilon_0} \\ \sigma_{\eta\varepsilon_1} & \sigma_{\varepsilon_1}^2 & .. \\ \sigma_{\eta\varepsilon_0} & .. & \sigma_{\varepsilon_0}^2 \end{bmatrix} = \begin{bmatrix} 1 & \sigma_{\eta\varepsilon_1} & \sigma_{\eta\varepsilon_0} \\ \sigma_{\eta\varepsilon_1} & \sigma_{\varepsilon_1}^2 & .. \\ \sigma_{\eta\varepsilon_0} & .. & \sigma_{\varepsilon_0}^2 \end{bmatrix} \quad (11)$$

In equation (11), σ_η^2 is $var(\eta)$, $\sigma_{\varepsilon_1}^2$ is $var(\varepsilon_1)$, $\sigma_{\varepsilon_0}^2$ is $var(\varepsilon_0)$, $\sigma_{\eta\varepsilon_1}$ and $\sigma_{\eta\varepsilon_0}$ are $cov(\eta, \varepsilon_1)$ and $cov(\eta, \varepsilon_0)$, respectively.

As the α coefficients in the selection model are estimable up to a scalar factor, the variance of the error term in selection equation is assumed to be equal to 1 (Dutoit, 2007). On the other hand, the covariance between ε_1 and ε_0 is undefined due to the fact that W_{1it} and W_{0it} in equation (10a) and (10b) cannot be observed simultaneously i.e., a household can only be observed in either of the regimes but not in both (Maddalla, 1983). Therefore, the expected values of the error terms conditional on the section equation are non-zero, since the error term in selection equation (η) is correlated with the error terms in the household welfare equations, $(\varepsilon_1, \varepsilon_0)$.

The presence of the selection bias implies that the expected values of the error terms in equation (10a) and (10b) conditional on commercialization decision are non-zero. Therefore, the expected values of the error terms can be written as follows:

$$E(\varepsilon_{1it}|C_{it} = 1) = \sigma_{\varepsilon_1\eta} \frac{\phi(X_i,\alpha)}{\Phi\,(X_i,\alpha)} = \sigma_{\varepsilon_1\eta}\,\lambda_{1it} \qquad \text{where } \lambda_{1it} = \frac{\phi(X_i,\alpha)}{\Phi\,(X_i,\alpha)} \qquad (12a)$$

$$E(\varepsilon_{0it}|C_{it} = 0) = \sigma_{\varepsilon_0\eta} \frac{\phi(X_i,\alpha)}{1-\Phi\,(X_i,\alpha)} = \sigma_{\varepsilon_0\eta}\,\lambda_{0it} \qquad \text{where } \lambda_{0it} = \frac{\phi(X_i,\alpha)}{1-\Phi\,(X_i,\alpha)} \qquad (12b)$$

Where, $\phi(.)$ is the standard normal probability density function, $\Phi(.)$ is the standard normal cumulative density function, λ_1 and λ_0 are the inverse mills ratio (IMR), $i\ and\ t$ represents household and time period, respectively.

To account for the selection bias, λ_1 and λ_0 are computed from the selection equation (9) and included in welfare equations (10a) and (10b) as follows (Maddala, 1983):

$$W_{1it} = \beta_1 X_{1it} + \sigma_{\varepsilon_1\eta}\,\lambda_{1it} + e_{1it} \qquad \text{if } C_{it} = 1 \qquad (13a)$$

$$W_{0it} = \beta_0 X_{0it} + \sigma_{\varepsilon_0\eta}\,\lambda_{0it} + e_{0it} \qquad \text{if } C_{it} = 0 \qquad (13b)$$

Where, $e_{1it} = \varepsilon_1 + \sigma_{\varepsilon_1\eta}\,\lambda_{1it}$ and $e_{0it} = \varepsilon_0 + \sigma_{\varepsilon_0\eta}\,\lambda_{0it}$ are the error terms with conditional mean equal to zero.

In equation (13a) and (13b), the standard errors are bootstrapped to account for the heteroscedasticity arising from the generated regressors,(λ).

In the two-step estimation procedure, including only the IMR and standard fixed effects does not lead to consistent estimates (Wooldridge, 2010). Therefore, a correlated random effects (CRE) approach is applied using the *Mundlak–Chamberlain* device (Mundlak, 1978; Chamberlain, 1982) to estimate the welfare equations in (14a) and (14b). The CRE approach has some advantages over the conventional random effect (RE) and fixed effect (FE) models. This approach preserves the advantages of FE approach, while enabling the inclusion of time invariant explanatory variables in the model (Wooldridge, 2010; Cameron & Trivedi, 2005). The two year balanced panel data offers the analytical advantage of controlling the unobserved time invariant individual household characteristics in the econometric model.

The CRE approach assumes that the unobserved time varying individual heterogeneity (Γi) and the vector of explanatory variables across all time periods (X_{it}) are correlated and therefore, there exists a linear relationship between them (Wooldridge, 2010; Cameron & Trivedi, 2005). In this case, the unobservable characteristics such as farm management skill might be correlated with the average of the time variant explanatory variables. Therefore, farm variant variable can be used to control for farm-specific fixed effects (Udry, 1996). As fish yield is a farm variant variable, the average value of fish yield ($\bar{X}_i$) is used as one of the explanatory variables in equation (13a) and (13b). Following Wooldridge (2010), and Cameron and Trivedi (2005), the CRE framework including the farm variant variable can be modeled as follows:

$$T_i = \pi + \theta\bar{X}_i + \gamma_i \quad (14)$$

Where, π is a scale coefficient, $\bar{X}$ is the average value of fish yield , θ is coefficient vector, γ_i is a normally distributed error term assumed to have zero mean, equal variance, and not correlated with $\bar{X}_i$ (Di Falco & Veronesi, 2013)

The final model including π into the intercept term, adding $\bar{X}$ as an additional explanatory variables with time invariant variables (Z_i) can be expressed in reduced from as follows:

$$W_{it} = \delta_t^* + \beta X_{it} + \theta\bar{X}_{it} + \sigma\,\lambda_{it} + \omega Z_i + \upsilon_{it} \quad (15)$$

Where, W_{it} is the outcome variable representing households' welfare indicators for commercialize and non-commercialize households at time period t, δ_t^* is intercept coefficient which is equal to ($\delta_t + \pi$), X_{it} represents observed vectors of covariates for commercialized and non-commercialized households, respectively, at time period t, the vectors of parameters are $\beta, \theta, \sigma, \omega$, $\bar{X}$ is the averages value of fish yield, Z_i is a vector of time invariant explanatory variables, λ_{it} is the inverse mills ratio, and υ_{it} is the error term which is equal to ($\gamma_i + e_{it}$) and are normally distributed with zero mean and constant variance.

Step 2: Counterfactual analysis for treatment effects

Using the above framework, this section formulates a counterfactual analysis to estimate the expected welfare outcomes for commercialized and non-commercialized households, respectively. Following Di Falco and Veronesi (2013) and Di Falco et al. (2011), the average treatment effect on the treated (ATT) and untreated (ATU) group are estimated by comparing the expected values of the outcome between commercialized and non-commercialized households in actual and counterfactual scenarios as follows:

Commercialized household with commercialization (actual scenario):

$$E(W_{1i}|C_i = 1; X) = \beta_1 X_{1i} + \sigma_{\varepsilon_1\eta}\,\lambda_{1i} \quad (16_a)$$

Non-commercialized household without commercialization (actual scenario):

$$E(W_{0i}|C_i = 0; X) = \beta_0 X_{0i} + \sigma_{\varepsilon_0\eta}\,\lambda_{0i} \qquad (16_b)$$

Commercialized household had they decided not to commercialization (counterfactual):

$$E(W_{0i}|C_i = 1; X) = \beta_0 X_{1i} + \sigma_{\varepsilon_{01}\eta}\,\lambda_{1i} \qquad (16_c)$$

Non-commercialized household had they decided to commercialization (counterfactual):

$$E(W_{1i}|C_i = 0; X) = \beta_1 X_{0i} + \sigma_{\varepsilon_1\eta}\,\lambda_{0i} \qquad (16_d)$$

For commercialized and non-commercialized household, equation (16_a) and (16_b) present the actual expected values of the outcome variables observed in the sample while equation (16_c) and (16_d) provide the expected values of the outcome variables in counterfactual scenario. Using the conditional expectations mentioned above, the average welfare outcome is computed by calculating the outcome difference between commercialized and non-commercialized household as follows:

The effect of commercialization on households who commercialize: The average treatment effect on the treated (ATT), which is the difference between equation (16_a) and (16_c):

$$ATT = E(W_{1i}|C_i = 1; X) - E(W_{0i}|C_i = 1; X) = (\beta_1 - \beta_0)X_{1i} + (\sigma_{\varepsilon_1\eta} - \sigma_{\varepsilon_{01}\eta})\,\lambda_{1i} \qquad (17)$$

The effect of commercialization on households who do not commercialize: The average treatment effect on the untreated (ATU) is the difference between equation (16_d) and (16_b):

$$ATU = E(W_{1i}|C_i = 0; X) - E(W_{0i}|C_i = 0; X) = (\beta_1 - \beta_0)X_{0i} + (\sigma_{\varepsilon_1\eta} - \sigma_{\varepsilon_{01}\eta})\,\lambda_{0i} \qquad (18)$$

4.4.2 Choice of Outcome Variables for the Model

Commercialization

Commercialization is measured at the household level in terms of percentage value of total marketed output of a product to total production (Mather, Boughton, & Jayne, 2013; Otieno et al., 2009; Omiti et al., 2009; Jaleta, Gebremedhin, & Hoekstra, 2009; Braun & Kennedy, 1994). However, there is always some amount of output that even a subsistence farmer would sell. Therefore, to incorporate this subsistence situation, marketed output beyond a certain minimum threshold needs to be classified to capture the actual level of commercialization among smallholder farmers (Abafita et al., 2016). However, most of the previous literature has defined household as subsistence or non-commercial, if they do not participate in the market by selling their output (Abera, 2009); Musah, Bonsu, & Seini, 2014; Asuming-Brempong et al., 2013). However, Doppler (1991) and Rutheberg (1971) have used a threshold of 10 and 25 percent for tropical areas to identify the farmers who are subsistence producers. According to Gebreselassie and Sharp (2007), farmers who sell at least 50 percent of their product can be considered as commercialize. Therefore, this paper uses three different thresholds (i.e., 10, 25 and 50 percent) in the empirical model to identify the level of subsistence production and to classify marketed output beyond a certain minimum threshold.

