Norwegian University of Life Sciences
Faculty of Social Science
School of Economics and Business

Philosophiae Doctor (PhD)
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Aquaculture in Bangladesh: Essays on production variability, consumer preferences and market integration

Akvakultur i Bangladesh:
Essays på produksjonsvariabilitet,
forbrukerpreferanser og markedsintegrasjon

Md Akhtarul Alam

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Dedication

To my parents and beloved family

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I praise and give thanks to Almighty Allah for his blessings upon me and for the good health of myself and my family, and for the ability to complete my PhD studies.

This thesis has been accomplished with the help and inspiration of many people.

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Md Akhtarul Alam

Ås, December 2017

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Paper 1: **Production risk and technical efficiency of tilapia aquaculture farming in Bangladesh**
Md Akhtarul Alam, Atle Guttormsen and Kristin Helen Roll

Paper 2: **Risk in aquaculture: Farmers' perceptions and risk management strategies in Bangladesh**
Md Akhtarul Alam and Atle Guttormsen
Submitted to *Aquaculture Economics and Management*

Paper 3: **Consumer preferences for fish attributes in Bangladesh: A choice experiment**
Md Akhtarul Alam and Frode Alfnes
Submitted to *Aquaculture Economics and Management*

Paper 4: **Market integration for new aquaculture species: The whitefish market in Bangladesh**
Md Akhtarul Alam

Summary

The main objective of this thesis is to increase knowledge about production, consumer and market issues related to aquaculture in Bangladesh. This is done by investigating (1) production risk and technical efficiency, (2) farmers' risk perceptions and risk management strategies, (3) consumer preferences for fish attributes and (4) market integration of aquaculture products. The thesis is based on data collected in two surveys and time series data from secondary sources. It contributes to the empirical literature on production risk, consumer preference studies and price movement of seafood products in a developing country. The thesis consists of an introductory chapter and four independent papers.

Paper 1 examines production risk and efficiency of a relatively fast-growing tilapia aquaculture industry. By employing a stochastic frontier production model with flexible risk specification, this paper quantifies production variability of tilapia fish farming by means of two main possible sources: production risk and technical inefficiency. There are significant production risks and technical inefficiencies in tilapia farming. Feed is the most important input in terms of variable cost sharing for tilapia production. Based on the estimated results, feed and fingerlings have risk-increasing effects, while capital has a risk-reducing effect. Extension services and training on management skills and technical knowledge for aquaculture production systems has reduced inefficiency. Credit has risk-reducing effects on production risk as well as reduced technical inefficiency.

Paper 2 examines Bangladeshi fish farmers' perception of risk sources, risk management strategies and the relationship with socio-demographic variables. We assess farmers' attitudes toward risk and their risk management strategies. The results reveal that the most important perceived sources of risk were fish diseases, fish price variability, low quality of feed and fingerlings, floods and credit constraints. The most important strategies to mitigate risks were the supply of good quality feed and fingerlings, disease prevention, crop insurance, increasing personal savings, and assurance of bank loans. The findings also show that farmers are engaged in multiple management strategies to reduce losses from aquaculture, and that socio-demographic variables have a significant effect on farmers' perceptions of risk sources and risk management strategies.

Paper 3 examines Bangladeshi consumer preferences regarding wild-caught and farm-raised fish. A choice experiment was conducted at the consumer level in three cities, and the data were analyzed with a mixed logit model in willingness-to-pay (WTP) space. The results

showed that on average, consumers were willing to pay more for indigenous fish than foreign fish species. Furthermore, they preferred domestic production to imported fish, and fresh to frozen fish. However, Bangladeshi consumers were not willing to pay a significant premium for wild-caught fish. The lack of consumer differentiation in regard to the production method is promising for aquaculture in this region and provides hope for reducing the pressure on wild fisheries.

Paper 4 investigates market integration between regional markets in Bangladesh and between traditional carps and the non-indigenous farmed species pangasius and tilapia. The results indicate that the species are partially integrated on the regional markets and that there is no price leader among the species in the market. Furthermore, the integration test between regional markets show that the regional markets for rohu, pangasius, tilapia and silver carp are fully integrated. This implies that all prices follow the same stochastic trend in the regional markets. There is no market leader among the regional markets, which indicates that markets have their own power to transmit price information.

Based on the findings, in the thesis I will argue that aquaculture has a potential to increase fish supply in Bangladesh. This increase largely depends on increasing production, reducing production risk, consumer acceptance and the number of new market segments for fish products. Fish production can be increased by reducing production risk and technical inefficiency. Management strategies related to supply of quality inputs, disease prevention and available credit can help to mitigate risk. In terms of consumers' preferences, domestic production and indigenous species have potential to increase fish supply. The performance of markets has increased in terms of market linkage. The government policy should focus on increasing the supply of quality inputs, improving extension services and training, supplying credit for small-scale farmers with less collateral and low interest rates and designing efficient marketing strategies.

Sammendrag

Hovedformålet med denne oppgaven er å øke kunnskapen om produksjon, forbruker- og markedsspørsmål knyttet til akvakultur i Bangladesh. Dette gjøres ved å undersøke (1) produksjonsrisiko og teknisk effektivitet, (2) bønderes risikooppfattelser og risikostyringsstrategier, (3) forbrukerpreferanser for fiskeattributter og (4) markedsintegrasjon av akvakulturprodukter. Avhandlingen er basert på data samlet i to undersøkelser og tidsseriedata fra sekundære kilder. Det bidrar til den empiriske litteraturen om produksjonsrisiko, forbrukerpreferanse og prisbevegelse av sjømatprodukter i et utviklingsland. Avhandlingen består av et innledende kapittel og fire uavhengige papirer.

Papir 1 undersøker produksjonsrisiko og effektivitet i en relativt raskt voksende tilapia akvakulturindustri. Ved å benytte en stokastisk grenseproduksjonsmodell med fleksibel risikospesifikasjon, kvantifiserer dette papir produksjonsvariabiliteten for tilapia oppdrett ved hjelp av to viktigste mulige kilder: produksjonsrisiko og teknisk ineffektivitet. Det er betydelige produksjonsrisikoer og tekniske ineffektiviteter i tilapia oppdrett. Fôr er den viktigste innsatsen når det gjelder variabel kostnadsdeling for tilapia-produksjon. På grunnlag av de estimerte resultatene har fôr og fingerlings risikoøkende effekter, mens kapital har en risikoreducerende effekt. Extensionstjenester og opplæring i ledelsesevner og teknisk kunnskap for akvakulturproduksjonssystemer har redusert ineffektivitet. Kreditt har risikoreducerende effekter på produksjonsrisiko samt redusert teknisk ineffektivitet.

Papir 2 undersøker Bangladeshs fiskebønderes oppfatning av risikokilder, risikostyringsstrategier og forholdet til sosio-demografiske variabler. Vi vurderer bøndenes holdninger til risiko og deres risikostyringsstrategier. Resultatene viser at de viktigste oppfattede risikokildene var fiskesykdommer, variasjoner i fiskpris, lav kvalitet på fôr og fingerlings, oversvømmelser og kredittbegrensninger. De viktigste strategiene for å redusere risikoen var tilførsel av fôr og fingerlings av god kvalitet, forebygging av sykdommer, avlsforsikring, økende personlige besparelser og forsikring av banklån. Resultatene viser også at bønder er engasjert i flere styringsstrategier for å redusere tap fra akvakultur, og at sosiodemografiske variabler har en betydelig effekt på bøndenes oppfatning av risikokilder og risikostyringsstrategier.

Papir 3 undersøker Bangladeshs forbrukerpreferanser angående villfanget og oppdrettsfisk. Et valgeksperiment ble utført på forbrukernivå i tre byer, og dataene ble analysert med en blandet logitmodell i WTP-plassering. Resultatene viste at forbrukerne i gjennomsnitt var villige til å betale mer for urfolk enn utenlandske fiskearter. Videre foretrukket de innenlands produksjon til importert fisk, og frisk til frossen fisk. Imidlertid var forbrukerne i Bangladesh ikke villige til å betale en betydelig premie for villfanget fisk. Mangelen på forbruksdifferensiering i forhold til produksjonsmetoden er lovende for akvakultur i denne regionen og gir håp om å redusere presset på viltfiske.

Papir 4 undersøker markedsintegrasjon mellom regionale markeder i Bangladesh og mellom tradisjonelle karper og ikke-urbefolkede oppdrettsarter pangasius og tilapia. Resultatene indikerer at arten er delvis integrert på de regionale markedene, og at det ikke er prisleder blant artene i markedet. Videre viser integrasjonstesten mellom regionale markeder at de regionale markedene for rohu, pangasius, tilapia og sølvkarpe er fullt integrert. Dette innebærer at alle priser følger samme stokastiske trend i de regionale markedene. Det er ingen markedsleder blant de regionale markedene, noe som tyder på at markedene har egen kraft til å overføre prisinformasjon.

Basert på funnene, i oppgaven vil jeg argumentere for at akvakultur har potensial til å øke fiskeforsyningen i Bangladesh. Økningen skyldes i stor grad økt produksjon, redusert produksjonsrisiko, forbrukernes aksept og antall nye markedssegmenter for fiskeprodukter. Fiskproduksjonen kan økes ved å redusere produksjonsrisiko og teknisk ineffektivitet. Administrasjonsstrategier knyttet til levering av kvalitetsinnspill, sykdomsforebygging og tilgjengelig kreditt kan bidra til å redusere risikoen. Når det gjelder forbrukernes preferanser, har innenlandsk produksjon og urbefolkning potensial til å øke fiskeforsyningen. Markedsutviklingen har økt med tanke på markedssammenheng. Regjeringens politikk bør fokusere på å øke tilbudet av kvalitetsinnspill, forbedre utvidetjenester og trening, gi kreditt til småbønder med mindre sikkerhet og lave renter og utforme effektive markedsføringsstrategier.

Part I: Introduction

1. Background

During the last few decades, world fish production has steadily increased at an average annual rate of 3.2% (FAO 2016). The global fish supply has increased from 60 million tons in 1970 to 167.2 million tons in 2014, and the per capita fish supply has reached 20 kg (FAO 2016) . Besides food supply, the fisheries and aquaculture sector plays an important role in food security, generating income and providing livelihoods to 10–12% of the world's population (Smith et al. 2010). Around 56.6 million people are directly involved in this sector for their livelihoods. In addition, fish contributes 20% of average per capita animal protein to more than 3.1 billion people across the world (FAO 2016). Aquaculture is a relatively new sector in global food production. It accounts for about 50% of the world's fish food (Bostock et al. 2010). Asia is the leading contributor for aquaculture, and it accounts for 89% of global production, with China, Indonesia, India, Vietnam, the Philippines and Bangladesh currently ranked as the top six (FAO 2016). The average annual growth rate was relatively faster in Asia, at 8.2% (excluding China) compared to a global rate of 6.2% from 2000–2012.

Seafood[1] has been a dynamic and fast-growing sector in Bangladesh (Belton et al. 2011). It contributes 3.65% to the national GDP, 23.81% to agriculture GDP and 2.01% to the foreign exchange earnings (BBS 2016). In Bangladesh, fish is a common element of the diet and a major source of animal protein, and it contributes 60% of animal protein with 18.06 kg average per capita consumption (HIES 2010). In 2016, the total fish production was 3.87 million tons, from a level of 0.75 million tons in 1963, and there is an average growth rate of 6.7% (DoF 2016). In addition to food supply, the fisheries sector significantly contributes to the livelihoods of rural Bangladesh. In the floodplain area, 73% of rural households are dependent on aquaculture for their livelihoods (Mazid 1999). According to Planning Commission Poverty Reduction Strategy papers, fisheries are identified as the most promising activity to generate income for rural households (Commission 2005; DoF 2006).

In Bangladesh, the fisheries sector can be divided into three subsectors; inland capture, inland culture and marine, correspondingly contributing 27%, 57% and 16% of total fish production respectively (DoF 2016). The domestic demand for fish has increased with the rising population. However, capture fisheries were considered as limited resources, and new sources of production were explored (Davidson et al. 2012). The increase in aquaculture production is

[1] Seafood includes harvested fish and shellfish from freshwater and marine capture and aquaculture.

the reason for the continuing increase of seafood supply since 1990. Aquaculture is now becoming the dominant source of fish production in Bangladesh.

Aquaculture in Bangladesh comprises freshwater as well as brackish water aquaculture. Freshwater aquaculture has significant contributions for domestic consumption, whereas brackish water aquaculture contributes to foreign exchange earnings. During the last few decades, the share of aquaculture production has expanded rapidly, whereas the share from marine and capture fisheries has been declining (Figure 1).

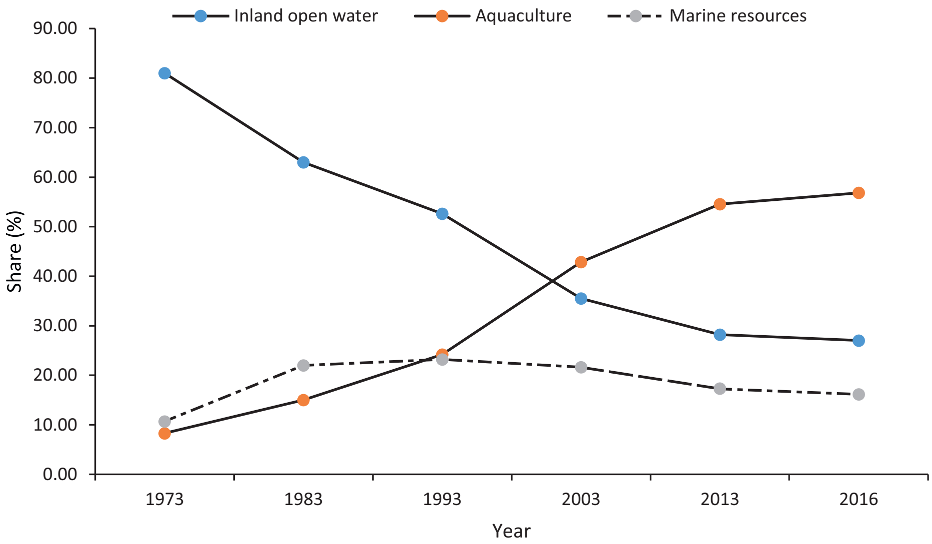

Figure 1. Percentage of fish production from different sources. Source: (Ali et al. 2010; DoF 2016)

Freshwater aquaculture includes pond culture, seasonal culture in farmland, cage culture and pen culture. Furthermore, pond aquaculture is a major source of aquaculture production. It contributes 44% to the country's total fish production, and 78% of its total aquaculture production (DoF 2016). This study is mainly focused on freshwater aquaculture, and particularly pond aquaculture.

The area for pond aquaculture expanded from 125,000 hectares in 1985 to 372,000 hectares in 2016 (DoF 2016). Most of the expansion came from the conversion of rice fields, because there is higher profitability in fish farming compared to rice farming (Khan 2012). During the last five years, most of the development in pond aquaculture is from increased production as well as yield, whereas the expansion of the area is almost stagnant (Figure 2). However, the average productivity in Bangladesh was much lower than in many other Asian countries (Sarker et al. 2016). Productivity can potentially be further increased by using advanced technology, high-yielding species, quality inputs, and reducing production risk and inefficiency.

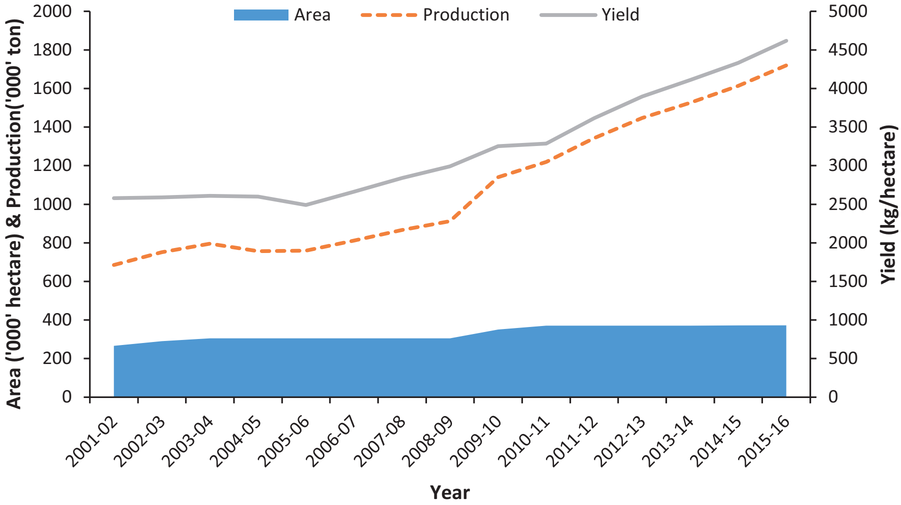

Figure 2: Pond culture area, production and yield in Bangladesh from 2001–15
Source: (DoF 2001; DoF 2003; DoF 2005; DoF 2007; DoF 2009; DoF 2011; DoF 2013; DoF 2015; DoF 2016)

Bangladesh has rich fish biodiversity with more than 250 different species of fish, and most of them are native species (Khan 2012). Recently, farmers generally practice a polyculture of rohu, catla, silvercarp and common carp in pond fish farming. Due to the low productivity of fish and the high demand for it, the production of high-yield, fast-growing species such as pangasius, tilapia and Thai koi fish has rapidly increased during the last fifteen years. This development in aquaculture can open up new opportunities in both self-employment and income generation for rural households, and also introduces a new dimension in the supply chain by increasing consumers' access to the market (Karim et al. 2006). Despite its impressive growth during the early years, aquaculture now faces challenges related to the incidence of fish diseases, quality feed and fingerlings, which causes production variability (Commission 2015). Therefore, in-depth research needs to be carried out to identify the risk factors and risk mitigation strategies for the development of this sector. In addition, it is important to understand consumer preferences, and to find competitive markets for farmed fish in order to sustain aquaculture in a developing economy.

1.1. Objective and research questions

The main objective of this thesis is to increase knowledge about economic aspects of aquaculture in Bangladesh, as well as to address production, consumer and market issues. To accomplish the main objective, I focus on production variability, risk sources and risk management strategies, consumer acceptance and market integration. The four issues are each investigated in one paper.

Research question paper 1: How does the intensity of input usages and technical inefficiency affect output variance in tilapia aquaculture production in Bangladesh?

Background for research question 1

Tilapia is rapidly becoming one of the most important aquaculture species in the world, and has a significant presence in the seafood market (Asche et al. 2009). It grows quickly and thus has a short production period, which effectively reduces capital asset problems and cost. Tilapia markets are highly segmented and diversified compared to salmon and shrimp, and tilapia has a high potential to become a globally traded species (Asche et al. 2009). Tilapia production has rapidly increased in Bangladesh. In 2016, the produced quantity was 337350 ton, a manyfold increase from only 16230 ton in 2009 (DoF 2016). Despite this impressive growth and seemingly favorable production characteristics, tilapia farming has experienced a number of constraints and production variations (Ahmed et al. 2012). A number of biophysical characteristics of the environment, such as water temperature variation and oxygen concentration, directly influence the growth of fish and increase output variation (Khan et al. 2017). Besides these biophysical factors, differences in production technologies and intensity of input usages among the farmers may augment risk further (Sarker et al. 2016). Different inputs have different effects on output risk. These risks might be higher in small-scale farming in developing countries, because farmers have less control over production compared to industrial aquaculture in developed countries. Moreover, improving farm-level technical efficiency is important in resource-scarce countries like Bangladesh.