Household welfare indicators

Most of the studies have used measures of consumption or income as proxy of household welfare (Deaton & Zaidi, 2002; Balisacan, Pernia, & Asra, 2003; Anand & Harris, 1994). However, for measuring household welfare, clear consensus exists relying on consumption over income in developing country where income is underestimated (Moratti & Natali, 2012; Korinek, Mistiaen, & Ravallion, 2006). Moreover, many households in developing countries try to diversify their income sources to reduce risks associated with production (i.e., price shock, crop diseases, flood, unpredictable rainfall, and other weather related events) and to smooth household consumption (Ellis, 2000; Reardon, Delgado, & Matlon, 1992). Besides, less opportunity to engage in multiple income sources might have serious welfare impact on smallholder farmers especially for those living in rural areas where availability of different income sources is limited (Ijaiya et al., 2009). Therefore, this study uses three welfare indicators, i.e. household income, poverty status and income diversification.

For calculating household income, net household income is considered in nominal term, which includes income from all available sources such as crops, livestock, wage and salaries, business, remittances, pension and social benefits in the calculation process.

Moreover, household expenditure is used to calculate the economic position of a household and identifies a household's poverty status. The poverty line threshold applied in this essay is jointly used by the Bangladesh Bureau of Statistics (BBS) and World Bank, and considered as the 'official methodology' to determine the incidence of poverty (BBS, 2011, p. 181). The estimates are based on the cost of basic needs (CBN) approach that calculates the poverty line based on the average level of per-capita expenditure at which a household is expected to meet their basic needs (WB, 2008). Any household with per capita expenditure below the threshold is considered as poor and above as non-poor. Since the poverty line is expressed in per capita terms, household income and expenditure are also converted into per capita per month term.

Additionally, this study uses the Simpson index for calculating income diversification. Income diversification means increase the number of income sources or balance the income among different sources. This implies that total income should earn from more than one sources and no one source is dominant compared to the other sources (Joshi et al., 2004). Using the Simpson index (Hirschman, 1945; Simpson, 1949), income diversification of a farm household is measured as follows:

$$ID_i = 1 - \sum_{j=1}^{N} \left(S_{i,j}\right)^2 \quad (19)$$

Where, ID is the income diversification index, S refers to share of income sources, j is number of income sources, i is number of households, N is total number of income sources.

The second term on the right side of equation (19) is popularly known as Herfindahl-Hirschman index (HI) of concentration that is used extensively by economists (e.g. Hirschman, 1964) to measure the extent of competition among firms in an industry. In this analysis, households who have more diversified income sources have a lower Herfindahl index and therefore, have higher income diversification index, and vice-versa.

4.5 Data and Descriptive Statistics

4.5.1 Data

This study is based on two-period (round) panel data collected from households who engaged in homestead pond aquaculture in Bangladesh. The first round of data was collection in year 2011 while the second round was in year 2016. A total of 518 households were surveyed in both the rounds while 494 were successfully resurveyed in second round in 2016 with an attrition rate of less than 5 percent.[21]

In first round, the data was collected from the survey of the ‘Economics of the Homestead Pond Aquaculture System’ under the United States Agency for International Development (USAID)-funded Cereal Systems Initiative for South Asia in Bangladesh (CSISA-BD) project implemented by WorldFish, Bangladesh in 2011. The second round was conducted jointly by University of Hannover, Germany and WorldFish, Penang, Malaysia in 2016 through a

[21] Attrition in 2016 household surveys occurs due to, (1) inability to locate the baseline dwelling for insufficient information about the location (18 households), (2) death of household head and therefore, split of the original family (2 households), and (3) migration of household (4 households).

household survey titled as 'Fish Production, Consumption and Nutrition Linkages in Bangladesh'.

A purposive random sampling technique was used in the WorldFish survey 2011 following a multi-stage process to select the households who are practicing different aquaculture technologies in Bangladesh. The households were located in twenty districts, i.e. sixteen districts in six aquaculture hubs[22] and four districts outside the hubs. Using a process of rapid appraisal with local key informants, the main aquaculture technologies practiced in each hub were identified. In this way, 14 aquaculture technologies have been identified that have been practiced so far in Bangladesh. Later on, the key informant interviews were conducted to identify villages with high concentrations of households practicing each technology. Finally, a census was conducted in each of the villages to capture information on households practicing different aquaculture technologies, and then the sampled households were selected randomly from the list of census households (Jahan et al., 2015, p. 8).

The survey in 2011 collected information of 2678 households practicing five major aquaculture production systems containing 14 aquaculture technologies in Bangladesh. Among the production systems, homestead pond aquaculture was the only non-commercial aquaculture production system and the only system where a major proportion of the aquaculture production was used for household's consumption. Under this system, households apply two technologies, i.e., fish polyculture without, and fish polyculture with small indigenous species covering five aquaculture hubs. Thus, to fulfill the objective of this study, households practicing homestead pond-based aquaculture production system were selected from the CSISA-BD project that comprises 518 households, and resurveyed independently in 2016 through a household survey to collect necessary information.

A structured household survey questionnaire was used to generate information on various aspects including household characteristics, income sources, expenditures, asset endowments, aquaculture production and practices. Finally, this study used 932 observations of balanced panel data drawn from 466 households.[23]

[22] Aquaculture hubs are the aquaculture clusters in Bangladesh that consist of groups of districts with similar agroecology. The main technologies practised in each hub were identified through a process of rapid appraisal with local key informants.

[23] Due to lack of sufficient information in the production module, information of 28 households from 2011 survey cannot be used in the estimation process.

4.5.2 Descriptive Statistics

Extent of commercialization among the homestead fish farmers in Bangladesh

The survey data indicates that household marketed on average one forth (i.e., 23 percent) of their total produced fish, which indicates a low level of commercialization among the homestead fish farmers in Bangladesh (Table 4.2). From 2011 to 2016, total output sold in the fish farming households increased by 7 percentage points (i.e., 28 percent increase). This increase is mainly driven by the households who sold above 50 percent of their product. Moreover, movement to a higher production level is observed among the sample households who are producing at the subsistence level (i.e. consumed 100% of their production) and who were selling below 25 percent of their produced fish. Additionally, a highly commercialized group was observed to be operated in 2016 capturing 5 percent of the total sample. If we consider a farmer who marketed above 25 percent of his output as commercially-oriented (Rutheberg, 1971), then 39 percent of the sample could be classified. In general, these data indicate that although the level of commercialization in the study areas is low, there is a progressive shift of production at the household level from home-consumption to sales in accessible markets.

Table 4.2: Level of commercialization among the homestead fish farmers

Level of commercialization	Number of households (%)				Output sold (%)			
	Total	2011	2016	Change	Total	2011	2016	Change
No sell	47.64	51.50	43.78	-7.72	0	0	0	0
Up to 10 %	6.44	8.58	4.29	-4.29	8.96	9.90	7.08	-2.82
11-25%	7.30	7.51	7.08	-0.43	18.84	19.23	18.42	-0.81
26-50%	18.67	14.38	22.96	8.58	38.61	40.33	37.53	-2.8
51-75%	14.70	11.37	18.03	6.66	62.88	61.93	64.39	2.46
Above 75%	5.26	-	10.52	-	85.90	-	85.90	-
Total	100	100	100	0	22.92	19.26	26.58	7.32

Source: Own calculation based on household survey 2011 and 2016.

Despite the relatively low level of commercialization among the homestead fish farmers in Bangladesh, the volume produced by households had increased (Table 4.3). From 2011 to 2016, the total production of fish among the homestead farmers had witnessed a 150 percent increase. It has been observed that both production and sale of fish had increased over the last 5 years. However, the volume traded among the households who sold below 50 percent of their produced fish had fallen while it had increased in the upper level who sold above 50 percent of their produced fish (Table 4.2). This implies that farmers in the subsistence and low commercialization level considered this increase in home consumption. Table 4.3 justifies this by showing that home consumption had increased in those households who sell below 50 percent of their product while it had decreased in the households who sell above 50 percent of their product. This implies that when production increases, consumption at the households who produce at the subsistence and low commercialization level increases more than the marketed output. This type of relationship between marketed output and consumed product is not unusual in a farming system dominated by poor smallholders (Gebreselassie & Sharp, 2007, p. 67).

Table 4.3: Production and consumption at different commercialization level

Level of commercialization	No of households	Production (Kg/year)			Consumption (%)		
		2011	2016	% change	2011	2016	% change
No Sell	47.64	68	101	48.53	100	100	0
1- 10 %	6.44	82	151	84.15	90.1	92.92	2.82
11-25%	7.30	142	148	4.23	80.77	81.58	0.81
26-50%	18.67	82	115	40.24	59.67	62.47	2.8
51-75%	14.70	119	282	136.97	38.07	35.61	-2.46
Above 75%	5.26	-	955	-	-	14.1	-
Total	100	86	220	155.81	80.74	73.42	-7.32

Source: Own calculation based on household survey 2011 and 2016.

The overall results from table 4.3 show that the majority of the fish farmers (i.e. 48 percent) operated at full subsistence level and consumed 100 percent of their production. Besides, 32 percent consumed more than they marketed and the remaining 20 percent consumed less than what they produce. From a policy perspective, it is important to examine what are the differences between the farmers who participate in output markets as sellers and who do not. For this, a two-way group mean comparison test was made between market participants and non-participants households. Households are defined as participants if they sell any amount of fish in the market and otherwise not.

Table 4.4 shows that about 48 percent of the households were not participating in the output markets as sellers. Household heads were found to be older both in participating and non-participating households. The average age is 50 years, and the age difference is not statistically significant. This result is unexpected, as risk-taking behavior tends to decrease, as people get older. However, considering women contributed most of the labor for pond preparation, stocking, fertilization and weeding (Castine at al., 2017), this can be true that household head requires less investment of time and energy for monitoring and harvesting. Therefore, older farmers are more likely to engage in aquaculture activities rather than other hard working job.