The technical inefficiency relates to the technological knowledge and socio-economic characteristics of the farms and farmers, which may also cause output variability. Therefore, it is important to take into account the effects of input usages on output variance when estimating production risk and technical efficiency simultaneously. However, to the best of our knowledge, there are no farm-level studies that address both production risk and technical inefficiency for tilapia farming. There is therefore a need for studies of the combined effects of production risk and technical inefficiency in tilapia farming.

Research question paper 2: What do Bangladeshi fish farmers perceive as sources of risk in aquaculture and what are the corresponding management strategies to mitigate this risk?

Background for research question 2

Farmers' perceptions of the sources of risk and management strategies to mitigate the risks have implications for risky production processes like aquaculture. Perceived risk has a large influence on an individual's decision-making behavior for a risky project, and it may greatly differ from the actual level of risk involved (Ahsan 2011). In Bangladesh, farmers change their production from rice farming to fish farming because of the higher potential profitability. However, this shift in production increases the risks for farmers, and they are facing severe challenges related to high input prices, low quality of inputs, output price fluctuations, lack of storage facilities, marketing difficulties and negative environmental effects (Ahsan 2011). Credit constraints and lack of government support are barriers for aquaculture production (Barua & Sarker 2010). These challenges are especially severe for small-scale farmers. There are no previous studies of Bangladeshi freshwater aquaculture farmers' perceptions of risk sources and risk management strategies, and therefore there is a need to investigate these issues.

Research question paper 3: Are Bangladeshi consumers willing to pay more for the attributes of wild-caught than for farm-raised fish, for fresh for than frozen fish and for local than for foreign fish species?

Background for research question 3

In Bangladesh, food consumption patterns have changed in recent years, and the per capita fish consumption increased by 17% from 2005 to 2010 (HIES 2010). Most of the increased supply is from farmed fish production, whereas much of the production concerns species that are not indigenous to Bangladesh (Beveridge et al. 2013). Low-priced, farm-raised foreign species are currently gaining on traditional species in the Bangladeshi diet. However, there is no knowledge about consumer preferences for seafood in this country, and there are very few studies on this subject in Southeast Asian countries. Hence, there is a need for research into consumer preferences in this region where the development of aquaculture is rapidly changing the available seafood products.

Research question paper 4: Are the farmed fish markets integrated and do they follow the law of one price (LOP). If they are integrated, to what extent?

Background for research question 4

Aquaculture production has boosted the global per capita consumption of fish, and the consumption of farmed fish products was relatively greater than wild fish in 2014 (FAO 2016). The competitiveness can be further increased through the development of product and marketing strategies, and predictable supply (Asche et al. 2009). A number of aquaculture species are farmed all over the world, and new species are being continuously introduced. Recently, tilapia and pangasius are significantly increasing in terms of global production, which introduces a new dimension in the market by supplying large quantities of farmed whitefish at very competitive prices (Asche et al. 2009). Recent significant progress in the production of new farmed fish species such as pangasius, tilapia and silvercarp have introduced a new dimension in the supply chain in Bangladesh. There are larger quantities being supplied and there is more access to fish products for consumers. There has been a rapid diversification of farmed fish consumption, shifting from traditional carps to introduced species such as pangasius and tilapia (Hernandez et al. 2017). These fast-growing new species are locally consumed and compete in the international whitefish market. However, it is important to know how the market for these new species is secured against traditional species. In this context, there is a growing interest in investigating the market linkage between the new and traditional species. Hence, there is need for research on the relationship between the market prices for different farmed fish species.

2. Theoretical framework and estimation methods

Although the main focus for all four papers is related to aquaculture in Bangladesh, the papers focus on different parts of the value chain. Therefore, we apply different theoretical frameworks in each of the papers. In section, I discuss the four theoretical concepts and estimation methods used in the thesis.

2.1. Production risk and Technical efficiency

Production risk means that uncertainty can cause production losses. The seminal paper (Just & Pope 1978) on risk is the foundation for theoretical and empirical research on production risk. The general form of the stochastic production function (Just & Pope 1978) is:

$$y_i = f(x_i; \beta) + u \ = f(x_i; \beta) + \ \mathrm{g}(x_i;\ \psi)v, \tag{1}$$

where x_i is the vector of input, $f(x_i; \beta)$ is the usual deterministic production function, which specifies the effects of the inputs on the mean production, $\mathrm{g}(x_i;\ \psi)$ is the variance function, which reflects the effect of inputs on the variance of the production, and v is the exogenous production shock and assumed to be independent and identically distributed $iid{\sim}N(0,1)$. The variance function allows heteroscedasticity in the error term. An input has a different effect on mean output and output variance, since $E(y) = f(x; \beta)$ and $V(y) = V(u) \ = g^2(x_i;\ \psi)$. One of the postulates of the Just–Pope function is that there should be no restrictions on the risk effects of inputs. Therefore, the marginal production risk of an input x_i can be defined as:

$$\frac{\partial \,\mathrm{var}(y)}{\partial x_i} = \frac{\partial g^2(x_i;\ \psi)}{\partial x_i} <=> 0, \tag{2}$$

i.e., the marginal risk of an input can be either increasing, decreasing or constant. Following Ramaswami (1992), the implications of the estimated risk is that a risk-averse farmer will use more risk-reducing inputs and fewer risk increasing inputs than the risk-neutral farmer. The risk aversion will be greater if the producer takes into account the input effect on the output variance when deciding the input quantity.

Technical efficiency is the ability of a decision-making unit to obtain maximum output from a given set of inputs and technology (Kumbhakar & Lovell 2003). In deterministic production function, a technology is considered as technically more efficient by producers if it produces a higher output than any other alternative technology for all inputs. However, a model with production risk deviates from the deterministic production function, and this has important implications, i.e., the measurement of technical efficiency will depend on the producers' risk preferences, and technology with higher output for all inputs may not necessarily be the most technically efficient (Tveterås 1999). For two production technologies with risk, a risk-averse producer therefore considers both the mean and variance of the output. For a given level of input vector x_1, the mean output and variance for two production technologies are presented in Figure 3. The mean output and variance for the technology 1 is smaller than the technology 2 for all levels of input x_1. In terms of expected utility, this does not mean that technology 1 is necessarily less technically efficient than technology 2. This will depend on the producer subjective trade-off between mean output and variance of utility function (Tveterås 1999).

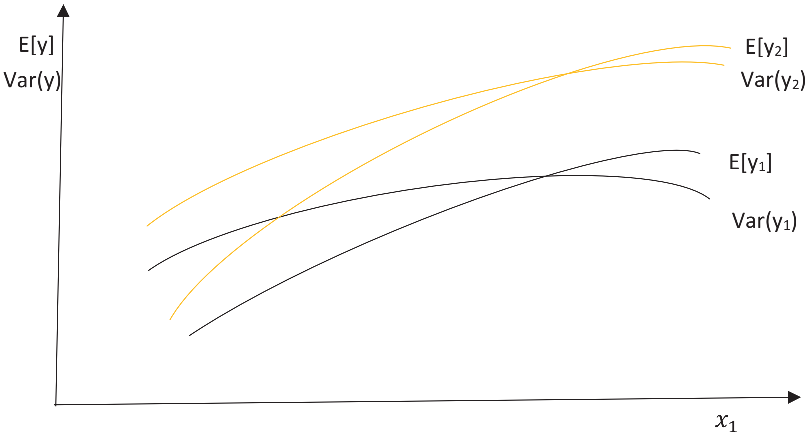

Figure 3: Mean and variance function of Just–Pope production technology 1 and 2, adapted from Tveterås (1999)

The Just–Pope model of equation (1) allows the integration of technical inefficiency as an additional source of production variability (Kumbhakar 2002). There are three possible alternatives for incorporating technical inefficiency into the Just–Pope approach (Bokusheva & Hockmann 2006). The first alternative is to add the inefficiency into the variance function together with the random error component (Battese et al. 1997). This produces a stochastic frontier (SFP) function with a flexible risk specified as:

$$y_i = f(x_i ; \beta) + g(x_i; \psi)(v - u), \quad (3)$$

where y_i, x_i, $f(x_i ; \beta)$, $g(x_i; \psi)$ and v are defined earlier. u is the non-negative random variable that captures the technical inefficiency effect of the firms. This introduction of technical inefficiency deviates from the conventional framework of the SFP model (Aigner et al. 1977), in which inefficiency was introduced in the mean production function (Kumbhakar 2002).

A second alternative is to append the inefficiency to the mean production function in a multiplicative form (Kumbhakar 2002). This is specified as:

$$y_i = f(x_i ; \beta)exp(-u) + g(x_i; \psi)v. \quad (4)$$

This specification keeps the standard form of the SFP model and the Just–Pope risk function in additive form, which preserves the properties of the Just–Pope approach. In this case, inefficiency is introduced as an additional assumption specified as $exp(-u) = 1 - u$.

Third, Kumbhakar (2002) suggested a more generalized flexible model where technical inefficiency is incorporated by means of its own function. This generalized SFA production model with flexible risk function is specified as:

$$y_i = f(x_i; \beta) + g(x_i; \psi)v - q(z; \delta)u. \tag{5}$$

Depending on the functional form, the specification of equation (5) can be reduced to an additive model when $(z) = g(x)$, and a multiplicative model when $q(z) = f(x)$. Furthermore, this specification corresponds to a generalization of the standard form of an SFA production model with heteroscedasticity in both the random error component and in the inefficiency effect. We employ the specification of equation (5) to measure production risk and technical efficiency for tilapia farming. Five inputs important for tilapia production: labor, feed, fingerlings, capital and farm size are used as explanatory variables. In addition to input variables, farmers' socio-demographic factors such as education, farming experience, training and extension services are also used to find the effect on inefficiency. The availability of credit to carry out timely purchased inputs into aquaculture production can increase farm productivity, efficiency, and reduce production risk in small-scale farming. A perfect credit market has implications for aquaculture farming. Therefore, credit is used as an explanatory variable in variance function and inefficiency function.

The unknown parameters β, ψ and δ relate to marginal products, and the marginal input risk and inefficiency effects of the equation (5) are estimated by optimizing the maximum log-likelihood estimator. We used the linear quadratic functional form for mean function, and the Cobb–Douglas functional form for variance function. Details of the estimations are explained in paper 1.

2.2. Perceptions of risk sources and risk management strategies

In paper 2, we use a descriptive approach to study farmers' behavior with regard to risk perceptions and management strategies. Risk perception is a subjective judgement of the probability of the occurrence of a specified type of uncertain event and its consequences (Sjöberg et al. 2004). Perceived risk influences an individual's decision-making behavior for a risky project, and it may differ from the actual level of risk (Ahsan 2011). According to Van Raaij's (1981) framework of economic behavior, a perceived economic environment determines the individual economic behavior with subjective well-being in mind (Lien et al. 2006). Figure 4 represents the framework used to study the farmers' perceptions. First, the influence of farm and farmers' personal characteristics (e.g. farming system, age, education, experience, farm ownership, training, off-farm work, geographic location and family size) on risk perceptions; second, the joint influence of farm and farmers' characteristics and risk perceptions of economic behavior (risk management strategies). Within this framework, a range of possible management strategies can be explored to cope with risk.

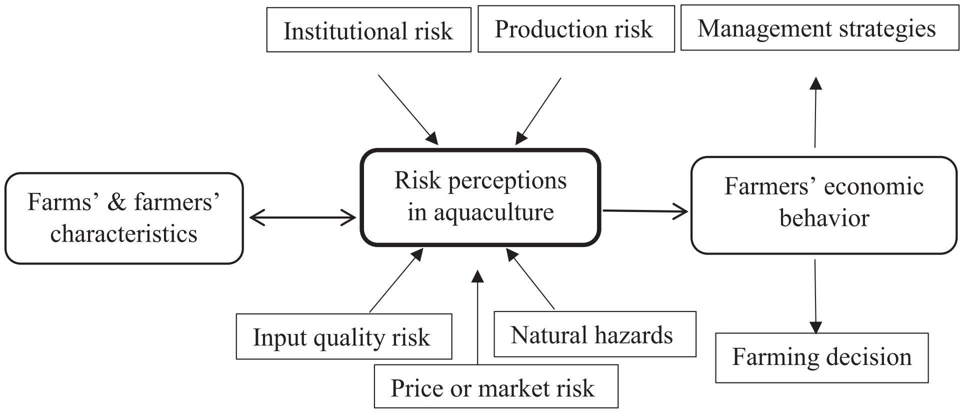

Figure 4: Modified model of a firm's decision-making behavior, based on Van Raaij (1981)

We therefore used this descriptive approach in tandem with a survey to explore the farmers' perceptions of risk and their management strategies for coping with these risks. The survey included questions related to farms' and farmers' demographic characteristics, perceptions of the sources of risk and perceptions of management strategies to mitigate the risk. The question about perceptions were in closed form, mainly five-point Likert-type scales (Schuman & Presser 1996). A total of 30 risk sources and 30 management strategies were presented in the questionnaire. Farmers were asked to give scores for each source of risk on a Likert scale from 1 (least significant) to 5 (most significant) to express how important they considered risk sources in terms of their potential impact on the farm's productivity and income. Farmers were also provided scores for the perceived importance of each management strategy on a Likert scale from 1 (not effective at all) to 5 (highly effective).

We used an exploratory common factor analysis to summarize the information in a reduced number of factors and their respective factor scores (Flaten et al. 2005; Le & Cheong 2010). Ordinary least square regression was used to find the influence of socio-demographic variables on farmers' behavior with regard to risk sources and risk mitigation strategies. For more details about the estimation, see paper 2.

2.3. Choice experiment

In paper 3, we use the random utility model as the theoretical foundation of the consumer study. The utilities derived from the products with different bundles of attributes can be different, because consumers choose their utilities among the alternatives based on the embedded attributes (Lancaster 1966). Random utility theory is the standard framework for explaining consumer choice data. The utility (U_{ijt}) from choosing *j* alternatives in the *t*-th choice situation can be modeled (McFadden 1974) as follows:

$$U_{ijt} = x_{ijt}\beta + \varepsilon_{ijt} ,$$

where β_i are individual-specific coefficients for different attributes, and ε_{ijt} is the random error that is an unobservable component of utility. In utility maximization, the probability of consumer *i* choosing alternative *j* in the *t*-choice situation is:

$$\begin{aligned} P_{ij} &= P_r(U_{it} > U_{ij}) \forall j \neq t \\ &= P_r(V_{it} + \varepsilon_{it} > V_{ij} + \varepsilon_{ij}) \forall j \neq t \\ &= P_r(\varepsilon_{ij} - \varepsilon_{it} < V_{it} - V_{ij}) \forall j \neq t \, . \end{aligned}$$

Different choice models can be obtained to analyze the data based on the distributional assumptions of the random error terms. With the assumption that the random error terms are independent and identically distributed ($i.i.d.$) and type 1 extreme value, the choice probability in the utility maximization of *j* alternatives in *t* choice situations is:

$$P_{ijt} = \frac{exp(x_{ijt\beta})}{\sum_{j=1}^{J} exp(x_{ijt\beta})} \, .$$

This is the conditional logit model, which assumes that consumers have the same preferences, and the property of independence of irrelevant alternatives (IIA). The mixed logit model overcomes the main limitations of the conditional logit by allowing random taste variation in the population, unrestricted substitution patterns and correlation of unobserved factors over time (Train 2003). Given the random parameter context, the probability of the *t* choice situations as:

$$P_{ijt} = \int \frac{exp(x_{ijt}\beta)}{\sum_{j=1}^{J} exp(x_{ijt\beta})} h(\beta)d(\beta).$$

We used this framework to analyze consumer choice preferences for different fish attributes. A choice experiment with 24 choice scenarios was created and each respondent was presented with six of the choice scenarios. The respondents were asked to choose between two fish alternatives and a none-of-the-above alternative in each choice scenario. To estimate the parameters of the model, we used a mixed logit model in WTP space. For more details about the WTP space estimation, see paper 3.

2.4. Market integration, LOP and product aggregation

In paper 4, I use the concept of market integration to test the market interaction between fish species and the regional markets. Market integration has been used as a typical approach to analyze the price relationship by focusing on cointegration and LOP. If the prices of goods are determined within the same market, prices follow the same stochastic trend over time, forming a long-run relationship (Nielsen et al. 2009). The long-run relationship between the prices of fish species can be expressed as follows:

$$P_t^1 = \alpha + \beta P_t^2 + e_t ,$$

where P_t^i is the logarithm of the observed price of fish species *i* at time period *t,* α is a constant term that captures transportation costs and quality differences between species; and β determines the relationship between the market price of fish species as well as the relationship between the regional markets. If $\beta = 1$, the LOP holds and the relative price is constant; the prices will change proportionally over time.

Another important concept is product aggregation, which provides evidence of whether the products can be aggregated. According to Hicks (1936) and Leontief (1936), if individual prices for a group of products move proportionally over time, then the group of products can be characterized using a composite prices index. However, the theorem assumes that the prices of all products within the same group must be perfectly correlated, which may not hold in empirical work. Therefore, Lewbel (1996) provides a generalized composite theorem that allows for some deviations from perfect collinearity of prices, and this is empirically useful. There are several ways to test the generalized composite commodity theorem. One simple way is to test whether the LOP holds for the nonstationary prices in a market delineation context (Asche et al. 1999). If the LOP holds, then the products can be aggregated according to the generalized composite commodity theorem. This is relevant with the intuition to test that the prices of aquaculture fish species move proportionally over time, and can be treated as one product in a developing economy.

I used the most common Johansen bivariate and multivariate cointegration approach to test the market integration and the LOP. Before investigating the market integration and the LOP, the unit root properties of the price series are tested using the augmented Dickey–Fuller (ADF) and KPSS (Kwiatkowski, Phillips, Schmidt & Shin) tests.

3. Study area and data

This thesis contains four papers based on farm-raised fish farming. The study area and related samples are presented in Table 1 and Figure 5. The first and second papers are based on freshwater pond aquaculture production. Data were collected from five upazilas (administrative units or sub-districts) of Mymensingh, Feni and Noakhali district through personal interviews. Mymensingh is the largest district for pond aquaculture, and it is a promising area for aquaculture because of the availability of fingerlings, fertile soil, abundant labor and favorable climate (Ahmed et al. 2012).

Table 1. Study area and data structure for each paper in the thesis

List of papers	Research period	Study area	Sample size
Paper 1	2014	Mymensingh, Feni and Noakhali	339 fish farmers
Paper 2	2014	Mymensingh, Feni and Noakhali	350 fish farmers
Paper 3	2016	Dhaka, Mymensingh and Gazipur	400 consumers
Paper 4	2006–2016	Dhaka, Rajshahi, Chittagong and Khulna	120 months

The districts of Feni and Noakhali are situated near the coast in the southeastern part of the country and they are promising areas for pond aquaculture. Data was collected using a well-structured questionnaire. A three-stage sampling technique was used to determine samples. A total of 350 farms were randomly selected from these areas.

For the third paper, we conducted a survey including a choice experiment in and around the cities of Dhaka, Gazipur and Mymensingh. Dhaka is the capital city, Gazipur is an industrial area and Mymensingh is a medium-sized city north of the capital. These three areas have consumers with a wide range of cultures, religions, socio-economic conditions and food consumption behavior. The survey was pre-tested with a small consumer sample, and minor changes were made before the final data were collected.

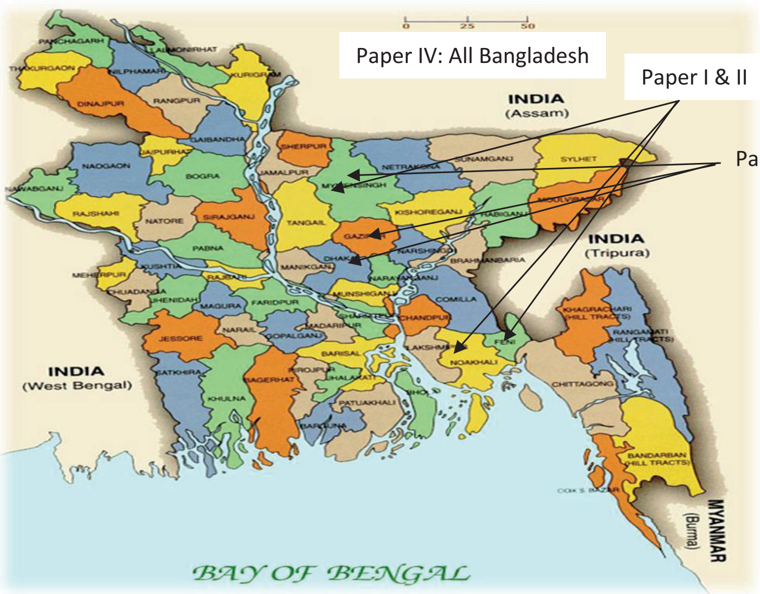

Figure 5: Map of Bangladesh showing study area of the thesis

For the fourth paper, I used the monthly retail price data obtained from the Department of Agricultural Marketing, Ministry of Agriculture, for four administrative divisions, namely Dhaka, Chittagong, Rajshahi and Khulna. I considered five seafood products in this study: rohu[2], catla, pangasius, tilapia and silvercarp. These species are among the 30 most highly and

[2] The Latin names of the fish species are *Labeo rohita* (rohu), *Catla catla* (catla), *Pangasius hypophthalmus* (pangasius), *Oreochromis mossambicus/ O. niloticus* (tilapia) and *Hypophthalmichthys molitrix* (silvercarp).

commonly consumed fish products in Bangladesh (DoF 2016). These species are mostly from aquaculture and have a significant contribution to the total fish supply. The five species together supply 42% of the total fish food supply in Bangladesh (DoF 2016).

4. Summary of research findings

This thesis presents four independent research papers. The following is a brief summary of each paper, highlighting the objectives, empirical analyses, major findings and contributions.

Paper 1: Production risk and technical efficiency of tilapia aquaculture farming in Bangladesh

Objective: The paper aims to estimate the combined effect of production risk associated with input usages and technical efficiency for tilapia fish farming in Bangladesh. More specifically, the objectives are to identify the factors responsible for production risk and inefficiency in the tilapia production process, and to measure the importance of production risk and technical inefficiency.

Empirical analysis: The empirical analysis was based on cross-sectional data. An SFP model with flexible risk specification was used, where a linear quadratic functional form for mean production function and the Cobb–Douglas functional form for the variance function was used. All the functions were estimated using the maximum likelihood method. The value of output and explanatory variables included in the mean function were normalized using their individual sample means. Therefore, the input elasticities were computed at individual point estimates.

Research findings: The findings of the study are that significant production risk and inefficiency exists in tilapia farming. Farmers could increase fish production using the inputs efficiently with existing technology. The average elasticity of feed was found to be 1.03, and is comparatively higher than other inputs, which implies that feed is the most important input for tilapia fish production. The estimated variance elasticity of feed and fingerlings has a positive and significant effect, implying that production risk increases with increased use of these input variables. This implies that risk-averse farmers are expected to use less feed and fingerlings compared to risk-neutral farmers. On the other hand, capital has a significant risk-reducing effect on production risk. Production risk makes the largest contribution to the total output variation. The estimated parameters of extension services and training were identified as important determinants for the variation in inefficiency. Both significantly reduced the technical inefficiency of the farmers. The average level of efficiency was 92% for the average farm, and indicates that an average farm could have increased output by 8% using inputs more efficiently. Credit has a risk-reducing effect on production risk as well as an inefficiency-reducing effect.

Contributions: There have been no previous studies of the combined effect of production risk and technical inefficiency on tilapia farming. The findings of the study are expected to diminish the knowledge gap in the literature regarding the risk effect of the intensity of input usages in tilapia farming. Moreover, the findings are also relevant for both farmers and policymakers, which in turn may help develop proper policies for expanding tilapia fish farming in a sustainable fashion.

Paper 2: Risk in aquaculture: Farmers' perceptions and management strategies in Bangladesh

Objective: The paper aims to investigate fish farmers' perceptions of risk sources and management strategies to mitigate risk. More specifically, the paper's objectives are to examine farmers' perceptions of risk sources and risk management strategies and to identify the relationship between the farmers' perceptions and socio-demographic variables.

Empirical analysis: Exploratory factor analysis was used to summarize the information in a reduced number of factors and their respective factor scores. The number of factors retained in the final solution was based on the latent root criterion (Eigenvalue > 1), and meaningful interpretation. Kaiser–Meyer–Olkin's and Barlett's test were used to test sample adequacy and suitability of the data. After factor extraction, factor scores for each farmer were predicted for regression analysis. Ordinary least square regression analysis was used to investigate the relationship between the socio-demographic variables and risk sources, and also with the risk management strategies.

Research findings: The findings show that the most important sources of risk are fish diseases, fish price variability, low quality of feed and fingerlings, floods and credit constraints. The most important strategies to mitigate risks are a supply of good quality feed and fingerlings, disease prevention, crop insurance, increasing personal savings and assurance of bank loans. The results revealed that a number of socio-demographic variables including age, education, experience, training, off-farm work and farming systems have significantly influenced the farmers' perceptions of risk sources and risk management strategies. Off-farm work was strongly associated with strategies like farm management, institutional support, extension services and financial management. Farmers' perceptions of involvement in off-farm activities were that such activities increased family well-being and reduced income risk from fish farming. Findings also revealed that farmers' risk management behavior was significantly influenced by their perceptions of risk sources. Most of the risk sources were significantly associated with multiple risk management strategies, implying that farmers engage in multiple management strategies to reduce losses from aquaculture production.

Contributions: The findings of the paper highlight the fact that government policy should focus on quality inputs, availability of credit with less collateral required and lower interest rates, developing a national crop insurance scheme, and increasing market monitoring capacity. The findings also contribute to the literature on small-scale farmers' perceptions of risk and risk management strategies in aquaculture.

Paper 3: Consumer preferences for fish attributes in Bangladesh: A choice experiment

Objective: The paper aims to assess consumer preferences and WTP for attributes of fish in Bangladesh. More specifically, the paper aims to estimate WTP in order to shed light on Bangladeshi consumer preferences regarding wild-caught and farm-raised fish, freshness, and origin of fish species.

Empirical analysis: For empirical analysis, we gathered the responses from 400 consumers who were responsible at least 50% of food purchasing in their family. Descriptive methods were used to investigate fish consumption patterns and perceptions among consumers' attitudes regarding fish attributes. To estimate consumers' WTP, a mixed logit model in WTP space with correlated random coefficient was used to analyze the data. The model was estimated using the maximum simulated likelihood method with the Stata "*mixlogitwtp*" command (Hole 2015). We also estimated mixed logit in preference space and models with demographic interaction effects. However, these models did not give any significantly different results.

Research findings: The study finds that on average, consumers were willing to pay more for indigenous than for foreign fish species. Furthermore, they preferred domestic production rather than imported fish, and they preferred fresh instead of frozen fish. However, Bangladeshi consumers were not willing to pay a significant premium for wild-caught fish. Retail price, product origin and fresh vs. frozen were identified as important determinants in consumers' choice decisions. The lack of consumer differentiation in regard to the production method is promising for aquaculture in this region and provides hope for reducing the pressure on wild fisheries.

Contributions: The paper contributes to fill the knowledge gap in relation to consumer preferences for different fish quality attributes in Southeast Asia. It also examines how the consumer preferences in developing Asian countries resemble those in developed countries over the last decade.

Paper 4: Market integration for new aquaculture species: The whitefish market in Bangladesh

Objective: The specific objective of this paper is to test: i) the market interaction or substitution between new species and traditional species such as, in particular, pangasius, tilapia and carp, and ii) the market integration between regional markets for individual fish products, to shed light on the situation in Bangladesh.

Empirical analysis: The monthly retail prices for new, farmed species such as pangasius, tilapia and silvercarp and traditional species such as rohu and catla were used for empirical analysis. The unit root properties of the time series data were tested using the ADF and KPSS tests. The results show that the price series for the different species were nonstationary in level form. However, all of the price series were stationary after the first difference. This implies that the price series for each species were integrated to the order of one, I (1), and market linkage can be investigated using the cointegration test. The Johansen (1988) bivariate and multivariate cointegration procedures were used to test market integration and determine market power. The LOP and weak exogeneity tests were also conducted to determine the market leader.

Research findings: The results show that the newly introduced species are partially integrated with traditional carp species, and that there is no price leader in the farmed fish market. However, among the new species, the tilapia price determines the price of pangasius. Moreover, on a species-by-species basis, the regional markets for rohu, pangasius, tilapia and silvercarp are fully integrated, indicating a national market in Bangladesh. However, there is no market leader among the regional markets, which indicates that markets have their own power to transmit price information.

Contributions: There is little knowledge about the market integration of aquaculture in developing countries. However, several studies have been conducted for the well-functioning markets in developed countries. The knowledge from our study will fill this gap, and it will be useful for policy perspectives, particularly for producers and suppliers to understand how the products are likely to move among the regional markets in developing countries. Our findings also provide useful information for policymakers to create efficient marketing strategies for distribution.

5. Overall conclusion and policy implications

Aquaculture production is the major source of fish supply in Bangladesh. Within aquaculture, most of the production comes from freshwater pond aquaculture. Most of the expansion for pond aquaculture consists of converted rice fields because there is higher profitability in fish farming compared to rice farming. However, the average productivity was found to be much lower than many other Asian countries. Productivity can be increased by using advanced technology, high-yielding species, quality inputs and reducing production risk and inefficiency. Moreover, it is important to understand consumer preferences, and to find competitive markets in order to sustain this sector. The main objective of this thesis is therefore to study the economic aspects of aquaculture farming in Bangladesh with regard to production variability, risk preferences, consumer preferences and market integration. Hence, it is difficult to come up with one overall conclusion and policy implication, and therefore the conclusions are drawn from the individual papers.

First, the main finding is that significant production risk and inefficiency exist in the tilapia production system. Hence, both are important in explaining production variability, although production risk accounts for the largest variance in the total output. There is also a wide range of variation in input usages that creates substantial output variability, in terms of both increases and decreases. An appropriate strategy would be to draw attention to the input factors that are found to both increase production and reduce risk. The results indicate that increased usage of capital and credit will reduce production risk. Capital is the most important risk-reducing factor. The government can provide incentives for increasing investment by subsidizing capital goods. Another strategy would be to facilitate access to credit, and thus insure that farmers can buy the optimal level of capital equipment. Extension services and training on technical knowledge for aquaculture production has a negative effect on inefficiency, i.e., positive effects on farm efficiency. Thus, policies should focus on improving farmers' management skills and efficiency through better extension services and training on production systems, and making sure that all farms have access to extension services and other types of formal training. Providing better training and extension services are also expected to contribute to reducing production variability by reducing production risk.

Second, farmers' perceptions of risk sources and management strategies to cope with risk have an implication for aquaculture farming. Farmers' risk perceptions and risk management behavior are significantly influenced by sociodemographic variables including age, experience, education, training, off-farm work, farm ownership, farming system and geographic location. Most of the risk sources were significantly related to multiple risk management strategies, indicating that multidimensional strategies are required to mitigate a specific type of risk. This implies that government policy interventions are essential to mitigate risks. Improved aquaculture farming is capital intensive, particularly for tilapia and pangasius farming. Therefore, the availability of credit is an important issue for small-scale fish farmers in developing countries. Credit constraints and quality inputs work as barriers to aquaculture production. In order to develop the aquaculture sector in a sustainable fashion, government policy should focus on ensuring the provision of quality inputs, providing bank loans with less collateral and lower interest rates, and developing a national crop insurance scheme.

Third, despite the impressive growth of aquaculture farming in South Asian countries, there is little knowledge about consumer preferences for seafood in this part of the world. Thus, more empirical studies should explore consumer preferences for different fish quality attributes in South Asia. To that end, it was found that Bangladeshi consumers on average were not willing to pay a significant premium for wild-caught fish. This means that the wild fisheries must compete with increasingly efficient aquaculture production on equal terms. Increased pricing pressure from farmed fish is likely to reduce the profitability of overfishing practices in capture fisheries. These findings have implications for aquaculture producers in this region, who can sell their products without a farmed-fish discount. Consumers have preferences for fresh fish, local origin and indigenous fish species, which paves the way for large-scale local production of farmed fish in Bangladesh.

Fourth, the performance of farmed fish markets has increased in terms of market share in domestic markets as well international markets. Markets for individual species are well linked. It is desirable that the market linkage for different fish species potentially decreases the price difference between the markets. Results indicate that the markets for the various species are partially integrated in the regional markets and that there is no price leader among the species.

However, among the new species, the tilapia price determines the price of pangasius. Moreover, on a species-by-species basis, the regional markets for rohu, pangasius, tilapia and silvercarp are fully integrated, indicating a national market in Bangladesh. In the short term, the price may possibly vary but may maintain equilibrium in the long run across the regional markets. There is no market leader among the regional markets, which indicates that markets have their own power to transmit price information. The findings have implication for market participants such as producers, suppliers and other stakeholders to understand how fish products are likely to likely move among regional markets, and which prices are interrelated to other market prices. It also provides useful information for policymakers to create efficient marketing strategies for distribution.

Lastly, the development of aquaculture largely depends on increasing production, reducing production risk and technical inefficiency, fostering consumer acceptance and the number of new market segments for fish products. Thus, policies should focus on those issues for sustainable development of this sector.

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Paper 1

Production risk and technical efficiency of tilapia aquaculture farming in Bangladesh

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Abstract

Tilapia is a relatively fast growing fish species that has huge potential for production in Bangladesh. Despite its impressive growth, production is highly volatile across farms and location. There are several sources of production volatility; both output risk and/or inefficiency will lead to variation in production. While a number of studies has been focusing on either technical efficiency or the adaption towards risk, few studies have been conducted of the combined effect of production risk and technical efficiency in aquaculture. By employing a stochastic frontier production model with flexible risk specification, this article quantifies production variability of tilapia fish farming by means of two main possible sources: production risk and technical inefficiency. Further, the analyses identify the factors influencing risk and inefficiency. Knowing the source of the variation is vital for farmers and policy makers in choosing the right strategy to discard the production variation.The empirical analysis is based on cross-sectional data from 339 sample farms. Main findings are that significant production risk and technical inefficiency exists in tilapia farming.

Key words: production risk, technical efficiency, stochastic frontier, aquaculture

1. Introduction

Tilapia is rapidly becoming one of the most important aquaculture species in the world, and had a significant presence in the seafood market (Asche et al. 2009). It grows quickly with a short production period which effectively reduces capital asset problems and cost. Tilapia markets are highly segmented and diversified compare to salmon and shrimp, and tilapia has a high potential to become a globally traded species (Asche et al. 2009). Tilapia's success in other Asian countries and its tolerance of high density compared to other species suggests that tilapia is a fish that can increase value added production on scarce land and water resources (Ahmed et al. 2012). Tilapia production has rapidly increased in Bangladesh. In 2016, produced quantity was 337350 tons, a many-fold increase from only 16230 tons in 2009 (DoF 2016).[1] Despite this impressive growth and seemingly favorable production characteristics, tilapia farming has experienced a number of constraints and production variation (Ahmed et al. 2012). Environmental risk and ecological problems are important issues due to the vulnerable position of the country due to climate change, which can be attributed to stochastic production shocks (Anwar 2011). A number of biophysical characteristics of environment, such as water temperature variation and oxygen concentration, directly influence the growth of fish and increase output variation (Khan et al. 2017). Besides these biophysical factors, differences in production technologies and intensity of input usage among the farmers may augment risk further (Sarker et al. 2016). In addition to risk, farm level technical inefficiency might also cause output variability, and is hence important (Sarker et al. 2016). Differences in production practice and size of the farms, limitations and usage important production factors, differences in social characteristics such as educational level, is presumed to affect the efficiency level of the farms. In resource-scarce countries like Bangladesh, farm level knowledge of production risk and efficiency is important for long-run sustainability, particularly for small-scale farmers production variation might cause great consequences for these farmers and their livelihoods (Khan et al. 2017).

Previous studies have shown that technical efficiency relates to the technological knowledge and socio-economic characteristics of the farms and farmers (Sarker et al. 2016). These same variables may also lead to farmers' input use decision that can cause output variability. Moreover, the presence of production risk influences not only outputs but also farmers' behaviour with regard to input usage, if production risk exerts an important role in farmers'

[1] Tilapia is also important for consumers', particularly for poor in Bangladesh, because of the comparatively low market price.

decision-making, then the measurement of technical efficiency may alter significantly (Bokusheva & Hockmann 2006). Therefore, the estimated technical efficiency considering production risk is different in a framework where the effect of production risk on input use decisions is not taken into account. This suggests to incorporating the output risk in the efficiency measurement framework to estimate production risk and technical efficiency simultaneously. Still, there are no studies investigating production risk associated with inputs usage for tilapia fish farming. This study attempts to diminish this knowledge gap by estimating of the production risk and technical efficiency of tilapia farming in Bangladesh. The main objective of this paper is to examine the importance of production risk and inefficiency in total observed output variance as a physical term, and to identify the risk factors that cause production risk, and the factors that reduce technical inefficiency in tilapia farming. Knowing the determinants of risk and inefficiency is important in designing the right strategy for remedy production variability. The empirical findings of this research will therefore provide useful information about risk reducing inputs and inefficiency reducing factors for both farmers and policymakers, which in turn may help to make better financial and institutionally based policies for expanding tilapia fish farming in a sustainable fashion.