Table 4.4: Basic characteristics of market participants and non-participants

Basic characteristics	Non-participants	Participants	Chi^2/t-test statistics
No of households (%)	47.64	52.36	-
Age of household head (years)	48.58	48.81	-0.24
Gender (% female headed)	2.93	3.69	0.41
Education of household head (years)	5	5	0.03
Dependency ratio	0.51	0.63	-0.12***
Household size	4.9	5.2	-0.31**
Total land holding (hectare)	0.67	0.78	-0.11**
% of households having off-farm income	70	74	-3.13*
% of households having farm income	96	93	1.42
Share of farm income	0.29	0.24	0.05
Share of off-farm income	0.55	0.56	-0.01
Share of remittance income	0.08	0.06	0.02
Distance to village market (kilometer)	1.92	1.19	0.731**
Experience in aquaculture activities (years)	12	19	-7.10***
% of household received credit	0	15	4.574***
% of households experience shocks in fish pond	12	13	0.18
% of households received technical support from fisheries offices	11.94	12.50	0.07
% of households received support from NGOs	89	82	10.73***
% of households member of farmers association	23	73	236.35***

Note: ***, ** and * indicate significant at 1%, 5% and 10% level respectively.
Source: Own calculation based on household survey 2011 and 2016.

It is general thought that household's participation in farm and non-farm activities might have an impact on non-participant households' market entry decision. However, table 4.4 does not support this argument. Households' participation in farm and non-farm activities, and especially the share of farm and non-farm income in total household income are almost similar in both types of households. Keeping other factors constant, it is found that the size of land holding, distance to village market, farming experience, access to credit, support from NGOs and membership in farmers' association significantly affect the farmers' ability or willingness to participate in output markets, and turn to be very important determinants of household market participation decision to commercialize. However, the above explanation is from the simple descriptive analysis. The true assessment to determine the market participation decision to commercialization requires controlling for household, farm and location characteristics along with addressing the potential endogeneity of aquaculture income. The next part explains the variables requires doing this assessment using the econometric analysis.

Definition of the variables used in the econometric analysis

Table 4.5 describes the variables used in the econometric analysis. The total household income is calculated from seven different sources, such as: crop production, livestock & poultry, aquaculture activities, self-employment activities, wage earning, pension & salary, and remittances. The Simpson index used in the analysis is constrained to lie between zero and one. A value of zero indicates that household's income is completely specialized in one source, while a value towards one implies that the income sources are highly diversified.

This study uses household total land holding and livestock are used as an indicator of household wealth.[24] The total landholding refers to the area of land under possession by a household. It includes all types of operating land for the purpose of farming, fishery and habitation. The variable livestock was defined as a dummy based on household ownership of livestock. The variable off-farm income was defined as the income generated from non-farm self-employment activities, wage-paying activities and other services. The dependency ratio shows the ratio of economically inactive compared to economically active members in a household. It was calculated as the ratio of number of dependents (aged zero to 14 and over the age of 65) to total household member aged 15 to 64. The variable experience of shocks in the pond was defined as a dummy if the household experience any kind of shocks during aquaculture production relate to production shocks as: flood, stolen of fish, fish disease etc. Additionally, the distance to village market was used as a proxy of transactions costs in this analysis, which was measured in kilometer based on the distance from household to the point of sale.

[24] The data from 2011 does not contain information of household asset. Therefore, the asset information from 2016 cannot be used during the estimation process.

Table 4.5: Definition of variables used in regression analysis

Name of Variables	Description of the variables
Dependent variables	
Total income per capita (in Taka)	Household income per capita adjusted for inflation using CPI 2016 (Tk./Year)
Poverty head count rate (%)	The fraction of households whose income falls below the poverty line
Income diversification index	How diversified is household income (range between 0 and 1)
Commercialize	If the household is commercialized (yes = 1 and no = 0)
Independent variables	
Age	Age of the household head in years
Age square	Square of household head's age
Gender	Gender of household head (female-0 and male=1)
Education	Completed years of schooling of the household head
Household size	Total number of family members
Dependency ratio	The total household members below 15 and above 65 divided by the total household member aged 15 to 64
Total land holding	Area of land under possession by a household in hectare
Have farm income (yes=1)	If the household has income from sale of crop, livestock, and farm related goods (yes = 1 and no = 0)
Have off-farm income (yes=1)	If the household has income from non-farm self-employment activities, wage paying activities and other services (yes = 1 and no = 0)
Have livestock? (yes=1)	If the household has livestock (yes = 1 and no = 0)
Experience shock in pond (yes=1)	If the household experience any kind of shocks relate to production in the pond. (yes = 1 and no = 0)
Aquaculture experience (years)	Experience in homestead aquaculture production of the household head in years
Fish Yield	Total fish production (kg/year)
Distance to market (km)	Distance from household to nearest village market in kilometer
Credit access (yes=1)	If the household receive credit for fish production (yes = 1 and no = 0)
Received support from fisheries officers (yes=1)	Received any kind of support relate to fish production from fisheries officers (yes = 1 and no = 0)
Received support from NGOs (yes=1)	Received support from NGOs relate to fish production (yes = 1 and no = 0)
Member of farmers association (yes=1)	If the household is a member of any fish farmers association (yes = 1 and no = 0)
Fish price	Weighted average market price of fish by species and by year in taka per kilogram (at district level)
Regional dummy (yes=1)	If the household belongs to a particular aquaculture clusters (yes = 1 and no = 0)

Source: Own calculation based on household survey 2011 and 2016.

Table 4.6 presents the descriptive statistics of variables used in the two-step estimation procedure. About 33 percent of the surveyed households were commercialized and have participated in market to sell fish in 2011, which increases to 45 percent in 2016. The per capita income of homestead fish farmers increased in between 2011 and 2016 although household who did not commercialize have the lower per capita income in comparison to the commercialize households. Moreover, commercialize households had higher per capita annual income and lower poverty headcount rate compared to their non-commercialized counterparts.

Table 4.6: Descriptive statistics of the variables

Variables	Total	2011	2016	C	NC
Dependent variables					
Commercialize	0.39 (0.49)	0.33 (0.47)	0.45 (0.49)	1.00 (0.00)	0.00 (0.00)
Total income per capita (in ’000 Tk.)	27.92 (22.00)	22.50 (18.79)	33.33 (23.61)	30.24 (11.58)	26.43 (21.52)
Head count ratio	0.80 (0.40)	0.89 (0.31)	0.71 (0.45)	0.78 (0.41)	0.82 (0.39)
Diversification index	0.41 (0.19)	0.41 (0.18)	0.42 (0.20)	0.41 (0.19)	0.41 (0.19)
Independent variables					
Age of head (years)	48.70 (12.97)	47.19 (12.66)	50.21 (13.11)	49.13 (12.49)	48.73 (13.26)
Gender of head (male=1)	0.97 (0.18)	0.98 (0.15)	0.95 (0.21)	0.97 (0.19)	0.97 (0.18)
Education of head (years)	5.26 (4.83)	5.24 (5.35)	5.29 (4.26)	5.24 (4.11)	5.27 (5.25)
Household size	5.07 (1.86)	4.92 (1.73)	5.23 (1.98)	5.21 (1.87)	4.98 (1.85)
Dependency ratio	0.58 (0.54)	0.57 (0.53)	0.58 (0.56)	0.64 (0.61)	0.54 (0.50)
Total land holding (hectare)	0.72 (0.83)	0.77 (0.98)	0.67 (0.65)	0.74 (0.75)	0.71 (0.88)
Have farm income (yes=1)	0.94 (0.23)	0.99 (0.06)	0.89 (0.31)	0.92 (0.27)	0.96 (0.20)
Have off-farm income (yes=1)	0.71 (0.45)	0.60 (0.49)	0.83 (0.37)	0.74 (0.44)	0.70 (0.46)
Have livestock (yes=1)	59.12 (0.49)	0.77 (0.42)	0.41 (0.49)	0.62 (0.49)	0.55 (0.50)
Experience shocks (yes=1)	0.13 (0.34)	0.10 (0.30)	0.16 (0.37)	0.14 (0.35)	0.12 (0.32)
Experience in aquaculture (years)	13.27 (8.61)	13.80 (8.49)	12.75 (8.71)	14.53 (8.77)	11.32 (7.99)
Fish yield (Kg)	153.00 (353.29)	85.89 (59.44)	220.11 (487.17)	246.58 (544.27)	93.03 (77.89)

Credit access (yes=1)	0.15 (0.07)	0.12 (0.05)	0.18 (0.09)	0.15 (0.07)	0.00 (0.00)
Received support from NGOs (yes=1)	0.86 (0.36)	0.87 (0.34)	0.83 (0.37)	0.80 (0.40)	0.88 (0.32)
Received support from FO (yes=1)	0.12 (0.33)	0.13 (0.33)	0.12 (0.32)	0.11 (0.31)	0.13 (0.34)
Fish price (Tk./Kg)	0.33 (0.47)	91.66 (38.57)	134.92 (74.21)	115.58 (79.81)	111.82 (49.21)
Selected instruments					
Distance (Km)	1.86 (0.80)	1.86 (0.80)	1.86 (0.80)	1.77 (0.86)	1.90 (0.76)
Member of farmers association (yes=1)	0.49 (0.50)	0.54 (0.49)	0.45 (0.49)	0.90 (0.31)	0.23 (0.42)
Observations	932	466	466	568	364

Note: Standard deviation in parenthesis; regional dummies statistics are omitted for brevity; standard deviations are in parenthesis. C and NC represent commercialize and non-commercialize households, respectively using a threshold of above 25 percent sell to define commercial production system.

Source: Own calculation based on household survey 2011 and 2016.

It has been found that majority of the surveyed households were male headed and there exists less difference between the commercialize and non- commercialize households. This might indicate that female headed households have less involvement in aquaculture activities either for barriers to participate in markets as sellers or they give priority to household activities. Summary statistics further shows that total landholding by both types of household were reduced overtime. Total average land holding was higher among the commercialized households compared to non-commercialized households. The average fish production increases overtime in between 2011 and 2016. Fish production was 2.5 time higher in commercialized household than non-commercialized households. Overall, almost 50 percent of the surveyed households were found to be member of fish farmers' association and majority of the commercialized households had membership in fish farmers' association. Public support service from local government through fisheries officers seems less attractive in the survey area as majority of the fish farmers received all needed support service from the local non-government organizations (NGOs).

Table 4.7 shows the year wise differences of the selected variables between commercialized and non-commercialized households. The commercialized households are defined as those who sold above 25 percent of their produced fish in the market. The statistics show that both type of households differ significantly by their per capita income. Besides, significant difference exists in case of received support service for aquaculture production such as: support from NGOs, credit facility and support from fish farmers' association. Moreover, commercialized and non-commercialized households differ significantly by their total fish production and farming experience.