The literature on production risk and efficiency in a single framework is scarce within the aquaculture framework. While a number of studies have been focusing on technical efficiency in Bangladesh (Alam 2011; Arjumanara et al. 2004; Ferdous Alam & Murshed-e-Jahan 2008), there are few studies on production risk. There have however been conducted some studies addressing Norwegian salmon aquaculture's production risk (Asche & Tveterås 1999; Tveterås 1999), risk preference and efficiency (Kumbhakar 2002). These risks might be different in small-scale farming in developing countries because farmers in these countries have less control over the production process compared to industrial aquaculture in developed countries. These risks also differ across species and regions due to different farming systems. While the literature on production risk and efficiency in a single framework is scarce within the aquaculture framework, some recent studies has conducted within the agriculture framework (Bokusheva & Hockmann 2006; Chang & Wen 2011; Tiedemann & Latacz-Lohmann 2013; Villano & Fleming 2006; Yang et al. 2016). All these studies have used the stochastic frontier approach (SFA) considering heteroscedastic error terms. Following this literature we also employed the SFA model with flexible risk specification to estimate the production, risk function and inefficiency function (Kumbhakar 2002). The analysis is based on data obtained from a survey of 339 tilapia fish farmers who were randomly selected from five upazilas (sub districts) in Bangladesh for the production period 2012/2013.

The article is organized as follows: section two presents methods and data followed by theoretical framework of the model, empirical model specification, and sampling procedure and data. The estimated results from the model are discussed in section three. The final section focusses on the policy implications and conclusion of the study.

2. Methods and data

2.1. Theoretical framework of the model

To estimate output risk and technical efficiency, we employ a modification of the standard stochastic production frontier, were we control for a heteroskedastic in both the random error component and in the inefficiency effect. The standard SFA approaches uses a parametric function for efficiency analysis (Aigner et al. 1977; Meeusen & van Den Broeck 1977), and has been widely used to determine the firm-level efficiency. The general specification of the conventional stochastic production frontier is as follows:

$$y_i = f(x_i;\beta)exp(\varepsilon_i = v_i - u_i) \quad (1)$$

where y_i denotes the output of the ith firm (i = 1, 2, 3,…n), x_i is the input vector, β is the unknown parameter vector to be estimated, v_i's are random variables which assumed to be independently and identically distributed $iid{\sim}N(0,\sigma^2\text{v})$, and the u_i's are non-negative random variables associated with technical inefficiency that represent the deviation of output from the production frontier. The technical efficiency for the ith firm can be defined as:

$$TE_i = exp(-u_i) = y_i/[f(x_i;\beta)exp(v_i)] \quad (2)$$

A drawback of the standard stochastic production frontier is the inability to control for production risk (Bokusheva & Hockmann 2006), as it is implicitly assumed that every input which has a positive marginal effect on output simultaneously increase the output variability. A more general stochastic specification that correct for this is the approach laid out by Just and Pope (1978). This model has the advantage of being able to difference between the impact of input on mean output and variance.

The general form of the Just and Pope Production function can be specified as;

$$y_i = f(x_i ; \beta) + g(x_i; \psi)v_i \quad (3)$$

where $f(x_i ; \beta)$ is the usual deterministic production function, which specifies the effects of the inputs on the mean production, and $g(x_i; \psi)$ is the variance function, which reflect the effect of inputs on the variance of the production, v_i is the stochastic error term and assumed to be independent and identically distributed $iid{\sim}N(0,1)$. The variance function allows heteroscedasticity in error term. An input has different effect on mean output and output variance, since $E(y) = f(x)$ and $V(y) = V(\varepsilon) = g^2(x; \psi)$. The marginal production risk of an input x_i can be defined as:

$$\frac{\partial \operatorname{var}(y)}{\partial x_i} = \frac{\partial g^2(x_i; \psi)}{\partial x_i} = 2g(x_i; \psi)g_i(x_i; \psi) \quad (4)$$

where, $g_i(x_i; \psi)$ is the partial derivatives of variance with respect to input *i*. The magnitude of this marginal risk can be either positive or negative depending on the signs of $g(x_i; \psi)$, and $g_i(x_i; \psi)$.

The Just-Pope model also allows to integrated technical inefficiency as an additional source of production variability (Kumbhakar 2002). There are three possible alternatives to incorporate technical inefficiency into the Just-pope approach (Bokusheva & Hockmann 2006). The first alternative is to add the inefficiency into the variance function together with the random error component (Battese et al. 1997). This produces a stochastic frontier production (SFP) function with a flexible risk specified as:

$$y_i = f(x_i ; \beta) + g(x_i; \psi)(v - u) \quad (5)$$

where y_i, x_i, $f(x_i ; \beta)$, $g(x_i; \psi)$ and v is defined earlier. u is the non-negative random variable that capture the technical inefficiency effect of the firms. This introduction of technical inefficiency deviate from conventional framework of SFP model (Aigner et al. 1977), in which inefficiency introduced in the mean production function (Kumbhakar 2002).

A second alternative is to append the inefficiency to the mean production function in a multiplicative form (Kumbhakar 2002). This is specified as:

$$y_i = f(x_i ; \beta)exp(-u) + g(x_i; \psi)v \quad (6)$$

This specification keeps the standard form of SFP model and the J-P risk function in additive form, which preserve the properties of Just-Pope approach. In this case, inefficiency is introduced as an additional assumption specified as; $exp(-u) = 1 - u$

Third, Kumbhakar (2002) suggested a more generalized flexible model where technical inefficiency is incorporated by means of its own function. This generalized SFP model with flexible risk function is specified as:

$$y_i = f(x_i ; \beta) + \mathrm{g}(x_i ; \psi)v - q(z; \delta)u \qquad (7)$$

Depending on the functional form, the specification of equation (7) can be reduced to additive model when $(z) = \mathrm{g}(x)$, and multiplicative model when $q(z) = f(x)$. Furthermore, this specification corresponds to a generalization of the standard form of SFP model with heteroscedasticity in both the random error component and in the inefficiency effect. Ignoring heteroscedasticity in the random error component might results in biased efficiency scores, and not allowing for heteroscedasticity in the inefficiency term causes the estimated parameter of the SFP model biased. Ignoring heteroscedasticity in both error terms may lead to both inconsistent estimates and biased efficiency scores (Kumbhakar & Lovell 2003). For this reasons we employ the third specification of equation (7) in our study, where we are considering heteroscedasticity in both error terms.

2.2. Empirical specification of the model

The choice of functional form for estimating stochastic production frontier with risk is important for consistent parameter estimates (Kumbhakar & Tsionas 2010). Specifying a linear quadratic form for the mean production function, have the following advantages:[2] i) it is consistent with the Just-Pope postulates, ii) it is flexible in the sense of a second-order approximation of any unknown mean output function (Kumbhakar & Tveterås 2003).

[2] The choice of functional form has an implication to estimate the consistent parameters for frontier analysis. We employed a likelihood-ratio test which function form that best describe the mean production function. We assumed that the Cobb-Douglas (C-D) production function with half-normal distribution is better than quadratic function. However, the result shows that the null hypothesis of the C-D specification in favor of quadratic function was rejected. It indicates that quadratic function with half-normal distribution provides a better fit with data. However, the model is not converging for truncated normal distribution. The empirical results of Just-Pope production function with linear-quadratic mean functions were also relatively robust compared to other functional forms (e.g. translog and Leontief) (Tveterås 1999).

The model in linear quadratic form is expressed as:

$$y_i = f\left(\beta_0 + \sum_{j=1}^{5} \beta_j x_{ij} + 0.5 \sum_{j=1}^{5} \sum_{k=1}^{5} \beta_{jk} x_j x_k + \sum_{d} \beta_d D_d\right) \tag{8}$$

where y_i is the production, which is measured as total quantities in kilogram (kg.) of the *i*th farm, and $x_{(s)}$ are vectors of J explanatory variables, which represent the inputs used by the *i*th farm including labor, feed, fingerlings, capital and farm-size. D is regional dummy variables.

For the risk function, we specify a Cobb-Douglas (C-D) functional form which is widely used previous studies (Bokusheva & Hockmann 2006; Chang & Wen 2011; Jaenicke et al. 2003; Khan et al. 2017; Kumbhakar 2002; Kumbhakar & Tveterås 2003; Ogundari & Akinbogun 2010; Villano & Fleming 2006). The risk function is specified as follows:

$$\sigma_v^2 = g\left(\psi_0 \prod_{j=1}^{5} X_j^{\psi_j}\right) \tag{9}$$

The explanatory variables (x_j) are assumed to explain the variance (σ_v^2). These are labor, feed, fingerlings, capital, farm-size, credit and regional dummies and are identified based on the theory and earlier studies on production risk in aquaculture production (Kumbhakar 2002; Ogundari & Akinbogun 2010; Tveterås 1999).

In inefficiency function, variables used to explain inefficiency are incorporated by changing the variance of the distribution of inefficiency σ_{ui}^2, and assumed a half normal distribution for the inefficiency term (Kumbhakar & Lovell 2003; Tiedemann & Latacz-Lohmann 2013).[3] The functional specification of the technical inefficiency is defined as;

$$\sigma_u^2 = q\left(\delta_0 \prod_{j=1}^{11} Z_j^{\delta_j}\right) \tag{10}$$

[3] The variables used to explain output variance and inefficiency can either be identical to the input variables or other variables such as farm and farmer characteristics (Jaenicke et al. 2003; Tiedemann & Latacz-Lohmann 2013).

Where $Z_{(s)}$ are the exogenous explanatory variables, which includes different farm-specific factors such as education and experience of the farmers, extension service, credit and training received, and also labor, feed, fingerlings, capital, farm-size and regional dummies.

The unknown parameters β, ψ and δ relates to marginal products, marginal input risk and inefficiency effects of the equations (8-10), and are estimated by optimizing the following log-likelihood function (Kumbhakar & Lovell 2003):

$$lnL = constant - \frac{1}{2}\sum_i ln[g(x_i;\ \psi)v + q(z_i;\delta)u]$$
$$+ \sum_i \ln \Phi \left(-\frac{\varepsilon_i\ \lambda_i}{\sigma_i}\right) - \frac{1}{2}\sum_i \frac{\varepsilon_i^2}{\sigma_i^2} \tag{11}$$

where, $\sigma_i^2 = \sigma_{vi}^2 + \sigma_{ui}^2 = g(x_i;\ \psi)v + q(z_i;\delta)u$, $\lambda_i = \sqrt{g(x_i;\ \psi)v}/q(z_i;\delta)u$ and Φ is the standard normal distribution. The technical efficiency of each firms is calculated following Battese and Coelli (1988) as $TE_i = E[exp(-u_i)|\varepsilon_i]$ and the production risk of each firms are determined by the exponential function of the variable specified in the risk function.

Inefficiency and production risk might both significantly influence in total observed output variability. To decompose this effect, we calculate the share of variance attributable to the total output variance for each farm as a physical term using the following equation (Kumbhakar & Lovell 2003; Tiedemann & Latacz-Lohmann 2013):

$$\sigma^2 = \sigma_v^2 + Var_u = \sigma_v^2 + \left(\frac{\pi - 2}{\pi}\right)\sigma_u^2 \tag{12}$$

Where σ^2 is the total output variance, σ_v^2 is production risk and Var_u is the variance of inefficiency in the case of a half-normal distribution.

2.3. Study area, sampling technique and data

The study is based on primary cross-section data collected from three districts in Bangladesh. The survey was conducted through personal interviews. A three-stage sampling technique was used to determine samples. In the first stage, the sample districts were determinated. Mymensingh, Feni and Noakhali districts were purposively selected because tilapia fish farms has expanded in these areas. Mymensingh is the largest district for pond aquaculture production, and promising area for tilapia culture, because of the availability of fingerlings, fertile soil, abundant labor and favorable climate (Ahmed et al. 2012). This region has additional advantage by having the best technologies, as well as having access to extension services and training from Bangladesh Fisheries Research Institute and Bangladesh Agricultural University. The districts Feni and Noakhali are situated in the southeastern part of the country, where 39% of the pond fish culture is occupied by tilapia farming (DoF, 2016). In the second stage of the sample selection five upazilas (administrative unit or sub-district) were selected based on secondary information of tilapia production. These are; Phulpur and Trishal from the Mymensingh district, Sonagazi and Parshuram from Feni, and Subarnachar from Noakhali. Finally, in the third stage, 350 farms were randomly selected from these upazilas, of which 339 farms were used in our analysis because rest of them were found to be outliers.

Table 1. Summary statistics of the tilapia fish farmers

Variable	Definition	Mean	Std. deviation	%
Output	Total fish production (kg/acre)	4159.12	1570.09	
Labor	Total labor used (Man-days/acre)	105.58	16.84	
Fingerling	Fingerlings (no/acre)	24419.80	8600.65	
Feed	Total feed used (kg/acre)	5928.85	2754.85	
Capital	Capital (BDT/acre)	39110.80	12819.51	
Farm-size	Total farm area (acre)	2.88	2.62	
Education	Number of years of education	8.37	4.36	
Experience	Farming experience (years)	7.09	4.95	
Off-farm income	1 if farmers involved in off-farm work; 0 otherwise			54
Training	1 if received training; 0 otherwise			37
Credit	1 if received credit; 0 otherwise			22
Extension service	1 if received; 0 otherwise			63
Mymensingh	Percentage of total farms			60
Feni	Percentage of total farms			20
Noakhali	Percentage of total farms			20

Source: Field study 2014

Table 1 presents summary statistics for output, inputs, and socio-demographic variables of the sample farmers. All inputs and output variables were accounted for one production cycle (approximately 6 months). *Output* is measured as production per acre. The average tilapia production was 4159 kg/acre. *Labor* is measured as man-day (1 man-day equal to 8 working hours). Both family and hired labor was used in production.

Fingerling is measured as numbers of fingerlings released per acre. The average number of fingerlings released per acre of pond was 24420. Good quality of fingerlings has an implication for production. The survey revealed that 86 % farms have used fingerlings from private owner hatcheries with average size 2.3 cm.[4] *Feed* is measured as kilo released per acer. Feed is one of the major inputs for fish production, which consists 74% of total variable cost in our studied sample. *Capital* is the total cost of land (rent of pond during production period) and other operational expenditure of the farms.[5] The average capital was 39110 BDT/acre. *Farm size* is measured as total farm size in acre. The average farm size was fond to be 2.88 acre.[6] [7] 61% farms were less than the average farm size, and indicate that most of the farms operate in small-scale. About 97% farms were operated by single ownership, and only 9% have disputes in partnership during leasing period of land.

Education is measures as number of years of education. The average educational level of the farmers was 8.36 years of schooling, but 9.41% of the farmers were illiterate. *Experienc*e is measured as years engaged in fish farming, and the average experience of the farmers was 7 years. *Off-farm income* is a dummy variable, where 1 indicate that the farmers is involved in off-farm work. Most farmers (54%) report that they also have off- farm income. *Credit*, *Training* and *Extension service* are also dummy variables, where 1 indicate if farmers received credit, training or had access to extension service. Farmers are engaged in different organizations namely NGOs, farmers' cooperative society to get extension services. Only 21% farmers report that they have received credit from bank. Most of the respondent farmers (63%) do not have necessary training on fish farming, but 63% of the sample farmers report that they utilize extension services over the sample period.

In this study, we have tested several hypotheses based of our expectation on inputs influence on output risk. In the production process, different inputs are expected to have different effects on output risk. While some inputs are expected to increase the production risk, others are expected to have a risk reducing effect. Our expectations build on previous studies on production risk in aquaculture (Khan et al. 2017; Kumbhakar & Tveterås 2003; Sarker et al.

[4] Sources of fingerlings: Own hatchery (4%), Government hatcheries (8%), private owner hatcheries (86%) and private traders (2%)
[5] There are wide range of culture systems used in the country. Most farmers follows either extensive (46%) or semi-intensive (43%) culture systems.
[6] 1 acre is equal to 100 decimal of land
[7] This is consistent with average farm size for pangas farming in Mymensingh district (Ali & Haque 2011).

2016; Tveterås 1999). Labor is expected to have a risk reducing effects because labor plays important role to increase monitoring capacity, controlling environment and efficient allocation of feed etc. (Khan et al. 2017; Tveterås 1999). On the contrary, an excessive use of fingerlings are likely to increase production risk because over stocking fingerlings may lead to oxygen shortage and too high concentration levels of carbon dioxide, and ammonia. In most of the biological studies, feed is found to be a risk increasing input, as excess feed might accumulate in the pond creating a harmful for environment for the fish (Alam et al. 2010; Asche & Tveterås 1999; Tveterås 1999). Investment in different capital equipment such as water supply equipment, farms house to monitoring and feeding equipment are expected to reduce the production variability and increased output.

Hypothesis related to inefficiency, tested the socio-economic and demographic variables effect on inefficiency. Extension services are expected to increase technical efficiency, because experts from extension organizations often have advanced technical knowledge on production processes, which are expected to increase farmers' efficiency. Training and education are assumed to increase farmers' managerial skills and responsiveness in adopting new technology, which is believed to have positive impacts on efficiency. The experience of the farmers could have positive impact on efficiency because increased farming experience enhances farmers managerial skill in resource allocation and monitoring bio-physical shocks (Sarker et al. 2016). Finally, credit availability for fish farming might be increase farmers preferences to invest in aquaculture and expected to increase technical efficiency (Khan et al. 2017).

3. Results and discussion

The estimated results are presented in the following sections. To test for production risk, we first estimated the quadratic mean production function using ordinary least square (OLS). Based on the OLS results, a Breusch-Pagan and White heteroscedasticity test were conducted. Both tests rejected the hypothesis of homoscedasticity (χ^2test statistics = 193.89 and 313.32 respectively) at the 1% level of significance, implying the presence of production risk in tilapia fish farming. We also performed maximum likelihood ratio test to check for the presence of production risk and technical inefficiency effects of the variance and inefficiency function, respectively. The null hypothesis assumes that tilapia fish production in Bangladesh is subject to considerable production risk besides environmental, and climate effects. The result of the log-likelihood ratio test shows that the null hypothesis was rejected at the 1% level of significance (Table 2), which implies that production risk depends on the intensity of input use, and support the functional specification of the model.

Table 2. Tests of hypothesis

Hypothesis	LR test statistics	No of restrictions	Mixture $\lambda^2_{0.01}$ critical value	Decision
I. Variance function $g(x_i;\ \psi)$ $H_0: \psi_1 = \psi_2 = \cdots\cdots = \psi_7 = 0$	37.69	7	17.75	Rejected
II. Inefficiency function $q(z; \delta)$				
No explanatory variables $H_0: \delta_1 = \delta_2 = \cdots\cdots = \delta_{12} = 0$	38.62	12	25.55	Rejected
No inefficiency $H_0: \lambda = 0$	55.15	13	27.02	Rejected

The critical value was obtained from Table 1 of Kodde and Palm (1986).