It is observed that commercialized households had almost 4 years of more experience in aquaculture production than their counterpart non-commercialize households. The average fish production was increased in between year 2011 and 2016. Within these 5 years, the commercialized households enjoyed a 3.5 times increase in total fish production compared to a 1.5 times increase of non-commercialized households. It is important to note that information sources play a crucial role for smallholder commercialization. Information and support provided by informal association of farmers and non-government organizations (NGOs) are important in this regard. It was observed that non-commercialized households rely more on the support and information provided by the NGOs while commercialized households rely more on the information form fish farmers' association. However, both group of households also received some support from formal extension through the government fisheries officers.

Table 4.7: Descriptive statistics of the variables by year and by commercialization status

Variables	2011			2016		
	NC	C	Chi^2/t-test	NC	C	Chi^2/t-test
Dependent variables						
Total income per capita (in '000 Tk.)	22.27	22.98	-0.71	31.57	35.45	-3.88*
Head count ratio	88.22	90.79	0.69	73.23	68.87	1.07
Diversification index	0.39	0.436	-0.05***	0.43	0.39	.035*
Independent variables						
Age (years)	46.92	47.73	-.80	50.28	50.12	.156
Gender (male=1)	98.09	97.37	0.25	94.88	96.23	0.48
Education of head (years)	5.24	5.22	0.02	5.31	5.24	0.07
Household size	4.86	5.03	-0.16	5.12	5.34	-0.21
Dependency ratio	0.55	0.60	-0.04	0.50	0.67	-0.16
Total land holding (hectare)	0.75	0.81	-0.06	0.64	0.68	-0.04
Have farm income (yes=1)	99.36	100.00	0.97	90.94	86.79	2.04
Have off-farm income (yes=1)	60.19	61.18	0.04	83.07	83.49	0.015
Have livestock (yes=1)	76.75	77.63	0.04	42.91	39.15	0.68

Experience shocks (yes=1)	9.87	9.87	0.00	14.57	17.45	0.720
Experience in aquaculture (years)	12.13	14.60	-2.46***	10.72	14.44	-3.71***
Fish yield (kg)	77.82	102.53	-24.70***	111.82	349.85	-238.03***
Credit access (yes=1)	0.00	0.12	3.574***	0.00	0.18	4.574***
Received support from NGOs (yes=1)	89.81	80.92	7.11***	86.22	80.19	3.05*
Fish price (Tk./Kg)	94.48	85.83	8.65**	133.25	136.91	-3.65
Distance (km)	1.92	1.71	0.21***	1.881	1.82	0.06
Received support from FO (yes=1)	9.21	14.33	-2.43	11.42	12.26	0.08
Member of farmers association (yes=1)	41.08	79.61	61.12***	1.18	96.70	426.61***
Observations	314	152	-	254	212	-

Note: C and NC represent commercialize and non-commercialize households. ***, ** and * indicate significant at 1%, 5% and 10% level respectively.
Source: Own calculation based on household survey 2011 and 2016.

Overall, the descriptive statistics from table 4.7 shows that there exist less structural differences between commercialized and non-commercialized households. However, the difference does exist in case of parameters relate to aquaculture production. The next part of this section explains the difference in farmers' production in terms of input and output parameters.

Table 4.8 presents the input and output data of production in homestead pond for commercialized and non-commercialized households. The total cost of production includes the fixed costs and the operating costs of production. The fixed costs in pond includes pond repairs, equipment, rental costs etc. while the operating costs include cost of purchasing fry and fingerlings, fertilizers, feed and cost relate to hiring labor, marketing, irrigation and water exchange.

Table 4.8: Input-output parameters by year and by commercialization status

Details	2011			2016		
	C	NC	Mean diff	C	NC	Mean diff
Pond area (in hectare)	0.07	0.05	0.02***	0.14	0.08	0.06***
	(0.003)	(0.002)	(0.004)	(0.01)	(0.01)	(0.01)
Fish yield (kg)	102.53	77.83	24.71***	449.51	111.82	337.69***
	(4.53)	(3.35)	(5.76)	(59.01)	(5.81)	(48.08)
Sold (%)	52.16	3.32	48.83***	55.25	2.65	52.59***
	(1.09)	(0.36)	(0.92)	(1.45)	(0.38)	(1.39)
Selling price (per kg)	133.25	136.91	-3.65	85.83	94.48	-8.65**
	(2.96)	(6.67)	(6.90)	(1.95)	(2.46)	(3.79)
Total cost (per kg)	63.69	67.39	-3.70	49.75	86.81	-37.06*
	(6.61)	(4.72)	(8.20)	(3.74)	(17.63)	(22.09)
Total income (Tk./year)	13924	13166	757	42048	14504	27543***
	(1824)	(2052)	(3212)	(5107)	(707)	(4729)
Net income (Tk./year)	7246	7756	-509	25675	9370	16304***
	(1013)	(1476)	(2237)	(3639)	(682)	(3406)
% of household income	6.96	6.83	-	13.58	5.73	-
Observations	152	314		212	254	

Note: C and NC represent commercialize and non-commercialize households, respectively; standard deviations are in parenthesis; ***, ** and * indicate significant at 1%, 5% and 10% level respectively.

Source: Own calculation based on household survey 2011 and 2016.

The results show that there exist significant differences in terms of costs and benefit between two groups of households. On average, commercialized farmers sold more than 50 percent of their produced fish in the market. The net income was highest for the commercialized households than their counterpart despite of the fact that they had the significantly lower (in 2016) selling prices. The production cost per kilogram was lowest for commercialized farmer, which explains that commercialized farmers are generating higher revenue with minimum production costs.

However, the above explanation is from the simple descriptive analysis. The next part explains the results from the econometric analysis.

4.6 Results from the Two-step Endogenous Switching Regression Model

A smallholder's market participation decision to sell fish and therefore, to commercialize the production process is influenced by many household, micro and macro-level factors. However, not all the homestead fish farmers take part in output markets are operating from the same macro-economic environment. Among them who do take part in the output market, the level of commercialization also varies. In this section, at first, the micro-economic determinants of household market participation decision to commercialize (or not commercialize) is identified. Using the household survey data, the relationship between household commercialization status and household level factors are established assuming the macroeconomic conditions remain constant. Later part of this section provides results from the counterfactual estimates to show how a household commercialization decision affect its welfare outcomes.

Step 1: Determinants of commercialization

The first column of appendix table A2, A3 and A4 presents the results generated from *probit* selection equation using the first stage of the binary endogenous switching regression (ESR) technique. For estimating the model, this study pooled the data based on household commercialization decision in year 2011 and 2016. The dependent variable is binary equal to one for households who are commercialized according to different threshold of 10, 25 and 50 percent. The test statistics of goodness-of-fit indicate that the selected covariates provide good estimate of the conditional density of commercialization model. The Wald test statistic (χ^2) from all three models indicates that explanatory variables are jointly statistically significant at 1 percent level.

Table 4.9, provides a list of variables from appendix table A2, A3 and A4 to identify the determinants of commercialization based on the significant variables. The results show that 'households' total land holding', 'farmer's experience in aquaculture production', 'household's membership in farmers' association' and 'distance to nearest village market' are the most important determinants of smallholder commercialization decision, which hold true for any commercialization level. The explanatory variables such as total land holding, experience in aquaculture production and members of farmers' association positively and significantly influence the farmers' decision to participate in the market to sell fish while the variable distance to village market has significant negative association with farmers' decision to participate in the market.

Table 4.9: Determinants of commercialization among homestead fish farmers

Name of variables	Model 1 (Sell > 10 %)	Model 2 (Sell >25 %)	Model 3 (Sell >50 %)
Age of head	X	0.061** (0.025)	X
Age squared	X	-0.001** (0.000)	X
Dependency ratio	X	X	-0.230** (0.112)
Total land holding (log)	0.239*** (0.064)	0.123* (0.066)	0.245*** (0.064)
Have farm income (yes=1)	-0.467** (0.217)	X	X
Have off-farm income (yes=1)	0.227* (0.127)	X	X
Experience in aquaculture (years)	0.017** (0.007)	0.025*** (0.008)	0.012* (0.008)
Credit access (yes=1)	X	0.782** (0.404)	1.520*** (0.580)
Received support from NGOs (yes=1)	X	0.238** (0.118)	0.263** (0.124)
Received support from FO (yes=1)	X	X	0.285* (0.160)
Distance to village market (log)	-0.687*** (0.205)	-0.505** (0.232)	-0.099*** (0.036)
Member of farmers' association (yes=1)	1.816*** (0.117)	2.219*** (0.142)	1.504*** (0.138)
Regional and time dummy			
Rangpur (yes=1)	0.845*** (0.179)	0.735*** (0.203)	0.669*** (0.244)
Mymensingh (yes=1)	0.735*** (0.213)	0.539** (0.227)	0.563** (0.271)
Faridpur (yes=1)	0.766*** (0.175)	0.824*** (0.194)	0.584** (0.236)
Time (year=2011)	0.594*** (0.114)	0.493*** (0.116)	0.325** (0.161)

Note: Robust standard errors are in parentheses; X represents coefficients are not significant in appendix table A 2, A 3 and A 4; Base category is jessore region; ***, ** and * indicate significant at 1%, 5% and 10% level respectively.

Source: Own calculation based on household survey 2011 and 2016.

The variable ‘total land holding’ is statistically significant and has positive influence on the decision for market participation of households. This implies that land is important for smallholder fish farmers, and as household land holding increases, the probability of decision to commercialization increases. This result is in line with Olwande and Smale (2014) and Muricho et al. (2017), who report the positive relationship between landholding and commercialization probability within the household. Moreover, the other wealth indicator, i.e., ownership of livestock is positively related to household commercialization decision, however, turns out to be insignificant in the model. Furthermore, experience in aquaculture production significantly increases the probability of farmers’ orientation towards commercialization holding other factors constant. Experienced famers know the production and marketing strategies better than less experienced farmers. The descriptive statistics in table 4.7 (see section 4.5.2) also reveal that there exists significant difference in case of farming experience between commercialized and non-commercialized households. Therefore, it is expected that the higher the farming experience, the higher will be the fish production, and the higher will be the level of commercialization. Additionally, information provided by informal association of farmers have a positive and significant effect on commercialization of homestead fish farmers in Bangladesh. Membership in farmers’ association is likely to facilitate access of information, increase the market bargaining power of smallholder and open the opportunity to enter in to lucrative markets that they could not have been able to access if they were not members (Shiferaw et al., 2008).