Further, we test the null hypothesis of no inefficiency, and no effects of the inputs and farm-specific exogenous factors on the inefficiency function (no inefficiency, $H_0: \lambda = 0$, i.e. $q(x; \delta)u$ = const., and $\sigma_u^2 = 0$, and no exogenous variables). The log-likelihood ratio test shows that these hypotheses were rejected at the 1 % level of significance (Table 2). This implies that aquaculture farmers in Bangladesh are technically inefficient and the farm-specific variables are important in explaining the technical inefficiency. The test results of variance and inefficiency function confirm the existence of production risk and inefficiency as a source of output variability in tilapia fish farming.

As the tests provide evidence that production risk and inefficiency are presence in tilapia fish farming, we therefore re-estimated the production function together with variance and inefficiency function (equations 8 to 10) using maximum likelihood estimation. The parameter estimates of mean production function are presents in Table 3.[8]

With the estimated parameters from the production function, we calculate the sample mean output elasticities. The elasticities were computed at individual point estimates and are reported in table 5.[9] All the input elasticities are non-negative suggests that the sample farms could increase production using the inputs with existing technology. The positive marginal product at sample mean also mean that the model satisfy the monotonicity conditions, and together an

[8] The value of output and explanatory variables included in the mean production function were normalized using their individual sample mean. This transformation move the observations toward the approximation point, assuring more reliable results for a range of observations (Ryan & Wales 2000).

[9] The elasticities were calculated at mean output and input level using the expression: $\varepsilon = \beta_j * \left(\frac{X_j}{Y}\right)$, where β_j is the marginal product from the mean production function.

quasi-concavity curvature conditions at the sample mean, the point approximation satisfies the neo-classical assumption of the production function (Ogundari & Akinbogun 2010). [10]

Table 3. Maximum likelihood estimates for parameters of mean production function

Variables	Coefficient	Std. error
Constant	***-0.023	0.007
Labor	**0.217	0.086
Feed	***0.664	0.041
Fingerlings	**0.096	0.043
Capital	0.026	0.055
Farm-size	0.143	0.115
Labor x Labor	-0.130	0.245
Feed x Feed	***-0.136	0.042
Fingerlings x Fingerlings	-0.114	0.122
Capital x Capital	**-0.146	0.073
Farm size x Farm size	-0.411	0.436
Labor x Feed	-0.064	0.102
Labor x Fingerlings	0.220	0.149
Labor x Capital	0.018	0.130
Labor x Farm size	-0.095	0.331
Feed x Fingerlings	**-0.132	0.052
Feed x Capital	*0.078	0.044
Feed x Farm size	***0.319	0.113
Fingerlings x Capital	**-0.118	0.053
Fingerlings x Farm size	0.066	0.147
Capital x Farm size	0.182	0.122
Mymensingh compared to Noakhali	0.011	0.008
Feni compared to Noakhali	-0.013	0.010

*, ** and *** denote significantly different from zero at the 10, 5 and 1 percent significance level, respectively.

[10] The curvature conditions relates to the conditions of the definiteness of Hessian matrices. A concavity test using the Hessian matrix (H) for the inputs at the sample mean were conducted. As there are five input variable in the mean function, the Hessian are expected to be fulfill the following conditions $(H_1 \leq 0)$, $(H_2 \geq 0)$, and$(H_3 \leq 0)$, so on, for details (Sauer et al. 2006). From the computation, we found that $H_1 = -0.130$,$H_2 = 0.013$,$H_3 = 0.001$, $H_4 = 0.001$ and $H_5 = 0.00009$. Based on this calculated Hessian, we can conclude that the estimated mean production function were found to be negative semidefinite, which fulfilled the concavity condition and implying diminishing marginal productivity of inputs (Tveterås 1999).

The average elasticity of feed was found to be 1.03, and is comparatively higher than other inputs. This implies that feed is the most important input for tilapia fish production. The large elasticity of feed was also found in aquaculture by other studies in different countries, e.g. in Norway (Asche & Tveterås 1999; Kumbhakar 2002), in Nigeria (Ogundari & Akinbogun 2010), and in Bangladesh (Khan et al. 2017; Sarker et al. 2016). The total elasticities, known as return to scale (RTS) was fond to be 1.691 at the sample mean, and indicate that farmers exhibit increasing return to scale.

Table 4. Parameter estimates of variance and inefficiency function

Variables	Coefficient	Std. error
Variance function		
Constant	***-20.828	3.795
Labor	1.096	0.887
Feed	***1.089	0.321
Fingerlings	***1.735	0.543
Capital	***-1.468	0.446
Farm size	-0.617	1.073
Credit	*-0.631	0.335
Mymensingh compared to Noakhali	*0.730	0.436
Feni compared to Noakhali	*0.826	0.449
Inefficiency function		
Constant	***-12.486	4.578
Labor	2.608	1.750
Feed	0.012	0.343
Fingerlings	-1.070	0.691
Capital	0.133	0.765
Farm size	0.822	1.790
Experience	0.023	0.026
Education	*0.065	0.038
Extension service	**-0.871	0.374
Training	**-0.761	0.370
Credit	-0.087	0.335
Mymensingh compared to Noakhali	***-1.594	0.518
Feni compared to Noakhali	*-1.463	0.882

*, ** and *** denote significantly different from zero at the 10, 5 and 1 percent significance level, respectively.

Table 5: Partial output elasticities for the sample mean

	Mean function elasticities estimates				
	Labor	Feed	Fingerlings	Capital	Area
Mean	0.005	1.030	0.323	0.329	0.004
Std. deviation	0.007	0.354	1.186	1.092	0.006

Because of the Cobb-Douglas specification of the risk function, the elasticities of the variance function can be discerned by looking directly at the parameter estimates from the variance function, reported in upper part of Table 4. The sign of the elasticity indicate if the input is risk increasing or decreasing; If the parameter is positive the input has a risk increasing effect, but if the parameter is negative the input is risk decreasing.

The estimated elasticity of feed and fingerlings is positive and significant, implying that production risk increases with increased use of these inputs. Risk increasing effect of feed was expected priori (Asche & Tveterås 1999; Khan et al. 2017; Kumbhakar 2002; Kumbhakar & Tveterås 2003; Ogundari & Akinbogun 2010; Tveterås 1999), because excess use of feed might create wastage, which can lead to scarcity of oxygen and increased level of ammonia in the water (Tveterås 1999). The risk-increasing effect of fingerlings was also expected (Asche & Tveterås, 1999; Khan et al., 2017; Sarker et al., 2016). High stocking density of fingerlings will lead to lower concentration of oxygen and higher concentration of carbon dioxide and ammonia in the water, which may decreases the productivity and increase risk.

Capital has significant risk-reducing effect on production risk. This is consistent with theoretical expectation, and in line with findings of earlier studies (Asche & Tveterås 1999; Khan et al. 2017; Kumbhakar 2002; Ogundari & Akinbogun 2010). Credit is found to have a significant risk-reducing effect on production risk. Aquaculture is capital intensive and a substantial amount of money is needed to invest on capital goods. The region-specific effect shows that there are significantly differences in production risk between the three regions.

The estimated parameters of the technical inefficiency function are presented in lower part of Table 4. The sign of the coefficient reveals the direction of the effect of exogenous factors on inefficiency not the magnitude of marginal effect (Kumbhakar et al. 2015). Unexpectedly, the coefficient of the education was found to be positively significant at 10% level, implying that education of the farmers has negative effect on efficiency. A possible interpretation might be that educated farmers are more likely to being involved in non-farm activities, which is the common scenario in rural areas of Bangladesh. The average level of education was higher for the farmers involved in non-farm activities compared with those that were only involved in farming in our surveyed sample. Education is also found to have a negative effect on efficiency in a study conducted on rice farmers in Bangladesh (Wadud & White 2000).

As expected, training and use of extension service were found to have a negative effect on inefficiency. The farmers who have more training have more managerial skill about production system that reduces inefficiency. The coefficient of extension service was fond to be negatively significant, indicating that technical efficiency increase with the number of contacts with extension staff, and services from government and non-government extension agents.

Table 6. Predicted TE with flexible risk function in stochastic frontier production model

TE distribution	Mean	Std. deviation	Minimum	Maximum
Estimated efficiency	0.92	0.08	0.51	0.99

The average level of efficiency is found to be 92% for the average farm, which indicates that the average farm could have increased its output by 8% using its inputs more efficiently. There is, however, a large spread in efficiency, as a small number of farms were found to be very inefficient and, at the other extreme, a small number were almost fully efficient.

To quantify the importance of production risk, equation (12) is used to decompose production variability into production risk and inefficiency. Result shows that production risk makes biggest contribution to the total output variation. For the majority of the farms the variation of production risk is greater than the variation of inefficiency; this is approximately 251 out of 339 observations. On an average, production risk contributes 66% to the total output variance in the surveyed sample. Figure 1 shows the volatility of the share of production risk and technical inefficiency in total output variability.

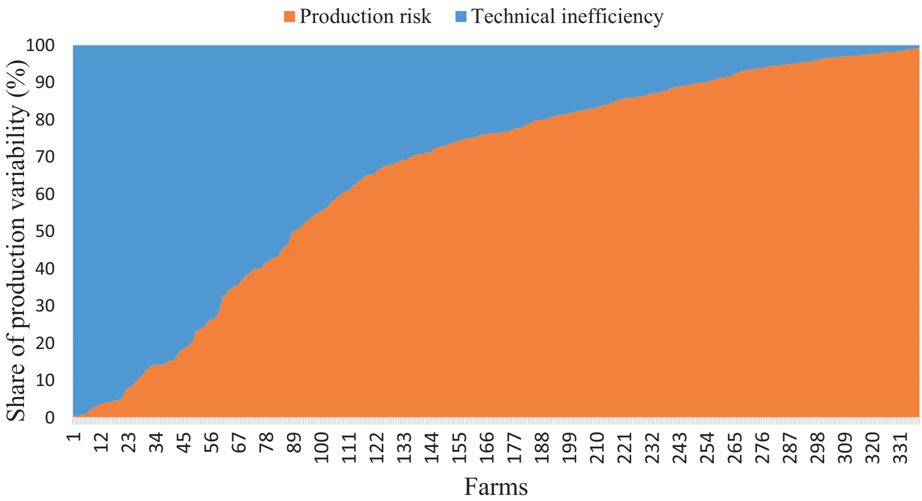

Figure 1: Percentage of production variability by production risk and inefficiency

4. Conclusion

Output variability is an intrinsic feature of the production process in most of the biological sectors, e.g., agriculture, aquaculture and fisheries, and livestock (Asche & Tveterås 1999). This is especially prominent in the aquaculture sector since a number of biophysical characteristics of environment, such as water temperature variation and oxygen concentration, directly influence the growth of fish and increase output variation (Khan et al. 2017). While production risk and technical inefficiency are observed as possible sources of output variability in aquaculture production, the literature on production risk and efficiency within a single framework is scare within the aquaculture framework. This article contributes to the literature by examine the production risk and technical inefficiency of tilapia fish farming in Bangladesh. Furthermore, we identify the risk factors that cause production variability, and the factors that reduce technical inefficiency in tilapia farming.

Results reveal that significant production risk and inefficiency exist in tilapia production system. Hence, both are importation in explaining production variability, and ignoring one will bias the other estimate (Yang et al 2016). Production risk is however found to be of largest importance, the research findings show that production risk contributes on average 66% of total variance. If the goal is to reduce production variability among the farmers, actions should be taken to reduce production risk. Both feed and fingerling are found have a risk increasing effect, and reducing the usage of these input will lower the production risk. The government has several tools to influence the usage of input factors, i.e. reducing the use of feed and fingerling by taxing the input or setting maximum limits are used in the aquaculture sector in other parts of the world (Coimbra 2001).[11] However, limiting these inputs will not only lead to reduced production risk – the productivity will also be reduced. The elasticity of feed (and fingerlings) was highest among the inputs, and a reduction of these inputs will therefor hamper the farmers.

A good strategy is to draw the attention on the input factors that is found to both increase production and reduce risk. Our results indicate that increased usage of capital and credit will reduce production risk. Capital is the most important risk reducing factor. A 1% increase in capital will reduce the risk by 1.47%. The government can stimulate to increased investment by subsidize capital goods. Another strategy is to facilitate access to credit, and by that insure that farmers can buy the optimal level of capital equipment. Besides indirectly reducing risk

[11] In Norway feed quotas was used in salmon aquaculture to limit production and the environmental pressure at a production site.

by making farmers available to buy capital goods, asses to credit is also risk-reducing by itself. Only 21% of farmers have access to credit in our surveyed sample. The Bangladesh government has a credit scheme for fish farming, but the availability is not sufficient compared with demand, and the farmers need high collateral or long term assets such as land (Khan et al. 2017). This collateral conditions work as a barrier for small-scale farmers to borrow credits from bank. The government initiative for supplying credit, particularly for small-scale farmers with less collateral and low interest rate, will reduce risk.

Although research findings show that production risk contributes to three quarters of total variance, there also significant influence of technical inefficiency. The average TE for the fish farmers is found to be 92%, implying that there is also a potential for reducing production variability by using its inputs more efficiently. According to the estimates of inefficiency function, training and increased usage of extension service has negative effect on inefficiency, i.e. positive effects on farm efficiency. Thus, policies should focus on improving farmers' management skills and efficiency through better extension service and training on production system.

Thus, policies should focus on improving farmers' management skills and efficiency through making sure that all farms have access to extension service, and/or other types of formal training. Establishing better training and extension services are also expected to contribute to reduced production variability by reducing production risk. This will be of particular importance if the government choose to adopt the strategy of facilitating increased use of capital good, as a better trained and enlightened farmer may have the ability to reduce risk associated with these new technologies.

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Paper 2

Risk in aquaculture: Farmers' perceptions and management strategies in Bangladesh

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Abstract

This study examines Bangladesh fish farmers' perception for risk sources, risk management strategies, and the relationship with socio-demographic variables. We collected data from a sample of 350 farmers in north-central and southeast regions in Bangladesh. Exploratory factor analysis of a set of perception measurement items was used to assess farmers' attitudes towards risk and their risk management strategies. Ordinary least square regression analysis was used to identify the relationship with socio-demographic variables and risk sources with management strategies. The result reveals that fish-diseases, fish price variability, low quality of feed and fingerlings, flood and credit constraints were perceived as the most important sources of risk. For risk management, supply of good quality feed and fingerlings, diseases prevention, crop insurance, increasing personal savings, and assurance of bank loans were considered as the important strategies to mitigate risks. Empirical evidence shows that farmers engage in multiple management strategies to reduce losses from fish production. In order to mitigate risk, government policy should focus on quality inputs, availability of credit with less collateral required and lower interest rates, development of a national crop insurance scheme, and market monitoring.

Key words: aquaculture, risk perception, risk management, factor analysis

1. Introduction

Aquaculture is a relatively new sector in global food production. It accounts for about 50% of the world's fish food (Bostock et al. 2010). Besides food supply, the fisheries and aquaculture sector has an important role in income generation and livelihoods, and assures 10-12% of the world's population livelihoods (Smith et al. 2010). Asia is by far the largest producer of aquacultured produce, and accounts for 89% of global production, with China, Indonesia, India, Vietnam, the Philippines and Bangladesh ranked as the top six (FAO 2016). The average annual growth rate of aquaculture was relatively faster in Asia, 8.2% (excluding China) compared to 6.2% of global rate during 2000-2012. During the last two decades, the average growth rate of aquaculture in Bangladesh has been 10%, and about 57% of the Bangladeshi fish supply is from aquaculture (DoF 2016).

Aquaculture is still an infant industry, heavily dependent upon the environment and weather. Hence aquaculture is a relatively risky business, and production is more volatile than other agricultural production such as for instance livestock (Tveterås 1999). Despite the importance of this sector, there are few studies that discuss and identify the different risk factors, and especially how farmers perceive risk. We also found very few studies that examine how farmers mitigate such risk. The aim of this paper is therefore to shed some light on this issue by studying Bangladeshi farmers' perceptions of risk sources as well as their management strategies for aquaculture.

Risk perception is a subjective judgement of the probability of the occurrence of a specified type of uncertain event, and its consequences (Sjöberg et al. 2004). Perceived risk influence an individual's decision-making behavior of a risky project, and may differ from the actual level of risk (Ahsan 2011). Risk averse individuals are likely to invest in those alternatives that they perceive as less risky. Agro-business is risky compared to other business. Farmers give more priorities on potential negative outcomes of risk, and are generally willing to avoid risk or uncertainty by losing potential income (Ahsan 2011; Ghadim & Pannell 2003). Management strategies are the process to reduce the severity of future risk and improve expected welfare (Patt & Schröter 2008). Farmers' perceptions about risk and their responses to risk are important to understanding risk behavior (Flaten et al. 2005).

In Bangladesh, farmers change their production from rice farming to fish farming, because of the potential for higher profitability. Within the study area, about 87% of fish farms were converted from cropland, particularly rice fields. However, even though this shift in production might increase farmers' potential profit it also increases risk for farmers as they face severe problems and challenges due to poor fisheries management and policy. In Bangladesh, fish farmers are facing several severe challenges related to high inputs prices, low quality of inputs, output price fluctuations, lack of storage facilities, marketing difficulties, and negative environmental effects. Credit constraints and lack of government support work as barriers to aquaculture production (Barua & Sarker 2010). These challenges are significant for small-scale farmers who often do not have access to credit. These issues suggest that proper policies are essential for sustaining the rapid growth of aquaculture in the future.

Within conventional agriculture, studies about risk perceptions and management strategies have been conducted extensively and provided useful information for stakeholders and policy makers. While similar studies in aquaculture are very few, a number of theoretical and empirical research studies have been conducted to analyze farmers' input choice with respect to their effect on output variability (Asche & Tveterås 1999; Khan et al. 2017; Kumbhakar 2002; Kumbhakar & Tveterås 2003). Risk perceptions and management strategies to cope with risk remain largely unexplained in aquaculture, though, a few recent studies have been conducted in different countries, e.g. salmon aquaculture in Norway (Bergfjord 2009), mussel aquaculture in Denmark (Ahsan & Roth 2010), catfish farming in Vietnam (Le & Cheong 2010) and shrimp farming in Bangladesh (Ahsan 2011). These studies provide information on farmers' perceptions of risk sources and management strategies. However, farming systems and perceived risks are not necessarily the same across species and regions.

In this study, we conducted a survey designed to investigate pond aquaculture farmers' risk perceptions, and their management strategies for coping with risk. We assume that the farmers' individual characteristics, geographic location and socio-demographic variables are significantly influencing their perceptions. The study is expected to provide information for policy makers, researchers, and other stakeholders in order to develop better-targeted policies for expansion and sustainable development of the growing aquaculture sector.

The paper is organized as follows: section two presents a brief description of aquaculture and associated risks in Bangladesh, section three provides the conceptual framework. Methods and data are discussed in section four, while section five is devoted to presenting estimated results from the analysis. The final section focusses on potential policy implications and concludes the study.

2. Background about aquaculture and associated risks in Bangladesh

The agro-climatic conditions and natural resources in Bangladesh are suitable for freshwater pond aquaculture. Hence, the total production has grown at an accelerated rate, with some fluctuation (Figure1). Extensive and semi-intensive pond polyculture are the major production systems in aquaculture, and Indian major carp and exotic carp are the dominant aquaculture species (Ahmed et al. 2012), accounting for 78% of total aquaculture production (DoF 2016). During the past 15 years, monoculture of tilapia and pangasius has increased rapidly. Tilapia is the most promising species since it is fast growing, and tolerate a wide range of environmental conditions, and are preferred by consumers (Ahmed et al. 2012). However, aquaculture farmers are facing problems due to inadequate technical knowledge, credit constraints, poor management, and lack of market and quality input policy.

Based on previous studies, types of risk can be specified as (i) production or yield risk; (ii) price or market risk; (iii) institutional risk; (iv) human risk; and (v) financial risk (Ahsan 2011; Harwood et al. 1999; Le & Cheong 2010).

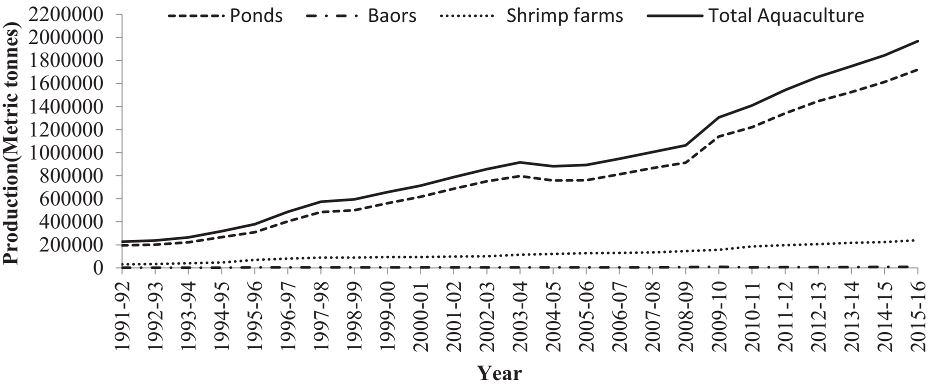

Figure1: Fish production from inland culture fishery/aquaculture (DoF, 2010, 2016).

In Bangladesh, farmers' have given more importance on risk sources related to diseases, price, input quality, and marketing of shrimp farming (Ahsan 2011). Inputs and output prices have fluctuated significantly over time, mainly because of the imperfect input and output markets (Ahsan 2011). Disease outbreaks and natural calamities like flood, cyclone, and droughts are other important issues. Financial risk is also an important risk for small-scale farmers as most farmers' buy feed from local distributors of feed manufacturing company in debt, and have to pay higher price compared to market price. They also borrow money from relatives or informal financial markets with high interest rates due to lack of access to credit from the government financial institutions.

3. Conceptual framework

Expected utility theory is the most widely used normative model for decision-making (Meyer 2002). The theory assumes that individuals behave rationally and make optimal choice under risk and uncertainty (Schoemaker & Hershey 1992), and that different procedures to determine attitudes of risk should give identical outcomes. However, empirical findings show that the results might differ across methods (Ahsan 2011; Maccrimmon & Wehrung 1986). The expected utility theory has been criticized by numerous studies because it fails to describe individuals' observed behavior (Flaten et al. 2005; Kahneman & Tversky 1979; Moschini & Hennessy 2001; Rabin & Thaler 2001), which in turn provides scope to propose the concept of subjective risk perception in the literature (Sjoberg 1998). Experimental outcomes show that probable outcomes of the same event can be perceived differently, based on the subjective judgement of the decision-maker (Ahsan 2011). Therefore, it is important to understand an individual's risk perception and its determining factors as it has a significant influence on decision-making behavior (Ho et al. 2008; Rabin & Thaler 2001). The study will use a descriptive approach, aim to characterize how aquaculture farmers perceive and manage risk in Bangladesh.

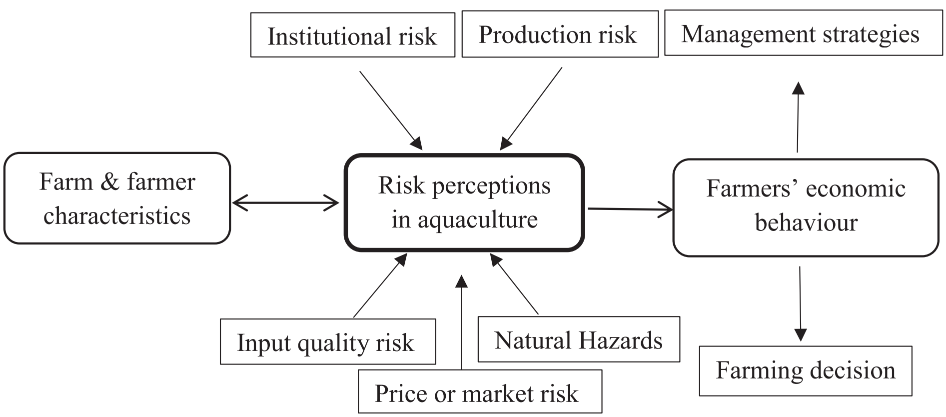

Figure 2: Modified model for firm's decision-making behavior of Van Raaij (1981)

Van Raaij's (1981) descriptive model is a framework of economic behavior, where perceived economic environment determines the individual economic behavior with subjective well-being in mind (Lien et al. 2006). Figure 2 represents the group of variables used in this study. First, the influence of farm and farmers' personal characteristics (e.g. farming system, age, education etc.) on risk perceptions; second the joint influence of farm and farmers characteristics and risk perceptions on economic behavior (risk management strategies). Within this framework, a range of possible management strategies can be explored to cope with risk. Recently, this model was used in aquaculture to explain farmers' risk perceptions and management strategies (Ahsan & Roth 2010; Ahsan 2011; Le & Cheong 2010). Hence, this study uses this descriptive approach in tandem with a survey to explore the farmers' perceptions of risk and their management strategies for coping with these risks.

4. Methods and data

In this section, sampling procedure, data collection and the econometric methods to analysis the data are briefly explained.

4.1. Sample and data

The survey was conducted in three districts in Bangladesh, Mymensingh, Feni and Noakhali (Figure 3). The survey was conducted using personal interviews.

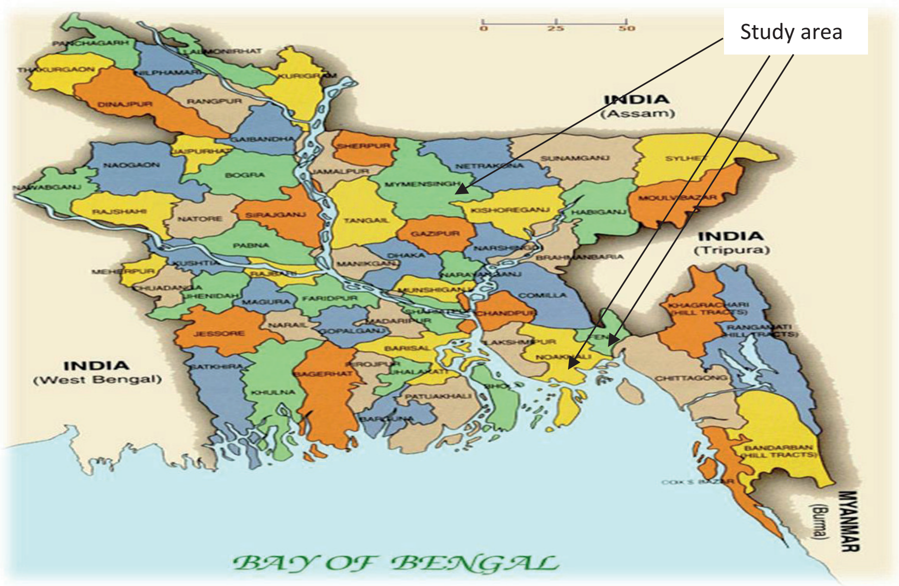

Figure 3: Map showing location of data sampling districts (Mymensingh, Feni and Noakhali)

Mymensingh is the largest pond fish producing (18.69%) area located in the north-central part of the country. Feni and Noakhali are located in the southeastern part of the country, close to coastal area, and have significant contribution to aquaculture production. A three-stage sampling was used to determine sample size. Prior to the survey, a focus group discussion was conducted with farmers, government officials, and extension workers with the aim to collect information and opinions about the sources of risk and management strategies. The questionnaire was pre-tested through a pilot survey with five farmers and improved based on information and comments from the farmers. In total, 350 farmers were interviewed.

The survey included questions related to farm and farmers' demographic characteristics, perceptions about the sources of risk, perceptions of management strategies to mitigate the risk, and motivation for involving aquaculture farming. Most of the questions about perceptions were in closed form, mainly five-point Likert-type scales (Schuman & Presser 1996). A total of 30 risk sources and 30 management strategies were presented in the questionnaire. Farmers were asked to give scores on each sources of risk on a Likert scale from 1 (least significant) to 5 (most significant) to express how important they considered risk sources in terms of its potential impact on the farm productivity and income. Farmers were given their perceived importance of each management strategy on a Likert scale from 1 (not effective at all) to 5 (highly effective).

4.2. Econometric methods

Descriptive methods were used to evaluate perceived importance of the risk sources and management strategies. We employed exploratory common factor analysis to summarize the information in a reduced number of factors and their respective factor scores (Flaten et al. 2005; Le & Cheong 2010). The number of factors retained in the final solution was based on the latent root criterion (Eigenvalue > 1), scree plots and meaningful interpretation. Oblique rotation was used for the factor matrix, which allows for correlation among the factors. Kaiser-Meyer-Olkin's (KMO) measure of sample adequacy and Barlett's test of sphericity were used to test suitability of the data for factor analysis. For factorable, individual and overall KMO has to be at least 0.5, and factor loadings of 0.4 were considered as significant (Hair et al. 2010; Hansson & Lagerkvist 2012). Standardized factor scores for each farmer were predicted for subsequent regression analysis.

Ordinary least square (OLS) regression was estimated to explore the relationship between farmers' characteristics and perceived risk, and management strategies, using the following specification:

$$FS_{i,j} = \sum_{i=1}^{10} \beta_i X_i + \varepsilon \quad (1)$$

where FS is the extracted factor scores and X_i is a set of explanatory variables as described in Table1. The basic assumptions of OLS were tested for possible violations.

5. Results and Discussion

5.1. Demographic and farm characteristics

Descriptive statistics of farms and farmers characteristics are presented in Table 1. The average age of the farmers was 43 years (range of 18 to 75 years). The average level of education was 8.36 years, while 9.41% of the sampled farmers were illiterate. The average farming experience of the respondents was 7.09 years.

Table 1. Descriptive statistics of the explanatory variables

Variables	Description	Mean	Std. deviation
Age	Age of the farmers (years)	42.72	10.84
Education	Number of years of education	8.41	4.36
Experience	Farmers experience in aquaculture farming (years)	7.09	4.93
Family size	Number of family members in household	6.13	2.70
Full-time farmer	1 if full time aquaculture farming; 0 otherwise	0.78	
Farm ownership	1 if personally owned farm; 0 otherwise	0.72	
Training	1 if received training; 0 otherwise	0.37	
Off-farm work	1 if farmers involved off-farm work; 0 otherwise	0.54	
Member of organizations	1 if farmers are the member of different organizations; 0 otherwise	0.18	
Farming system	1 if farming system is semi-improved and semi-intensive; 0 otherwise	0.89	
Geography	1 if north-central region; 0 otherwise	0.60	

Source: Field survey 2014

Training is important for large-scale farming, and about 37 % farmers have received aquaculture related training, and 18 % farmers were involved in different cooperative organizations. Most of the farmers (89%) followed semi-improved and semi-intensive farming system. About 72% farmers have their own farm while the rest are lease farms from others.

5.2. Farm income, off-farm income and farmers' motivation for aquaculture farming

The average net farm income of the respondent was $2152USD per acre[1], whereas around 7% of the farmers experienced loss. Small-scale farmers were making a marginal profit from aquaculture farming because of high feed price and others operation cost. They also faced risk from various sources such as input quality, natural calamities, diseases and output price variation, etc.

However, even though aquaculture farming is the main occupation for 78% of respondents, around 54% of the farmers were involved in off-farm activities, and income was approximately $ 2782USD per household. Most of the off-farm activities (65.78%) were businesses (e.g. small and medium scale), and about 20% was in the service sector. Farmer's participation in off-farm activities can affect the timing of aquaculture farming activities and reduce efficiency. However, additional income from off-farm activities increase average income that could help to reduce income risk from fish farming, and improve timely purchase of inputs, and family well-being. Based on farmer's perception, the top ranked reason to involve in off-farm activities was related to an increased family income (Table 2). The fourth was the reduction of income risk from farming. Like crop production, aquaculture involves risk of production loss due to low quality of inputs, natural disasters and diseases. The off-farm income increase family income that could help to minimize income loss due to production losses and negative environmental shock.

Table 2. Reasons for involvement in off-farm work (answer based on a scale from 1 = do not agree to 5 = fully agree)

Reasons	Mean	Std. deviation
Increase family income	4.04	0.99
Increase standard of living or family well-being	3.68	1.02
Utilization of working capacity	3.38	1.01
Reduction of income risk from aquaculture farming	2.94	0.98
Desire to work on something else	2.82	1.11
To help others	2.21	1.11

[1] 1 acre is equal to 100 decimal of land

In the survey, we observed that most of the farms were old rice cropland converted to fish farming, and about 86% of the respondents has the opinion that aquaculture are more profitable than other crop production. A significant number (53%) of farmers want to expand their farm area, and want to convert cropland into fish farms. The decisions to expand fish farming are likely to be motivated by economic benefits. The farmers were asked for their opinions on economic benefit and environmental effect (based on a scale 1= no effect to 5 = very high effect). The average score for perception of profitability was 3.48, and the nutritional diversity and biodiversity scores were 2.51 and 2.09, respectively. These comparative advantages of aquaculture sector is the motivation for the development of aquaculture as a new industry. Hence, understanding the expected risk sources and their mitigation strategies are very important for the sustainable development of this sector.

5.3. Farmers perceptions on risk sources and risk management strategies

5.3.1. Sources of risk

In total, 30 sources of risk were considered. The six top ranked risk sources were fish-diseases, output price variation, low quality of feed, flood, low quality of fingerlings and capital risk (Table 3). The standard deviation of these sources are less than 1, indicating a high level of consensus among the farmers. Farmers perceived level of these risk sources are presented in Figure 4. *Fish diseases* have been identified as the top ranked source of risk. It is perceived as a significant source of risk by 44 % of farmers, and as most significant by 32% of farmers. Disease has caused severe losses in aquaculture production. The second highest perceived risks were *fish price variability*. Variation in sales prices caused have big losses in profit. About 50% of farmers perceive price variation as a significant impact on farm income. This is consistent with Vietnamese catfish farmers' perceptions (Le & Cheong 2010). European agricultural farmers also have perceived price volatility as an important risk factor (Morales et al. 2008). In Bangladesh, farmers are produced fish without any guarantee in sales price, or sales contract with intermediaries. Hence, it is important to understand the reasons for this price variation, and farmers' perceptions about management strategies to cope with price risk.

Low quality of feed was the third ranked source of risk, which 41% of the respondents perceived as a significant source of risk in fish farming. Due to limited technical knowledge on quality of feed, most of the farmers depend on suggestions or opinions from local feed distributors or feed manufacturing companies. *Low quality of fingerlings* was the fourth most important source of risk, and 50 % farmers have perceived it as a significant impact on farm production. This is similar to Vietnamese catfish farmers' perceptions (Le & Cheong 2010). Additionally, *flood and drought* were perceived as substantial risk sources in aquaculture, and *capital risk* is perceived as an important source of risk by 41% farmers. Use of private capital also produces substantial risk in shrimp farming (Ahsan 2011).

Farmers perceive different sources such as polluted water, disease infected fingerlings, price variation of feed, pond management as important risk (average score > 3.0) in aquaculture farming. Other risk sources such as water quality, pond location, high labor cost, proper management, infrastructure facilities, inaccessibility to market, weak enforcement in conducting sale contact with intermediaries and inaccessibility of credit are also important in aquaculture. However, these were considered as less risky (average score < 3.0) by the respondents. Uncertainty about future price and demand, and foreign markets also have impact on investment decisions. These findings show that farmers have no clear perceptions on these issues, and this is likely due to the absence of well-established market information and lack of formal education amongst farmers. However, farmers in developed countries are concerned about future demand and price of their products e.g. in Norway (Lien et al. 2006).

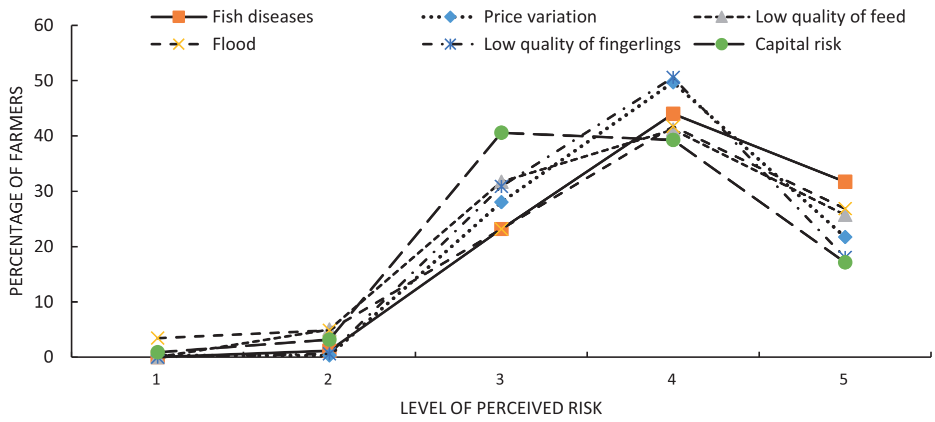

Figure 4: Farmers' perception on the importance of risk sources

5.3.2. Risk management strategies

In total, 30 risk-mitigating strategies were considered for analysis. Based on average scores of strategies, the first cluster consists of good quality of fingerlings, preventing disease, and good brand of feed with scores of 3.70, 3.64 and 3.54 respectively. The second cluster consisted of six strategies with average scores from 3.45 to 3.21, which are more effective to risk mitigation.