In addition, this study finds a significant negative association between aquaculture commercialization and the distance to nearest village market. A shorter distance from farm to market reduces the transaction cost, and thereby, increases the probability of selling more fish in the market (Muricho et al., 2017). This finding highlights the importance of market access, transactions costs and remoteness in curtailing farming households from commercializing their aquaculture product.

The other important variables for smallholder commercialization are access to credit for aquaculture production, NGOs support and support from fisheries officers. However, these variables are significant at the higher commercialization level such as households who sell above 25 and 50 percent of their produced fish in the market. Access to credit is always important for smallholder fish farmers. As credit access increases, the probability of households’ orientation towards commercialization increases (Olwande & Smale, 2014). However, it is important to explain the type of credit farmers receive for homestead production.

The fisheries sector in Bangladesh is highly influenced by informal moneylenders (i.e., arotdars and mohajans), who provide loan to fish-farmers, sometimes on condition that farmers sold fish to them only, with predetermined prices (Apu, 2014). This types of loan and credit facility is much popular among the smallholder fish farmers in Bangladesh. Additionally, information provided by both formal agricultural extensions through government fisheries officers and non-government organization (NGOs) have a positive and significant effect on commercialization of homestead fish farmers in Bangladesh. Support provided by NGOs through training and technical assistance is most important for commercialization of smallholder farmers. The descriptive statistics in table 4.6 (see section 4.5.2) also support this statement by showing that almost 90 percent of the homestead farmers have received support from the NGOs.

Moreover, it is found that extension support from fisheries offices has a significant positive association with aquaculture commercialization for households who sell above 50 percent of their fish. In the context of Bangladesh, the adoption and spread of fishing technologies for homestead farmers largely depend on the quality and effectiveness of the services provided by fisheries officers. However, in this study, less farmers are reported to have this extension services. The descriptive statistics how that only 12 percent (see table 4.6 in section 4.5.2) of the farmers have received extension supports from fisheries officers. This can be for two reasons. The first is inaccessibility of services, and second is support service from the NGOs. As majority of the fish farmers receive necessary support from NGOs, support from fisheries officers require occasionally. Moreover, for the accessibility of services, it can be said that under the current fisheries extension service system in Bangladesh, fisheries officers are charged with the dual responsibility of promoting improved fishery technologies, and identifying the defaulters of fisheries regulations (Rahman & Ahmed, 2002, p. 243). At the field level, they are also responsible for enforcing fisheries laws, providing training, and monitoring large water bodies (ibid.). Therefore, in most of the cases, it is questionable how far they can maintain these combined roles. This study finds out this shortfall. Although the role of fisheries officers is important at the grass root level for aquaculture sector development, their service seems to be unpopular among the homestead fish farmers in Bangladesh.

Moreover, farm and off-farm income are found to be important for households with low level of commercialization. The results show a significant negative association between aquaculture commercialization and farm income and a significant positive association between aquaculture commercialization and off-farm income. This implies that as farm income increases, the probability of farmers' participation in the fish market reduces. This can be, as farmers' participation in the crop market increases, they might be less efficient in the aquaculture production, and therefore, have less chance of having surplus production for sale. On the other hand, off-farm income is important for farmers for two reasons. First is to complement aquaculture income, and other is to generate sufficient income so that no need to sell fish in the market and therefore, marketed less. It is observed from table 4.4 (see section 4.5.2) that a majority share of household income comes from off-farm activities for both market participant and non-participant households. This means that the second statement is not true and non-commercial farmers are not marketing less output for having off-farm income. Therefore, the first statement can be true and off-farm income acts as a complement of aquaculture income for those households who are producing at the subsistence level.

Finally, some of the regional dummies are correlated with household commercialization decision reflecting the ecological differences among different aquaculture clusters.

The later part of appendix table A3 presents the results from the endogenous switching regression model to show the determinants of household welfare outcomes. To select the appropriate functional form for the switching model, different functional specification has been implemented such as linear–linear, log–linear and the log–log specification. Following Di Falco & Chavas (2009), the Akaike's information criteria (AIC) as well as the Bayesian information criteria (BIC) have been used to select the appropriate functional form for the econometric model of this study. For income regression, the AIC criterion shows that the linear–linear, log-linear and the log–log model have a value of 21000.07, 20988.31 and 3391.42 respectively while for the BIC criterion are 21121, 21109.24 and 3512.35 respectively. The AIC and BIC criterion both are least for the log–log model and hence, the log–log specification is chosen for the income equation.

The validity of chosen instruments is tested based on the falsification test suggested by Di Falco et al. (2011). The Wald test statistics on selection instruments (i.e., distance to village market and members of farmers association) show that the instruments are jointly statistically significant ($\chi^2 = 245.27, p = 0.00$) in the *Probit* selection equation in appendix Table A 3. However, they are jointly insignificant in three welfare equations of non-commercialized households in appendix Table A1 ($F\ stat = 0.28, p = 0.68$; $F\ stat = 0.97, p = 0.43$; $F\ stat = 0.31, p = 0.28$). This implies that selected instruments affect household commercialization decision but no longer affect the welfare outcomes of the non-commercialized farmers. This validates their use to identify the outcome equations and makes the econometric model more robust.

The results from the ESR model show that as expected, a bigger household size significantly reduces household income per capita, and increases households' probability of being poor, which is applicable for both the commercialized and non-commercialized farm households. Moreover, household landholding is positively and significantly associated with income per capita and income diversification, while negatively associated with poverty rate of non-commercialized households. This implies that land holding is important for determining the welfare of non-commercialized households.

At the household level, it is found that off-farm income and ownership of livestock are important for both commercialized and non-commercialize households. These variables have a positive and significant effects on household income per capita and income diversification however, have a negative association on poverty head count rate. This implies that households who have more off-farm income and livestock will have higher per capita income and lower poverty rate. These households will be also more diversified in terms of their income sources.

Moreover, access to credit turns to be an important indicator of household welfare for non-commercialized households who do not either participate in the market or sell a minimum amount of their harvested product. Most importantly, fish production increases the welfare of both commercialized and non-commercialized fish farmers. Moreover, mean fish yield is significant for income diversification of commercialized farmers. This indicates the presence of unobserved heterogeneity in the selected welfare outcomes. Therefore, applying Mundlak's fixed effects through mean fish yield helps us to control for the presence of unobserved factors in the ESR model.

However, the selection bias correction terms (inverse mills ratio) in all equations are not statistically significant indicating that commercialization will have the same impact on the farm households who are still non-commercialized, if they choose to be commercialized.

Step 2: Results of commercialization impacts using counterfactual estimations

Table 4.10 and table 4.11 provide the results of the counterfactual analysis and the estimated impacts of selling fish generated from the ESR model. This model not only helps to correct for self-selection bias but also controls for both observed and unobserved heterogeneity between treated and untreated groups. Table 4.10 presents the average treatment effect on the treated (ATT) household for income, poverty head count rate, and income diversification under actual and counterfactual scenarios. The comparison is made between e.g., the actual income of commercialized farmers to the counterfactual income if they were non-commercial farmers. Moreover, table 4.11 presents the average treatment effect on the untreated (ATU) households where comparison is made between e.g., the actual income of non-commercial farmers with their counterfactual income in case they were commercialized.

Table 4.10: ATT effects at different level of commercialization

Outcome variables	**Decision**		ATT= (a-c)
	(a) Actual (Commercialized)	(c) Counterfactual (Non-commercialized)	
Income per capita (log)			
Model 1 (sell above 10 %)	11.527	11.428	0.099***
	(0.037)	(0.049)	(0.032)
Model 2 (sell above 25 %)	11.522	11.296	0.226***
	(0.041)	(0.054)	(0.034)
Model 3 (sell above 50 %)	11.726	11.136	0.590***
	(0.041)	(0.055)	(0.034)
Poverty headcount rate			
Model 1 (sell above 10 %)	0.787	0.843	-0.055***
	(0.010)	(0.010)	(0.006)
Model 2 (sell above 25 %)	0.780	0.845	-0.064***
	(0.011)	(0.011)	(0.034)
Model 3 (sell above 50 %)	0.763	0.876	-0.112***
	(0.017)	(0.014)	(0.013)
Income diversification			
Model 1 (sell above 10 %)	0.418	0.419	-0.001
	(0.005)	(0.005)	(0.003)
Model 2 (sell above 25 %)	0.414	0.416	-0.001
	(0.006)	(0.006)	(0.003)
Model 3 (sell above 50 %)	0.462	0.502	-0.034
	(0.007)	(0.008)	(0.005)

Note: Standard errors are in parentheses. ***, ** and * indicate significant at 1%, 5% and 10% level respectively.
Source: Own calculation based on household survey 2011 and 2016.

Table 4.11: ATU effects at different level of commercialization

Outcome variables	**Decision**		ATU= (d-b)
	(d) Counterfactual (Commercialized)	(b) Actual (Non-commercialized)	
Income per capita (log)			
Model 1 (sell above 10 %)	11.596	11.208	0.388***
	(0.032)	(0.034)	(0.023)
Model 2 (sell above 25 %)	11.454	11.247	0.207***
	(0.030)	(0.032)	(0.023)
Model 3 (sell above 50 %)	11.452	11.262	0.190***
	(0.023)	(0.028)	(0.015)
Poverty headcount rate			
Model 1 (sell above 10 %)	0.978	0.811	-0.167***
	(0.010)	(0.007)	(0.008)
Model 2 (sell above 25 %)	0.764	0.813	-0.049***
	(0.009)	(0.006)	(0.008)
Model 3 (sell above 50 %)	0.795	0.815	-0.020***
	(0.010)	(0.008)	(0.008)
Income diversification			
Model 1 (sell above 10 %)	0.403	0.406	-0.003
	(0.004)	(0.005)	(0.003)
Model 2 (sell above 25 %)	0.416	0.410	0.006**
	(0.004)	(0.004)	(0.003)
Model 3 (sell above 50 %)	0.466	0.399	0.067**
	(0.004)	(0.004)	(0.003)

Note: Standard errors are in parentheses. ***, ** and * indicate significant at 1%, 5% and 10% level respectively.
Source: Own calculation based on household survey 2011 and 2016.

The ATT effect of income show that selling fish has positive and significant impacts on household income. Households those are commercialized would have earned less had they not commercialized. However, the fall in income varies at different commercialization level. Farm households who are in the low commercialization level (i.e., 10 percent) would have earned 10 percentage points less had they not commercialized. The fall in income is higher for households who sell above 25 and 50 percent of their fish. For them, the loss of income equal to 23 percentage points and 59 percentage points, respectively had they not commercialized. Correspondingly, the ATU effect of income shows that if the non-commercialized households choose to be commercialized, they can increase their income between 19 to 39 percentage points. It is found that non-commercialized household who are subsistence producers, and are operating at a low commercialization level can achieve higher level of income by selling additional fish. However, the income effect is lower if the households who sell half of their produced fish in the market decide to sell more than existing using their current resource endowment.

For poverty head count rate, the ATT results show that selling fish has a positive and significant impacts on poverty reduction. There will be have an increase in poverty head count rate among the commercialized households had they not commercialized. The poverty headcount rate will have increased from 5.5 percentage points to 11.2 percentage points at different commercialization level. It is found that household who sell more fish will suffer more from poverty if they do not sell fish. Similarly, the ATU effects show that if the non-commercialized households participate in the market, it will reduce their poverty rate from 4.9 to 16.7 percentage points. However, the impact of selling fish will have higher effect on the poverty head count rate of the households who are more subsistence-originated.

Moreover, the ATT results for income diversification show that participation in the fish market has no significant impact on diversification of income sources of commercialized farmers. This reflects the importance of aquaculture activities in the livelihood strategies of homestead fish farmers. Moreover, it also reveals that the commercialized households have already diversified across farm and off-farm income sources, which is reflect in the table 4.6 (see section 4.5.2). On the other hand, the ATU effects finds a positive and significant impact of commercialization on diversification of household income sources if household who are non-commercialized can sell more than 50 percent of their produced fish in the market. This will have an effect of 7 percentage point on their income diversification. However, the impact is really low (i.e., 0.6 percentage points) if non-commercialized household managed to sell only above 25 percent of their produced fish. This implies that higher level of commercialization can promote income diversification among the non-commercialized household, and therefore, have less effect on their vulnerability.

The overall results show that commercialization has a significant impact on household income and poverty both for commercialized and non-commercialize households. Across different commercialization level, the impact on income and poverty is larger for commercialized households who sell more fish, and fall under the category of higher commercialization level. However, the impact is smaller for more subsistence-oriented households who sell less of their produced fish in the market. Moreover, across different commercialization level, for non-commercialized households, the impact on income and poverty is larger for more subsistence-oriented households if they commercialize. However, the impact results do not necessarily reflect that the added income benefit of commercialization will directly translate to a welfare gain for non-commercialized households. This is because of the existence of significant difference between these two groups of households in terms of resource use, cost of production and the price they receive. Table 4.8 (see section 4.5.2) shows that the difference is significant in terms of production cost and benefit received. Commercialized farmers are generating higher revenue than their counterpart with minimum production costs and significantly lower selling prices of fish. This implies that commercialization can be an intermediate outcome on the way to welfare gains if the resource returns or efficiency of the non-commercialized households can be improved up to the level of the commercialized households.

4.7 Summary, Conclusions and Policy Implications

This study evaluates the welfare impact of commercialization on smallholder fish farmers in Bangladesh. It is examined to what extent commercialization provides additional benefits to homestead fish farmers. Using a panel household data collected from 518 homestead fish farmers, the impact of commercialization on household welfare indicators of per capita income, poverty, and the diversity of income sources using a binary endogenous switching regression model with a counterfactual analysis is being investigated.

The study findings show that the extent of commercialization among the homestead fish farmers is relatively low. Before the turn of the millennium, the majority of fish farmers operated at full subsistence level and consumed 100 percent of their produced fish. However, between 2001 and 2016, a progressive shift of production from home-consumption to sales in accessible markets could be observed.

Assessing input and output data of homestead fish produces show that commercialized households are earning more income than their counterpart non-commercialized households, in spite of lower selling prices for fish. Additionally, the total production cost was lowest for commercialized farmer, which explains that commercialized farmers are generating higher revenue with minimum production costs.

The findings also show that 'household land holding', 'farmer's experience in aquaculture production', 'household membership in farmers' association, 'distance to nearest village market', access to credit for aquaculture production, support from NGOs are the most important determinants of smallholder commercialization and output market participation decision. This suggest that credit constraint need to be relaxed for aquaculture commercialization to take place. Moreover, transaction costs are very important in determining aquaculture commercialization among homestead fish farmers in Bangladesh. Households may face different transaction costs to participate in the market if market access is not uniform (Omamo, 1998a, 1998b). Therefore, the distance variable, which reflect transaction costs, is found to be negatively related with aquaculture commercialization.

The counterfactual analysis shows that while both groups of farm households would benefit from commercialization, farm households who remain in the low-intensity, subsistence mode of production would benefit a lot from commercialization, most likely even more than those who did commercialize. Therefore, there is huge potential for income growth and poverty reduction if homestead fish producers could be convinced to go on the market.

Overall, these findings suggest that commercialization of homestead aquaculture should be encouraged not only to strengthen local economies, but also to achieve welfare gains for smallholders. However, to do so, the observed knowledge gap between commercialized and non-commercialized households needs to be minimized by sharing knowledge and transferring information of latest aquaculture production technologies to non-commercialized households.

Moreover, it is also true that addressing only the knowledge sharing alone cannot reduce the gap between commercialized and non-commercialized households. For smallholder commercialization, proper strategies are needed to improve the support services from government fisheries officers who are responsible for aquaculture sector development in Bangladesh. These strategies can be, first, creation of a separate cell to divide the dual responsibility of fisheries offices. The extension role with the intended technology adopters can be one separate cell/division while the enforcement of fisheries regulations can be another cell/division to effectively monitor and to increase the coverage of beneficiaries (i.e., fish farmers). Second, at the field level, proper training, and instruments need to be ensured for the fisheries offices as the field level officials are reported to have lack of proper training, field experience and vessels needed to monitor large water bodies (Rahman & Ahmed, 2002, p. 243). Third, proper dissemination of information at the field level, and arrangement of formal credit from the Department of Fisheries (DoF) need to be arranged for facilitating the implementation of commercialization strategies among smallholder fish farmers.

This study finding also highlight the role of aquaculture-specific umbrella organizations such as fish farmers' association in the context of Bangladesh for success of smallholder commercialization. Farmers' association can act as an efficient access point for information and communication among smallholder fish farmers. Farmers can share information among themselves regarding pooling resources to lower the production costs, gaining market access, disseminate information among the members of farmers' association regarding new technology, share problems regarding existing technology, and the way out to solve any sudden production problem associated with aquaculture (FAO, 2014). Therefore, strengthening the capacity of the fish farmers' association is an effective policy instrument to boost smallholder commercialization.

To conclude, it can be said that homestead pond aquaculture is an important income-generating enterprise for smallholder farmers who produce and sell fish. Therefore, this study finding reinforces the call for interventions to expand the capacity of smallholder homestead fish farmers in Bangladesh to produce for the market for a broader distribution of benefits (BPC, 2005; Danida, 2008; Olwande & Smale, 2014, p. 28). Increased market participation of homestead fish farmers will not only increase incomes and contribute to poverty reduction, as explained here, but will also contribute to improving household food security and nutrition through increasing home consumption of fish.

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Appendix

Table A1: Parameter estimates: Test on the validity of the selection instruments

Variables	For households that did not commercialize		
	Income per capita (log)	Probability of being poor	Income diversification
Age of head	0.049	-0.004	-0.002
	(0.043)	(0.007)	(0.003)
Age squared	-0.0004	0.00003	0.00003
	(0.0004)	(0.00001)	(0.00003)
Gender of head (male=1)	0.127	-0.032	0.026
	(0.612)	(0.099)	(0.035)
Education of head	0.009	-0.004	0.002*
	(0.012)	(0.003)	(0.001)
Household size	-0.174***	0.029***	-0.004
	(0.037)	(0.009)	(0.004)
Dependency ration	-0.180	0.095***	-0.003
	(0.136)	(0.030)	(0.015)
Total land holding (log)	0.150*	-0.087***	0.033***
	(0.082)	(0.020)	(0.009)
Have livestock (yes=1)	0.470**	-0.017	0.086***
	(0.185)	(0.034)	(0.017)
Have farm income (yes=1)	0.755**	-0.381***	0.070
	(0.298)	(0.010)	(0.048)
Have off farm income (yes=1)	0.790***	-0.170***	0.175***
	(0.218)	(0.036)	(0.018)
Experience shock in pond (yes=1)	-0.060	0.030	-0.037*
	(0.272)	(0.052)	(0.023)
Aquaculture experience (years)	0.009	0.0003	0.0002
	(0.010)	(0.002)	(0.001)
Fish price (kg)	0.005**	-0.001***	-0.0002
	(0.002)	(0.0003)	(0.0002)
Fish yield (log)	0.382**	-0.019	0.026
	(0.180)	(0.026)	(0.011)
Credit access (yes=1)	-0.278	0.126*	0.299***
	(0.238)	(0.065)	(0.031)
Received support from NGOs	0.128	0.052	0.0001
(yes=1)	(0.326)	(0.060)	(0.029)
Received support from fisheries	0.043	0.062	0.002
officers (yes=1)	(0.219)	(0.078)	(0.031)
Mundalk's fixed effect			
Mean fish yield	0.00003	-0.00005	0.00001
	(0.0001)	(0.0001)	(0.00003)
Selection instruments			
Distance to village market (log)	-0.142	0.006	-0.049
	(0.260)	(0.060)	(0.031)

Member of farmers association (yes=1)	0.098 (0.150)	-0.052 (0.040)	0.006 (0.019)
Constant	6.734*** (1.585)	1.502*** (0.264)	0.079 (0.112)
Wald test for joint significance of instruments (F stat)	0.28	0.97	0.31
Model Diagnosis			
Pseudo R^2/R^2	0.175	0.233	0.282
F (25,541)	10.12***	5.41***	9.40***
Number of observations	568	568	568

Note: Robust standard errors are in parentheses; Mundlak's fixed effects at panel level are included; Estimates for division dummy and time dummy were omitted for brevity; ***, ** and * indicate significant at 1%, 5% and 10% level, respectively.

Source: Own calculation based on household survey 2011 and 2016.