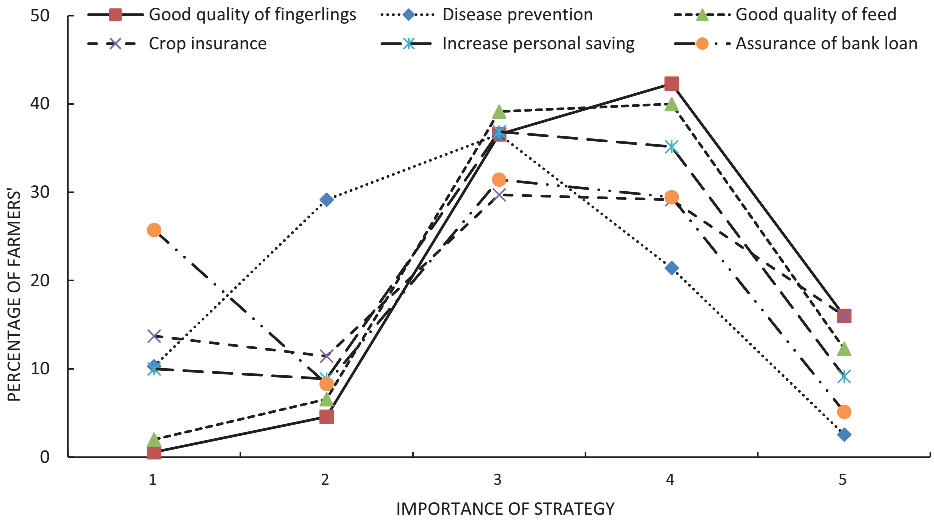

Figure 5: Farmers perception on the importance of risk reducing strategies

The third cluster consisted of seven strategies, which rated as a moderate efficacy to mitigate risk. All remaining strategies are grouped in the final cluster for which the average scores are below the median of the measuring scale (<3.0). The top ranked six strategies are presented in Figure 5. *Good quality of fingerlings* was the top most strategy, which was perceived as effective by 42% of farmers, and highly effective by 16% of farmers. This was expected since low quality of fingerlings was perceived as important risk source (Table 4). *Disease prevention and good quality of feed* were the second and third highest risk coping strategies, respectively.

About 37% of farmers perceived disease prevention as a very effective strategy to minimize risk. Previous studies, e.g. salmon farming in Norway (Bergfjord 2009), and shrimp in Bangladesh (Ahsan 2011), have found disease prevention as the most important risk management strategy. About 40% of the respondents perceived good quality of feed as an effective strategy. *Crop insurance,* and *availability of bank loans* are perceived as very effective management strategies by 30% of farmers. *Increasing personal savings* is perceived as an effective strategy by 35% of farmers. Keeping cash in hand and liquidity was found as the most important strategy in earlier studies, e.g. dairy farming in Norway (Flaten et al. 2005) and mussel farming in Denmark (Ahsan & Roth 2010). The standard deviation of the strategies were relatively low compared to previous studies (Ahsan 2011; Le & Cheong 2010). This suggests that the respondents were homogenous in terms of their perceptions. Hence, future policy should give more emphasis on these strategies to reduce risk. The study found fish price variation was the second most important source of risk (Table 3), but management strategies to mitigate price risks such as cooperative marketing, sales contract with intermediaries or processors, or production contract with predetermined size were not perceived as important strategies. This is consistent with Vietnamese catfish farmers' perceptions (Le & Cheong 2010). A possible reason might be that farmers depend on good quality of inputs and management practices to maximize profit instead of reducing price risk. Moreover, price risk is difficult to minimize for farmers, and government intervention is essential to mitigate price risk.

5.4. Factor analysis

Exploratory factor analysis with oblique rotation was used to find precise understanding of the farmers' perceptions on the consequences of risk sources and management strategies. Variables with factor loading value (i.e., loadings< |0.40|) were considered as not significant loading and deleted from the risk sources (Flaten et al. 2005; Hair et al. 2006; Le & Cheong 2010).

5.4.1. Sources of risk

The rotated factor structure of the farmers' perceptions on risk sources are presented in Table 3. The overall KMO of the factor matrices was 0.88 with individual ranges of 0.61–0.94, and Bartlett's test of sphericity was statistically significant at the 1% level ($\chi^2 = 4.160\ E^3, df = 406, P = 0.000$). The result shows that the sample data is appropriate for factor analysis (Hair et al. 2006). The latent root criterion suggested that seven factors with eigenvalues greater than one are most meaningful, which explained 85.94% of total variance.

The first factor interpreted as reflecting production risk was comprised of risk sources related to yield variation, limited knowledge about use of preventives and fingerlings, uncertainty about future price and demand, labor cost and availability of credit. The second factor comprised of risk sources related to pond water management and waste management, and over feeding which was interpreted as reflecting environmental risk. Factor 3, interpreted as institutional &

marketing risk, was comprised of risk sources related to lack of storage and transportation facilities, uncertainty about future market, inaccessibility to the market and weak enforcement with intermediaries. Factor 4 was comprised of risk sources related to flood, drought and water pollution, which was interpreted as reflecting natural hazards. Factor 5 consisted of risk sources related to diseases and quality of fingerlings and feed, which reflecting the risk due to low quality of inputs and interpreted as inputs quality. Factor 6 was interpreted as financial risk and comprised of risk such as price fluctuation of feed and fish, and financing by own capital, while factor 7 was interpreted as pond location and quality risk.

[Table 3 about here]

5.4.2. Risk management strategies

Similar to sources of risk, factor analysis extracted six factors which explaining 67.68% of total variance. The overall KMO of the factor matrices was 0.85 with individual ranges of 0.70 – 0.92, and Bartlett's test of sphericity was statistically significant at the 1% level ($\chi^2 = 3.883E^3, df = 435, P = 0.000$). The result indicating that the sample data is appropriate for factor analysis (Hair et al. 2006). The rotated factor structure for risk management strategies are presented in Table 4.

Factor 1 was interpreted as reflecting farm management and marketing strategies, consisting of strategies related to training, farm location, checking pond water, reduced farm size, market information, cooperative marketing, and sale contact with intermediaries, and farmers' cooperative associations. Factor 2 comprised of strategies related to quality fingerlings, good quality of feed, use of factory made (pellet) feed, and buying fingerlings and feed from reliable sources, which together were interpreted as quality inputs. Strategies related to disease prevention, management of pond water and treating water before stocking fingerlings were interpreted as environmental management in Factor 3. Factor 4 was interpreted as reflecting institutional support, consisting of strategies related to removal influence of intermediaries by government policy, improved storage and transportation facilities, and increase personal savings. Factor 5 was interpreted as an extension service comprised of strategies related to following expert recommendations, attending workshops, and government policy. Factor 6 was interpreted as financial management and comprised of strategies related to variables assurance of available bank loans and involvement in off-farm activities.

[Table 4 about here]

5.5. Regression analysis

5.5.1. Impact of farm and farmers characteristics on farmers' attitudes to risk sources

Table 5 shows the result of the regression analysis. All of the models were statistically significant at the 1% level. The adjusted R^2 of the models were relatively low. The low levels of goodness of fit indicate that those variables are important to explain farmers' perception have been excluded. However, this is consistent with previous studies on risk perception (Flaten et al. 2005; Le & Cheong 2010; Patrick & Musser 1997).

[Table 5 about here]

The average variance inflation factor (VIF) was 1.16 with individual range of 1.32 to 1.03, indicating absence of multicollinearity in the models. White heteroscedasticity test shows that the null hypothesis of homoscedasticity was rejected for the equation of factor ‘production’, ‘institutional’, and ‘natural hazards’. Hence, robust standard errors were estimated for consistent variance. Since the study used cross-sectional data for the regression analysis, autocorrelation seems not to be serious problem in making consistent estimations.

The results revealed that older farmers perceived production risk as an important factor compared to younger. This is consistent with catfish farmers’ perception in Vietnam (Le & Cheong 2010). Farmers training, farming systems and off-farm work has a positive significant relationship with production risk. On the contrary, farm ownership and large size of households has a significant negative impact, implying that these farmers were less concerned about production risk. Production risk was perceived as significantly importance in Mymensingh region, and this region have been identified as a promising area for freshwater pond aquaculture (Ahmed 2009). Full-time farmers perceived the environment-related risk as an important factor. On the other hand, the environmental risk factor was perceived as less important to farmers who are older, and have large household size.

Experience in fish farming was positively related to the institutional and financial risk, which is consistent with the findings of shrimp farming (Ahsan 2011). Institutional risk was perceived as important source of risk in Norway (Lien et al. 2006). On the other hand, members of organizations and older farmers were significantly less concerned about institutional risk. Full-time farmers perceived institutional and marketing, and environmental risk factors as important because they are fully dependent on farming for their livelihoods. However, their perceptions are negatively related with input quality and pond location. Farmers who had training in farming perceived risk related to production, financial, and pond location as important factors. This implies trained farmers are very concerned about those risk sources that can create variations in yield. Risk related to production and institutional support were perceived as important by farmers who had off-farm work. However, off-farm work was negatively related with natural hazards and input quality. With regard to the members of organizations, the result showed the significant negative relationship with the factors of production, environment, institutional, natural hazards and input quality risk.

Farming systems have a significantly positive relationship with risk related to production and environmental and input quality. This relationship implies that farmers who used improved farming system are more concerned with production and input risk. With regard to the variable geographic location of farm, the result shows a positive relationship with risk factors of production, input quality, financial management and pond location, implying that farmers in the Mymensingh region perceive these risk factors more than southeast region. This implies that risk sources are differ significantly between these two regions. Household size was negatively related to the risk factors of production, environment, institutional, and natural hazards. Family members contribute to farming as non-wage earning workers. In addition, large households have additional incomes from non-farm and off-farm activities, which might increase average income and reduce risk.

5.5.2. Impact of farm and farmers characteristics on attitudes to management strategies

Table 6 summarizes the results of the regression analysis. All models were statistically significant at the 1% level, with adjusted R^2 ranges of 0.29 to 0.66. The mean VIF was 1.35 with ranges of 1.12 to 2.00, which indicate absence of multicollinearity. White's consistent robust standard errors were estimated because the null hypothesis of homoscedasticity was rejected in regression equations with factor 'farm management', 'quality input', and 'financial management'.

The age of the farmers was significantly related to the farm management strategies, which indicate that older farmers perceived farm management as an important strategy to reducing risk, because they are experienced with production systems and are more concerned about production risk. The level of farmers' education positively influenced the farm management and institutional support strategies. Experienced farmers rated extension services and training management strategies highly effective. Full-time farmers perceived farm management, quality input and financial management as important strategies. Educated farmers were more concerned about institutional support and government policies related to aquaculture. Farm ownership was significantly related to the farm management strategies.

Trained farmers placed greater importance on quality inputs to mitigate risk. Farmers' involvement in off-farm work was significantly related to all risk management strategies, while positively related with farm management, institutional support, extension service and financial management strategies. This implies that the farmers, who have additional income from off-farm work, are willing to adopt such strategies to increase farm income as well as mitigate risks.

cooperative organizations perceived financial management as a relevant management strategy, whereas their perceptions were negatively related to the quality inputs strategy. One reason might be that farmers get access to quality inputs and extension services through organizations. Farming systems were negatively related to the strategies of quality inputs and extension services, implying that the farmers who used improved farming systems were less concerned about these factors. However, this preference seem contradictory because improved farming systems needs good quality of inputs and technical knowledge. Farm geographical location was positively related to quality inputs and financial management strategies, though negatively related to farm management strategy.

Farmers' perception of risk sources can significantly influence their economic behavior and farming decisions. The results show that most of the risk sources were significantly associated with multiple strategies (Table 6). This is consistent with previous studies in aquaculture (Ahsan 2011; Le & Cheong 2010). For instance, farmers who perceived production risks to be a significant source of risk have emphasized multiple management strategies such as farm management, extension service, quality inputs and financial management, which is realistic since production risk cannot be reduced by only one specific strategy. Institutional risks are an important source of risk that cannot be mitigated by a single strategy. Thus the important question is: how do farmers cope with this risk? The result shows that institutional risk was significantly related with all of the risk management strategies, which indicating that multiple strategies are essential to cope with risk. Natural hazards were highly associated with good management practices, quality inputs and environmental management. The reduction of input quality risk requires good quality and reliable source of inputs, as well as appropriate government policy. Financial risk was highly related to quality inputs, extension services, and financial management. Pond location was related to farm management, institutional support, extension services, and financial management. The multidimensional relationships between risk sources and management strategies implies that multiple strategies are required to mitigate a specific type of risk. Hence, government interventions such as institutional support, ensuring fair prices, perfect inputs, and output markets along with farmers' management strategies are essential to mitigating risks for sustainable development of the aquaculture sector in Bangladesh.

[Table 6 about here]

6. Summary and conclusions

This study provided empirical insights into farmers' perceptions of risk sources and strategies to cope with risks, and the relationship between these variables and farmers' socio-demographic characteristics. The results reveal that fish diseases, fish price variability, low quality of feed and fingerlings, flood, and financing by own capital were perceived to be important sources of risk with highest scores in terms of potential impact on farm income. On the other hand, good quality of feed and fingerlings, disease prevention, crop insurance, increase personal savings, and assurance of bank loans were perceived as the most important management strategies. Hence, unexpected variability of fish price, inputs quality and operating capital are the major issues to sustain the growth of aquaculture.

The government of Bangladesh operated a purchasing scheme for the major crops such as rice and wheat to protect the farmers when market prices are declined in the harvesting season. However, these same risk management strategies are difficult to enact for a perishable product like fish. However, government intervention in input and output markets and flow of market information could be useful policy options to reduce price variation.

The results also revealed that a number of socio-demographic variables including age, education, experience, training, off-farm work, farming systems etc., significantly influenced farmers' perceptions on risk and management strategies. Off-farm work was highly associated with strategies like farm management, institutional support, extension services, and financial management. Farmers' perception of involvement in off-farm activities were that such activities increased family well-being as well as reduced risk from fish farming. The study revealed that farmers' risk management behavior was significantly influenced by their perceptions of risk sources. Most of the risk sources were significantly associated with multiple risks management strategies, implying that multidimensional strategies are required to reduce a specific type of risk. However, there are some disparities between farmers' perception of risk and perceived management strategies, which is consistent with previous studies e.g., catfish farming (Le & Cheong 2010) and shrimp farming (Ahsan 2011). For instance, good quality of inputs and institutional support are not perceived as relevant strategies for production risk reduction. This is because of the low levels of education, training, and technical knowledge for fish farming. Proper training, education, and extension services could reduce production risks significantly.

Improved farming systems is capital intensive, particularly for tilapia and pangasius farming. Previous studies (Khan et al. 2017) found that feed cost was 71% of total variable cost for pangasius production, which is not affordable for small-scale farmers. Hence, availability of credit is an important issue for fish farmers, which is consistent with the perception of financial management strategies. The Bangladeshi government has implementing a credit scheme for fisheries through the government-owned institution Bangladesh Krishi Bank (BKB), which requires high collateral such as land or long term assets. However, credit is not sufficient compared with demand. This collateral condition is a constraint for small-scale farmers to access credit from government institutions, which is a common problem in developing countries (Ghosh et al. 2000). This liquidity constrain forces the farmers to use low quality of feed, collect credit from private banks, and local moneylenders with high interest rates. Hence, the institutional support from the government to assure the availability of bank loans at low interest rates that require less collateral are essential to reducing risk and sustaining the growth of aquaculture.

Crop insurance was perceived as one of the most important risk management strategies. Theoretically, crop insurance is an efficient instrument in risk management that can protect farmers from loss either of their products or of farm income caused by natural hazards or output price variation (Aditto et al. 2012). Thus, the Bangladeshi government should emphasis to develop a national crop insurance scheme. The government-owned Sadharan Bima Corporation (SBC) has introduced crop insurance as a pilot project in 1977, but did not sustain the project due to lack of management policy, partnership with stakeholders, monitoring and implementation (Habiba & Shaw 2013). Policy makers should give emphasis on the successful implementation of crop insurance through partnership with relevant stakeholders. Furthermore, the input and output markets are imperfect and lack transparency. Due to imperfect market information and enforcement, individual farmers' do not have adequate information about pricing of inputs and outputs at different levels in the supply chain. Bangladesh badly needs a price and marketing policy to achieve higher growth by promoting sustainable development of the aquaculture sector, and should ensure equal distribution of institutional supports.

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Table 3. Mean scores and rotated factor loadings for risk sources

Risk Sources	Mean	Std. deviation	Rank by Mean	Factor loading: Most important factors[1]						
				1	2	3	4	5	6	7
Fish diseases	4.06	0.77	1	-0.184	-0.140	0.060	0.188	**0.562**	0.329	0.134
Fish price variation	3.92	0.73	2	-0.047	-0.004	0.065	0.092	0.151	**0.648**	0.080
Low quality of feed	3.91	0.79	3	-0.258	0.002	-0.009	-0.150	0.359	**0.579**	0.016
Flood	3.87	0.95	4	-0.030	-0.079	-0.010	**0.889**	-0.029	-0.045	0.224
Low quality of fingerlings	3.86	0.70	5	0.131	-0.189	-0.023	0.101	**0.774**	0.072	-0.070
Under financing by own capital	3.69	0.80	6	0.223	-0.036	-0.265	0.239	0.133	**0.512**	-0.147
Disease infected water/ polluted water	3.51	0.99	7	-0.124	0.243	0.165	**0.645**	0.088	0.054	0.224
Disease infected fingerlings	3.51	0.79	8	0.100	0.113	0.008	-0.128	**0.653**	-0.087	0.367
Drought	3.50	0.96	9	0.304	0.225	0.030	**0.514**	0.001	-0.082	-0.126
Price fluctuation of feed and chemicals	3.23	0.91	10	0.136	0.037	0.052	-0.174	-0.219	**0.690**	0.117
Pond located in flood affected area	3.19	0.88	11	-0.017	-0.138	0.162	0.207	0.096	0.013	**0.665**
Pond do not treated before stocking fingerlings	3.10	0.70	12	-0.234	**0.984**	-0.279	0.077	-0.143	-0.032	0.291
Over feeding caused waste accumulation	3.00	0.91	13	0.176	**0.431**	0.062	0.037	0.165	0.306	-0.225
Low quality of water(high turbidity)	2.96	0.90	14	0.237	0.142	-0.084	0.140	0.212	0.115	**0.599**
Lack of storage and transportation facilities	2.92	1.07	15	-0.223	-0.208	**0.917**	-0.034	0.196	-0.062	0.112
Low quality of pond soil	2.87	0.88	16	0.193	0.272	-0.071	0.058	0.004	0.026	**0.750**
High price of fingerlings and not available due time	2.74	0.82	17	0.244	**0.411**	0.286	-0.179	0.356	-0.108	0.248
High cost of equipment	2.70	1.08	18	**0.494**	0.152	0.063	-0.295	-0.135	0.203	0.057
No reserve area for waste management	2.68	0.97	19	0.109	**0.557**	0.168	0.029	-0.208	0.008	-0.151
Applying chemical and medicines improperly	2.68	1.05	20	**0.689**	0.188	-0.071	-0.058	0.295	0.053	-0.056
High wage of labor/hired labor cost	2.64	1.04	21	**0.733**	-0.124	0.078	0.014	-0.152	0.122	0.208
Limited knowledge about use of preventives	2.61	1.11	22	**0.884**	-0.070	-0.086	-0.030	0.194	-0.050	0.042
Over stocking fingerlings	2.58	0.98	23	**0.580**	0.231	0.016	0.080	0.007	-0.136	-0.137
Inaccessibility to the market	2.49	1.14	24	0.203	0.248	**0.428**	0.133	-0.060	0.054	-0.176
Uncertainty about future price and consumer demand	2.47	1.17	25	**0.717**	0.040	0.035	0.069	-0.172	0.040	0.229
Low credit availability	2.35	1.44	26	**0.960**	-0.289	-0.148	-0.049	0.060	-0.048	0.073
Use of under size / oversize fingerlings	2.33	1.01	27	**0.617**	0.162	0.079	0.055	0.124	-0.115	-0.058
Fish yield variation	2.2	1.12	28	**0.820**	-0.118	0.056	0.013	-0.077	-0.014	0.101
Weak enforcement with middlemen	2.19	1.11	29	0.195	0.091	**0.610**	0.044	-0.064	-0.011	-0.252
Uncertainty about market	2.09	1.14	30	0.195	-0.101	**0.634**	0.113	-0.302	0.082	0.113
Percentage of the total variance				23.11	14.90	10.81	10.39	08.90	08.63	07.70

[1]Factors 1 to 7 are production, environmental, Institutional & marketing, natural hazard, input quality, financial, pond location & quality, factor loading >0.40 are shown in bold.