Table A 2: First stage estimates from the endogenous switching regression (Model 1-using a threshold of 10 percent)

Dependent variables	*Probit* estimates (C=1)	Household welfare outcomes					
		Income per capita (log)		Probability of being poor		Income diversification	
		C	NC	C	NC	C	NC
Age of head	0.034	-0.007	0.056	0.001	-0.004	0.003	-0.001
	(0.023)	(0.029)	(0.046)	(0.008)	(0.008)	(0.004)	(0.004)
Age squared	-0.0003	0.00001	-0.0005	-0.00006	0.00003	-0.00003	0.00001
	(0.0002)	(0.0003)	(0.0004)	(0.0001)	(0.0001)	(0.00003)	(0.00004)
Gender of head (male=1)	0.025	-0.065	0.289	-0.201**	0.024	-0.055	-0.046
	(0.271)	(0.281)	(0.744)	(0.100)	(0.118)	(0.046)	(0.043)
Education of head (years)	0.006	0.016	0.008	-0.009*	-0.003	-0.002	-0.002*
	(0.010)	(0.019)	(0.015)	(0.005)	(0.004)	(0.002)	(0.001)
Household size	-0.026	-0.164***	-0.169***	0.029**	0.036***	0.001	-0.004
	(0.028)	(0.037)	(0.043)	(0.011)	(0.010)	(0.005)	(0.004)
Dependency ratio	-0.072	-0.188**	-0.210	0.042	0.073**	0.001	-0.002
	(0.096)	(0.089)	(0.173)	(0.029)	(0.033)	(0.014)	(0.017)
Total land holding (log)	0.239***	0.093	0.215	-0.050*	-0.130***	0.015	0.031***
	(0.064)	(0.091)	(0.093)	(0.025)	(0.023)	(0.011)	(0.010)
Have farm income (yes=1)	-0.467**	-0.253	-0.610*	0.061	0.372***	0.160***	0.062
	(0.217)	(0.444)	(0.346)	(0.093)	(0.108)	(0.040)	(0.051)
Have off-farm income (yes=1)	0.227*	1.105***	0.778***	-0.204***	-0.193***	0.135***	0.176***
	(0.127)	(0.198)	(0.215)	(0.044)	(0.040)	(0.025)	(0.019)
Have livestock (yes=1)	0.042	0.134	0.431**	-0.040	-0.007	0.059***	0.096***
	(0.107)	(0.141)	(0.194)	(0.042)	(0.036)	(0.019)	(0.017)
Experience shocks (yes=1)	-0.141	-0.176	-0.099	0.053	0.017	-0.018	0.049*
	(0.157)	(0.207)	(0.307)	(0.054)	(0.059)	(0.024)	(0.024)
Experience in aquaculture (years)	0.017**	0.003	-0.015	0.0002	-0.001	-0.001	0.001
	(0.007)	(0.007)	(0.012)	(0.002)	(0.002)	(0.001)	(0.001)
Fish price (Kg)	0.001	0.001	0.005	-0.001	-0.001*	0.00004	-0.00007
	(0.001)	(0.002)	(0.004)	(0.000)	(0.001)	(0.0002)	(0.0002)

Fish yield (log)	-	0.213***	0.372**	-0.042***	-0.031	0.020***	0.026**
		(0.078)	(0.185)	(0.014)	(0.027)	(0.007)	(0.012)
Credit access (yes=1)		0.316		-0.160		0.117	
	N/A	(0.369)	N/A	(0.204)	N/A	(0.074)	N/A
Received support from NGOs	0.132	0.163*	0.230	-0.077	-0.004	0.031	-0.024
(yes=1)	(0.112)	(0.104)	(0.266)	(0.050)	(0.044)	(0.020)	(0.020)
Received support from FO	0.111	-0.009	0.040	-0.032	-0.147*	-0.049	-0.008
(yes=1)	(0.156	(0.254)	(0.245)	(0.108)	(0.082)	(0.039)	(0.034)
Regional and time dummy							
Rangpur (yes=1)	0.845***	-0.315	-0.250	0.221**	0.201***	-0.017	-0.030
	(0.179)	(0.227)	(0.287)	(0.092)	(0.061)	(0.038)	(0.024)
Dinajpur (yes=1)	-0.378	-0.118	-0.080	-0.074	0.020	-0.147***	-0.074*
	(0.249)	(0.434)	(0.287)	(0.146)	(0.083)	(0.053)	(0.041)
Mymensingh (yes=1)	0.735***	-0.621*	-0.205	0.174	0.060	-0.062	-0.022
	(0.213)	(0.341)	(0.206)	(0.128)	(0.092)	(0.048)	(0.040)
Barisal (yes=1)	0.126	-0.274	-0.589	0.117	0.111	-0.061	-0.093**
	(0.371)	(0.286)	(0.491)	(0.111)	(0.100)	(0.046)	(0.045)
Faridpur (yes=1)	0.766***	-0.249	-0.186	0.096	0.113	-0.014	-0.066**
	(0.175)	(0.240)	(0.369)	(0.105)	(0.071)	(0.040)	(0.027)
Time (year=2011)	0.493***	-0.083	-0.764**	-0.145***	-0.021	-0.012	0.028
	(0.116)	(0.211)	(0.326)	(0.052)	(0.047)	(0.022)	(0.019)
Selection instruments							
Distance to village market (log)	-0.687***						
	(0.205)	-	-	-	-	-	-
Member of farmers' association	1.816***						
(yes=1)	(0.117)	-	-	-	-	-	-
Wald test on instruments (χ^2)	244.37***	-	-	-	-	-	-
Mundalk's fixed effect							
Mean fish yield	-	0.0002	-0.00001	-0.0001	0.00006	0.0001**	-0.00002
		(0.0001)	(0.0004)	(0.0001)	(0.0001)	(0.00002)	(0.0001)

Inverse mills ratio	-	-0.148	0.060	0.042	0.055	0.002	0.001
		(0.163)	(0.259)	(0.039)	(0.061)	(0.019)	(0.024)
Constant	-2.035***	9.896***	7.599***	1.087***	0.682**	0.080	0.188
	(0.708)	(1.221)	(1.897)	(0.267)	(0.300)	(0.124)	(0.133)
Model diagnosis							
Log pseudo likelihood	-405.77	-	-	-	-	-	-
Wald chi^2 (25)	311.68***	201.70***	187.24	132.45***	134.33***	195.44***	256.79
Prob > chi^2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R^2/ Pseudo R^2	0.365	0.289	0.185	0.248	0.240	0.299	0.301
Number of observations	932	428	504	428	504	428	504

Note: For probit, robust standard errors are in parentheses; Base category is jessore region; ***, ** and * indicate significant at 1%, 5% and 10% level, respectively. N/A is to define the variable dropped during the estimation process. For outcome variables, bootstrapped standard errors (1000 replications) in parenthesis; Fixed effects at panel level are included; C and NC represent commercialized and non-commercialized households, respectively.

Source: Own calculation based on household survey 2011 and 2016.

Table A 3: First stage estimates from the endogenous switching regression (Model 2-using a threshold of 25 percent)

Dependent variables	*Probit* estimates (C=1)	Household welfare outcomes					
		Income per capita (log)		Probability of being poor		Income diversification	
		C	NC	C	NC	C	NC
Age of head	0.061**	0.015	0.041	-0.003	-0.002	0.006	-0.002
	(0.025)	(0.035)	(0.041)	(0.009)	(0.007)	(0.004)	(0.003)
Age squared	-0.001**	-0.0002	-0.0004	0.00003	0.00001	-0.00005	0.000
	(0.000)	(0.0004)	(0.0004)	(0.0001)	(0.0001)	(0.00004)	(0.000)
Gender of head (male=1)	0.268	0.081	0.120	-0.174	-0.026	-0.066	-0.034
	(0.227)	(0.321)	(0.620)	(0.122)	(0.106)	(0.057)	(0.036)
Education of head (years)	0.013	0.014	0.010	-0.009*	-0.004	-0.003	-0.002
	(0.010)	(0.021)	(0.014)	(0.005)	(0.004)	(0.002)	(0.001)
Household size	-0.012	-0.152***	-0.168***	0.030**	0.032***	0.003	-0.003
	(0.029)	(0.044)	(0.034)	(0.013)	(0.010)	(0.005)	(0.004)
Dependency ratio	-0.075	-0.156*	-0.151	0.008	0.082***	-0.002	0.000
	(0.096)	(0.097)	(0.137)	(0.031)	(0.031)	(0.015)	(0.015)
Total land holding (log)	0.123*	0.066	0.237***	-0.059**	-0.117***	0.017	0.027***
	(0.066)	(0.101)	(0.076)	(0.027)	(0.021)	(0.012)	(0.010)
Have farm income (yes=1)	-0.226	-0.025	-0.791**	0.011	0.371***	0.158***	0.067
	(0.183)	(0.465)	(0.307)	(0.098)	(0.101)	(0.043)	(0.048)
Have off-farm income (yes=1)	0.055	1.074***	0.821***	-0.229***	-0.184***	0.131***	0.174***
	(0.136)	(0.185)	(0.219)	(0.049)	(0.035)	(0.025)	(0.017)
Have livestock (yes=1)	0.015	0.235*	0.426**	-0.059	0.014	0.059***	0.090***
	(0.106)	(0.142)	(0.177)	(0.048)	(0.033)	(0.021)	(0.017)
Experience shocks (yes=1)	-0.013	-0.197	-0.100	0.046	0.040	-0.018	0.038*
	(0.162)	(0.220)	(0.258)	(0.059)	(0.054)	(0.026)	(0.022)
Experience in aquaculture (years)	0.025***	-0.007	-0.008	0.0001	-0.001	-0.000008	0.000
	(0.008)	(0.007)	(0.011)	(0.003)	(0.002)	(0.001)	(0.001)
Fish price (Kg)	0.0004	0.001	0.004	-0.001	-0.001**	0.0001	-0.00003
	(0.001)	(0.003)	(0.003)	(0.001)	(0.001)	(0.0003)	(0.0002)

Fish yield (log)	-	0.222***	0.387**	-0.043***	-0.024	0.019***	0.024**
		(0.084)	(0.179)	(0.015)	(0.027)	(0.007)	(0.012)
Credit access (yes=1)	0.782**	0.620	-0.499**	-0.300	-0.180***	0.117	0.282***
	(0.404)	(0.488)	(0.235)	(0.241	(0.067)	(0.088)	(0.031)
Received support from NGOs	0.238**	0.204*	0.146	-0.114**	-0.004	0.032	-0.017
(yes=1)	(0.118)	(0.126)	(0.218)	(0.059)	(0.040)	(0.021)	(0.018)
Received support from FO	0.106	0.168	0.046	-0.052	-0.159**	-0.057	-0.001
(yes=1)	(0.178)	(0.308)	(0.216)	(0.119)	(0.072)	(0.040)	(0.030)
Regional and time dummy							
Rangpur (yes=1)	0.735***	-0.368*	-0.205	0.256***	0.203***	-0.023	-0.031
	(0.203)	(0.232)	(0.269)	(0.090)	(0.058)	(0.041)	(0.022)
Dinajpur (yes=1)	-0.244	-0.007	-0.134	0.018	0.004	-0.170***	-0.069*
	(0.278)	(0.382)	(0.279)	(0.158)	(0.075)	(0.056)	(0.038)
Mymensingh (yes=1)	0.539**	-0.748**	-0.242	0.291**	0.032	-0.090*	-0.010
	(0.227)	(0.383)	(0.168)	(0.133)	(0.078)	(0.048)	(0.035)
Barisal (yes=1)	-0.020	-0.317	-0.447	0.185*	0.073	-0.079*	-0.084**
	(0.410)	(0.277)	(0.394)	(0.109)	(0.090)	(0.048)	(0.036)
Faridpur (yes=1)	0.824***	-0.219	-0.142	0.138	0.092	-0.030	-0.064*
	(0.194)	(0.230)	(0.330)	(0.102)	(0.068)	(0.044)	(0.026)
Time (year=2011)	0.594***	0.118	-0.765***	-0.174**	-0.035	-0.019	0.031*
	(0.114)	(0.210)	(0.285)	(0.077)	(0.042)	(0.028)	(0.016)
Selection instruments							
Distance to village market (log)	-0.505** (0.232)	-	-	-	-	-	-
Member of farmers' association	2.219***	-	-	-	-	-	-
(yes=1)	(0.142)						
Wald test on instruments (χ^2)	245.27***	-	-	-	-	-	-
Mundalk's fixed effect							
Mean fish yield	-	0.0002	-0.0001	-0.0001	-0.00003	0.00005**	0.00006
		(0.0001)	(0.0003)	(0.0001)	(0.0001)	(0.00002)	(0.0001)

Inverse mills ratio	-	0.016	-0.013	-0.001	0.053	-0.001	-0.006
		(0.106)	(0.245)	(0.044)	(0.054)	(0.021)	(0.022)
Constant	-3.443***	9.044***	8.302***	1.146***	0.660**	0.056	0.192*
	(0.746)	(1.343)	(1.720)	(0.298)	(0.273)	(0.133)	(0.120)
Model diagnosis							
Log pseudo likelihood	-339.06	-	-	-	-	-	-
Wald chi^2 (25)	317.32***	179.72***	292.16***	131.20***	180.95***	177.36***	2863.47***
Prob > chi^2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R^2/ Pseudo R^2	0.456	0.313	0.190	0.263	0.237	0.319	0.286
Number of observations	932	364	568	364	568	364	568

Note: For probit, robust standard errors are in parentheses; Base category is jessore region; ***, ** and * significant indicate at 1%, 5% and 10% level, respectively. For outcome variables, bootstrapped standard errors (1000 replications) in parenthesis; Fixed effects at panel level are included; C and NC represent commercialized and non-commercialized households, respectively.

Source: Own calculation based on household survey 2011 and 2016.

Table A 4: First stage estimates from the endogenous switching regression (Model 3-using a threshold of 50 percent)

Dependent variables	*Probit* estimates (C=1)	Household welfare outcomes					
		Income per capita (log)		Probability of being poor		Income diversification	
		C	NC	C	NC	C	NC
Age of head	0.042	0.017	0.028	-0.014	0.0004	0.002	0.001
	(0.028)	(0.023)	(0.036)	(0.014)	(0.006)	(0.005)	(0.003)
Age squared	-0.0004	-0.0001	-0.0003	0.0001	-0.00001	-0.00002	0.00006
	(0.0003)	(0.0002)	(0.0004)	(0.0001)	(0.0001)	(0.0001)	(0.00003)
Gender of head (male=1)	0.269	0.172	0.025	-0.107	-0.072	-0.045	-0.051
	(0.309)	(0.665)	(0.464)	(0.277)	(0.078)	(0.080)	(0.035)
Education of head (years)	0.012	0.023	0.007	-0.005	-0.005	0.001	-0.003**
	(0.010)	(0.017)	(0.013)	(0.008)	(0.003)	(0.003)	(0.001)
Household size	0.037	-0.085**	-0.189***	0.027	0.029***	0.002	-0.001
	(0.031)	(0.034)	(0.036)	(0.021)	(0.008)	(0.007)	(0.004)
Dependency ratio	-0.230**	-0.064	-0.214**	0.035	0.058**	0.005	-0.007
	(0.112)	(0.085)	(0.112)	(0.044)	(0.024)	(0.022)	(0.013)
Total land holding (log)	0.245***	0.167*	0.155**	-0.040	-0.099	0.023	0.024***
	(0.064)	(0.089)	(0.070)	(0.056)	(0.019)	(0.020)	(0.009)
Have farm income (yes=1)	-0.249	-0.429	-0.446	-0.023	0.286***	0.133**	0.114***
	(0.266)	(0.304)	(0.337)	(0.185)	(0.083)	(0.061)	(0.035)
Have off-farm income (yes=1)	0.115	0.767***	0.952***	-0.282***	-0.178***	0.130***	0.164***
	(0.136)	(0.137)	(0.194)	(0.071)	(0.033)	(0.035	(0.016)
Have livestock (yes=1)	0.034	0.023	0.220	0.025	-0.011	0.030	0.087***
	(0.120)	(0.140)	(0.156)	(0.077)	(0.030)	(0.029)	(0.014)
Experience shocks (yes=1)	-0.102	-0.029	-0.251	0.090	0.022	-0.049	0.032*
	(0.151)	(0.145)	(0.237)	(0.090)	(0.044)	(0.038)	(0.019)
Experience in aquaculture (years)	0.012*	-0.010	-0.008	0.0001	-0.001	0.0003	0.0002
	(0.008)	(0.008)	(0.009)	(0.005)	(0.002)	(0.002)	(0.001)
Fish price (Kg)	-0.003	0.003	0.002	-0.001	-0.001**	0.0004	-0.00006
	(0.003)	(0.002)	(0.002)	(0.002)	(0.000)	(0.001)	(0.0001)

Fish yield (log)	-	0.152*	0.240***	-0.110**	-0.036***	0.036*	0.019***
		(0.086)	(0.086)	(0.053)	(0.014)	(0.019)	(0.007)
Credit access (yes=1)	1.520***	0.311	0.641***	-0.380	0.229***	0.059	0.296***
	(0.580)	(0.407)	(0.171)	(0.305)	(0.057)	(0.095)	(0.027)
Received support from NGOs	0.263**	0.219*	0.013	0.148**	0.005	0.026	-0.003
(yes=1)	(0.124)	(0.110)	(0.174)	(0.069)	(0.034)	(0.024)	(0.016)
Received support from FO	0.285*	0.176	-0.041	-0.088	-0.104	-0.040	-0.017
(yes=1)	(0.160)	(0.329)	(0.193)	(0.182)	(0.068)	(0.054)	(0.028)
Regional and time dummy							
Rangpur (yes=1)	0.669***	-0.343	-0.214	0.390**	0.181***	-0.037	-0.031
	(0.244)	(0.270)	(0.227)	(0.167)	(0.048)	(0.070)	(0.021)
Dinajpur (yes=1)	-0.344	-0.480	-0.066	0.204	-0.028	-0.135	-0.095***
	(0.303)	(0.464)	(0.278)	(0.284)	(0.074)	(0.088)	(0.035)
Mymensingh (yes=1)	0.563**	-0.538	-0.490**	0.301	0.088	-0.121	-0.018
	(0.271)	(0.459)	(0.206)	(0.250)	(0.073)	(0.082)	(0.032)
Barisal (yes=1)	-0.383	-0.241	-0.254	0.340*	0.069	-0.136*	-0.070**
	(0.458)	(0.321)	(0.336)	(0.199)	(0.079)	(0.081)	(0.031)
Faridpur (yes=1)	0.584**	-0.432	-0.057	0.293	0.078	-0.051	-0.056*
	(0.236)	(0.299)	(0.260)	(0.188)	(0.060	(0.077)	(0.023)
Time (year=2011)	0.325**	-0.106	-0.388**	-0.042	-0.091***	-0.061	0.017
	(0.161)	(0.208)	(0.191)	(0.144)	(0.034)	(0.058)	(0.014)
Selection instruments							
Distance to village market (log)	-0.099***	-	-	-	-	-	-
	(0.036)						
Member of farmers' association	1.504***	-	-	-	-	-	-
(yes=1)	(0.138)						
Wald test on instruments (χ^2)	120.63***						
Mundalk's fixed effect							
Mean fish yield	-	0.0003	0.0001	-0.00003	-0.00004	0.00002	0.00006
		(0.0002)	(0.0002)	(0.0001)	(0.0001)	(0.00004)	(0.0005)

Inverse mills ratio	-	-0.022	-0.402**	-0.079	0.098*	-0.033	0.049*
		(0.157)	(0.186)	(0.096)	(0.062)	(0.045)	(0.028)
Constant	-3.521***	10.003***	8.896***	1.708***	0.809***	0.131	0.154*
	(0.887)	(1.010)	(1.372)	(0.586)	(0.216)	(0.213)	(0.095)
Model diagnosis							
Log pseudo likelihood	-339.201	-	-	-	-	-	-
Wald chi^2 (25)	184.87***	137.52***	373.38***	81.33***	248.88***	81.42***	3796.21***
Prob > chi^2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R^2/ Pseudo R^2	0.272	0.429	0.185	0.313	0.224	0.323	0.280
Number of observations	932	186	746	186	746	186	746

Note: For probit, robust standard errors are in parentheses; Base category is jessore region; ***, ** and * indicate significant at 1%, 5% and 10% level, respectively. For outcome variables, bootstrapped standard errors (1000 replications) in parenthesis; Fixed effects at panel level are included; C and NC represent commercialized and non-commercialized households, respectively.

Source: Own calculation based on household survey 2011 and 2016.