Table 4. Mean scores and rotated factor loadings for risk management strategies

Risk Management Strategies	Mean	Std. deviation	Rank by Mean	Factor loading: Most important factors[1]					
				1	2	3	4	5	6
Supply quality fingerlings	3.70	0.79	1	-0.158	**0.704**	0.122	-0.112	-0.129	0.119
Apply medicine to prevent diseases	3.64	0.97	2	-0.049	-0.238	**0.434**	0.262	0.038	0.244
Choose good quality/ brand of feed	3.54	0.86	3	-0.119	**0.694**	0.212	-0.007	-0.110	-0.104
Crop insurance	3.45	1.08	4	0.300	0.193	**0.569**	-0.106	-0.223	0.047
Increase personal saving	3.41	0.91	5	0.173	0.210	0.252	**-0.602**	0.019	0.144
Assurance of available bank loan	3.40	0.80	6	-0.042	0.045	-0.019	-0.022	0.003	**0.814**
Treat water before stocking fingerlings	3.34	0.96	7	-0.040	0.071	**0.616**	-0.043	0.080	-0.151
Improved transportation facilities	3.24	1.00	8	0.032	0.368	0.002	**0.704**	-0.174	0.046
Management good environment of water	3.22	0.72	9	-0.121	0.067	**0.719**	0.094	0.046	0.035
Established storage facilities	3.21	0.99	10	0.032	0.305	0.051	**0.750**	-0.105	0.054
Off-farm work	3.19	0.85	11	0.096	0.088	0.015	-0.161	0.076	**0.788**
Established farm in less flood affected area	3.19	0.91	12	-0.083	**0.452**	-0.006	0.132	0.179	0.366
Attending workshop/ training	3.13	0.85	13	**0.660**	0.126	-0.263	-0.148	0.112	-0.026
Appropriate price policy for inputs and output	3.12	0.98	14	-0.106	-0.127	-0.030	0.012	**0.583**	0.367
Buying fingerlings from reliable sources	3.09	0.99	15	0.131	**0.706**	-0.054	0.081	0.087	0.009
Buying feed from reliable sources	3.08	0.99	16	0.142	**0.737**	-0.055	0.103	0.139	-0.085
Follow recommendation from expert	3.06	0.83	17	0.141	0.166	-0.116	-0.116	**0.612**	0.032
Regular checking the fingerlings	2.99	0.87	18	**0.620**	-0.069	0.275	-0.084	0.108	-0.112
Use only factory made (pellet) feed	2.97	1.01	19	-0.008	**0.595**	-0.079	0.068	0.270	0.162
Preventing diseases by regular checking and observation	2.90	0.89	20	-0.021	0.264	0.074	**0.459**	0.354	-0.189
Availability of market information	2.87	0.90	21	**0.678**	0.048	0.019	-0.142	0.022	-0.164
Farmers' cooperative association	2.86	0.81	22	**0.760**	-0.198	-0.063	0.238	-0.116	0.155
Established farm near good water sources	2.85	1.10	23	**0.652**	0.084	0.237	-0.030	0.003	-0.082
Supplied fingerlings in appropriate time	2.80	0.85	24	-0.019	0.080	0.253	0.078	**0.628**	-0.024
Sale contact with the intermediaries'	2.72	0.96	25	**0.489**	-0.232	0.317	-0.123	0.143	0.136
Increase cooperative marketing	2.68	0.92	26	**0.794**	0.031	-0.177	0.093	-0.103	-0.012
Increase solvency ratio	2.66	0.95	27	**0.658**	0.071	-0.039	0.078	0.041	0.203
Reduce farm size in appropriate scale	2.62	0.97	28	**0.585**	-0.061	0.093	0.287	-0.026	0.012
Removal influence of intermediaries by govt. policy	2.53	1.04	29	0.182	-0.147	0.121	**0.630**	0.243	-0.093
Percentage of total variance				17.54	12.72	10.40	10.06	08.69	07.43

[1]Factors 1 to 6 are farm management, quality inputs, environment, institutional support, extension and financial management factor loading >0.40 are shown in bold

Table 5. Influence of farm and farmers characteristics on farmers' perceptions of risk sources

Independent variables	Sources of risk (Dependent variables)						
	Production	Environmental	Institutional	Natural hazard	Input quality	Financial	Pond locati
Intercept	***-1.203	0.022	0.751	0.581	-0.551	*-0.629	-0.0
	(0.332)	(0.370)	(0.385)	(0.414)	(0.377)	(0.366)	(0.40
Age	***0.013	*-0.002	*-0.009	0.009	0.003	*0.008	-0.0
	(0.004)	(0.004)	(0.005)	(0.005)	(0.004)	(0.005)	(0.00
Education	-0.015	**-0.025	-0.017	-0.007	0.007	-0.010	-0.0
	(0.012)	(0.012)	(0.014)	(0.012)	(0.011)	(0.014)	(0.01
Experience	-0.019	0.004	**0.023	-0.001	0.011	**0.021	0.0
	(0.011)	(0.012)	(0.010)	(0.011)	(0.011)	(0.010)	(0.01
Full-time farmer	0.154	*0.248	*0.233	-0.095	***-0.351	0.011	***-0.4
	(0.126)	(0.142)	(0.132)	(0.112)	(0.101)	(0.127)	(0.13
Farm ownership	***-0.289	-0.021	-0.119	-0.078	0.012	-0.141	0.1
	(0.109)	(0.114)	(0.116)	(0.121)	(0.114)	(0.111)	(0.11
Training/extension service	**0.276	-0.050	-0.071	*-0.248	*-0.174	***0.298	***0.3
	(0.112)	(0.112)	(0.121)	(0.127)	(0.102)	(0.108)	(0.09
Off-farm work	***0.354	0.149	*0.205	**-0.251	***-0.369	-0.068	0.0
	(0.115)	(0.116)	(0.124)	(0.121)	(0.110)	(0.112)	(0.10
Member of organizations	*-0.233	*-0.246	**-0.304	***-0.378	**-0.332	-0.191	0.0
	(0.124)	(0.129)	(0.133)	(0.157)	(0.130)	(0.136)	(0.14
Farming system	***0.979	***0.570	0.109	0.236	**0.411	0.061	*-0.3
	(0.167)	(0.144)	(0.155)	(0.160)	(0.182)	(0.151)	(0.17
Geography	***0.287	**-0.242	***-0.295	0.107	***0.737	***0.525	***0.6
	(0.104)	(0.115)	(0.110)	(0.110)	(0.106)	(0.106)	(0.11
Household size	***-0.046	**-0.045	***-0.066	***-0.065	0.003	-0.021	0.0
	(0.017)	(0.017)	(0.016)	(0.020)	(0.019)	(0.017)	(0.02
R-squared adjusted	***0.189	***0.066	***0.064	***0.089	***0.189	***0.121	***0.1
White heteroscedasticity	125.17	64.83	97.89	114.91	89.68	75.67	78.
test statistics[a]	(0.000)	(0.652)	(0.015)	(0.000)	(0.056)	(0.300)	(0.23

$^{(*)}$ $^{(**)}$ and $^{(***)}$ denote level of significance at 10% 5% and 1% probability level figure in the parenthesis are the standard errors

Table 6. Influence of farm and farmers 'characteristics on management strategies to cope with risks

Independent variables	Risk management strategies (Dependent variables)					
	Farm management	Quality input	Environmental	Institutional	Extension service	Financial
Intercept	**-0.603(0.234)	-0.531(0.340)	0.154(0.311)	-0.216(0.290)	-0.071(0.329)	-0.423(0.356)
Age (years)	*0.005(0.003)	0.008(0.004)	-0.001(0.004)	0.003(0.003)	0.001(0.005)	0.002(0.005)
Education (years)	**0.018(0.008)	0.013(0.009)	0.004(0.011)	**0.024(0.009)	-0.003(0.012)	0.008(0.011)
Experience (years)	-0.003(0.006)	0.007(0.008)	-0.003(0.009)	0.002(0.008)	*0.017(0.008)	0.003(0.009)
Full-time farmers	*0.152(0.086)	**0.197(0.096)	-0.091(0.107)	-0.052(0.108)	0.129(0.115)	*0.243(0.126)
Farm ownership	*0.123(0.068)	0.058(0.088)	0.138(0.098)	0.072(0.089)	0.076(0.097)	-0.017(0.110)
Training/extension service	-0.076(0.074)	*0.142(0.081)	0.055(0.095)	*-0.148(0.086)	0.012(0.103)	0.107(0.108)
Off-farm work	**0.143(0.072)	*-0.144(0.087)	*-0.199(0.103)	*0.148(0.089)	*0.185(0.100)	**0.225(0.108)
Member of organizations	0.121(0.087)	**-0.228(0.106)	-0.091(0.116)	-0.160(0.100)	-0.052(0.119)	**0.304(0.130)
Farming system	0.070(0.111)	*-0.245(0.148)	-0.150(0.137)	0.003(0.142)	**-0.324(0.162)	-0.113(0.137)
Geography	*-0.135(0.074)	***0.606(0.104)	-0.014(0.100)	-0.046(0.098)	-0.111(0.111)	*0.212(0.114)
Family size	-0.006(0.010)	0.021(0.013)	0.008(0.018)	-0.016(0.013)	0.004(0.015)	-0.024(0.022)
Sources of risk						
(1) Production	***0.304(0.045)	***-0.399(0.052)	0.089(0.058)	***-0.362(0.054)	***0.279(0.070)	***0.306(0.073)
(2) Environmental	***0.112(0.040)	0.037(0.048)	***0.263(0.0561)	***-0.155(0.045)	*0.111(0.064)	**-0.193(0.065)
(3) Institutional	***0.447(0.041)	***0.296(0.038)	***0.192(0.055)	***0.669(0.040)	***0.271(0.051)	*0.098(0.053)
(4) Natural hazards	***0.210(0.039)	***0.201(0.046)	***0.346(0.058)	0.024(0.043)	*-0.100(0.058)	0.007(0.064)
(5) Input quality	-0.053(0.037)	***0.239(0.045)	0.011(0.059)	**-0.089(0.041)	0.003(0.049)	-0.067(0.063)
(6) Financial	-0.014(0.039)	***0.165(0.043)	0.035(0.057)	0.016(0.043)	***0.170(0.052)	*0.116(0.060)
(7) Pond location	***-0.117(0.038)	-0.017(0.052)	0.026(0.058)	***0.221(0.050)	***0.293(0.051)	***0.291(0.061)
R-squared adjusted	***0.662	***0.516	***0.386	***0.516	***0.319	***0.296
White heteroscedasticity test statistics[a]	210.02 (0.075)	220.05 (0.028)	226.52 (0.013)	186.58 (0.392)	192.28 (0.286)	217.55 (0.036)

(*), (**) and (***) denote level of significance at 10%, 5% and 1% probability level, figure in the parenthesis are the standard errors.
[a]White heteroscedasticity statistics of the original regressions and P-values in parenthesis.

Paper 3

Consumer preferences for fish attributes in Bangladesh: A choice experiment

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Abstract

Over the last decade, there has been a rapid increase in aquaculture in South and Southeast Asia, and both domestic and imported farm-raised fish are now readily available in local markets. However, few consumer studies of fish preferences have been conducted in South and Southeast Asian markets; therefore, the aim of this study was to shed light on Bangladeshi consumer preferences toward wild-caught and farm-raised fish. A choice experiment was conducted at the consumer level in three cities, and the data were analyzed with a mixed logit model in willingness-to-pay space. The results showed that on average, consumers were willing to pay more for indigenous than for foreign fish species. Furthermore, they preferred domestic to imported production and fresh to frozen fish. However, Bangladeshi consumers were not willing to pay a significant premium for wild-caught fish. The lack of consumer differentiation in regard to the production method is promising for aquaculture in this region and provides hope for reducing the pressure on wild fisheries.

Keywords: aquaculture, Bangladesh, choice experiment, consumer preferences, mixed logit in willingness-to-pay space

1. Introduction

During the past few decades, world fish production has increased steadily, at an average annual rate of 3.2% (FAO 2016). Wild-caught fish are a limited seafood source, and most of the increase in seafood production has come from aquaculture. Aquaculture now accounts for about half of the seafood production in the world, and the largest aquaculture-producing countries are all in Asia, with China, Indonesia, India, Vietnam, the Philippines and Bangladesh ranked as the top six (FAO 2016). Most of the farm-raised fish in these countries are consumed locally or in other countries in the region. Despite the importance of these markets, there is little knowledge about consumer preferences for seafood in this part of the world. In this paper, we use a choice experiment (CE) to study Bangladeshi consumer preferences for wild-caught vs. farm-raised fish, fresh fish vs. frozen fish, country of origin, and indigenous and foreign fish species.

Total fish consumption in Bangladesh has increased because of the rising population and increased per capita fish consumption (Dey & Ahmed 2005). From 2005 to 2010, per capita fish consumption increased 17%, reaching 18.06 kg in 2010 (HIES 2010), which is similar to the global consumption of 20 kg in 2014 (FAO 2016). In Bangladesh, during the last two decades, the average yearly growth in farm-raised aquaculture production was 10%, whereas that of wild-caught fish was only 3.73% (DoF 2013). About 55% of the Bangladeshi fish supply is from aquaculture, 28% is from inland or wild capture, and the remaining 17% is from marine capture (DoF 2013). Much of the aquaculture production is of species that are not indigenous to Bangladesh (Beveridge et al. 2013), and low-price, farm-raised foreign species are currently gaining on traditional species in the Bangladeshi diet.

Previous studies have found that consumers in many different countries have a willingness-to-pay (WTP) for attributes such as freshness, method of production, and origin (Ahmad Hanis et al. 2013; Davidson et al. 2012; Fonner & Sylvia 2014; Loose et al. 2013; Nguyen et al. 2015; Roheim et al. 2011; Uchida et al. 2014a; Zhou et al. 2016). However, the results of consumer preference studies are often not transferable to other regions of the world. In this study, we attempt to address the knowledge gap in relation to consumer preferences for different fish quality attributes in South Asia. It is also of general interest to examine whether consumer preferences in developing Asian countries resemble those in developed countries over the last decade.

2. Fish consumer studies in Asian countries

As a background to our Bangladesh study, here we give a review of the literature on Asian consumer preferences for seafood. The main focus of Asian fish preference studies has been on food safety (Ahmad Hanis et al. 2013; Debnath et al. 2012; He et al. 2014; Hu et al. 2014; Jan et al. 2006; Thong & Olsen 2012; Wang et al. 2009), sustainable and eco-labeled fish products (Ariji 2010; Uchida et al. 2014a; Uchida et al. 2014b; Xu et al. 2012), and genetically modified (GM) fish feed (Chern et al. 2002; McCluskey et al. 2003).

Wang et al. (2009) and He et al. (2014) found that Chinese consumers were willing to pay more for safe and traceable fish products. A study by Jan et al. (2006) in Taiwan found strong demand and good market potential for safe food and a higher WTP for milkfish and oysters produced under hazard analysis critical control point (HACCP) regulations.

Thong and Olsen (2012) found that perceived quality and price were significant indicators explaining variations in consumer attitudes, and that the availability of fresh fish was an important factor explaining the variation in fish consumption in Vietnam. Freshness was an important attribute that influenced preferences (e.g., as found in India by Debnath et al., 2012 and in China by Hu et al., 2014). Ahmad Hanis et al. (2013) found that Malaysian consumers preferred fish fresh, packed fish, and fish from the supermarket.

Eco-labeling is widely used in developed countries to help consumers identify environmentally friendly products and foster awareness about the sustainability of harvesting. Some studies in Japan found that consumers were willing to pay more for different eco-labeled fish products, e.g., bluefin (Ariji 2010), for eco-labeled over non-labeled salmon (Uchida et al. 2014b), and for the perceived environmental quality of seafood (Uchida et al. 2014a). In China, Xu et al. (2012) found that consumers consider seafood labels to be an important information source and were willing to pay more for green and eco-labeled seafood. These findings are consistent with those from studies in France (Chen et al. 2015) and the United States (Zhou et al. 2016).

Chern et al. (2002) studied consumer WTP for GM foods in Japan, Norway, Taiwan and the United States, and found that consumers were willing to pay substantial premiums for non-GM salmon compared with GM and GM-feed salmon. A study by McCluskey et al. (2003) in Japan estimated the discount needed for consumers to purchase GM food products, and found that it was related to high levels of self-reported risk perceptions in relation to GM food and concerns about food safety and the environment.

Regarding production methods and the origin of products, to our knowledge, there are no previous studies from South or Southeast Asia. Uchida et al. (2014) found preferences for wild and domestic over farmed and imported salmon in Japan. This is consistent with studies in Europe (Nguyen et al. 2015; Rickertsen et al. 2017). However, wild-caught fish are not always preferred; for example, Zhou et al. (2016) found that consumers preferred farm-raised to wild-caught tuna in Kentucky in the United States.

To sum up, the Asian literature is mainly from China and Japan, while very little is from South and Southeast Asia; this is surprising given the rapid increase in aquaculture production and consumption in many Asian countries over the last decade. Furthermore, the focus of these studies has been on attributes often not used for differentiation in markets in developing Asian countries (food safety standards, GM, eco-labeling, etc.). Hence, more knowledge is needed about Asian seafood consumers and their preferences, especially in the developing countries where no such studies have been conducted.

3. Methods and data

We conducted a survey in February and March of 2016. The first part of the survey elicited information about socioeconomic characteristics, household consumption patterns, and attitudes and preferences regarding fish. The second part of the survey was a CE. The survey was pre-tested with a small consumer sample, and minor changes were made before the final data were collected.

3.1. Sample and data

We selected three different sites and conducted personal interviews. To achieve a good spread of respondent characteristics, we conducted the survey in and around the cities of Dhaka, Gazipur, and Mymensingh. Although this sample was not truly representative, these three areas have a mix of consumers in terms of culture, religion, socioeconomic conditions and food consumption behavior. Dhaka is the capital city, Gazipur is an industrial area, and Mymensingh is a medium-sized city north of the capital. In Bangladesh, it is common for the head of household to purchase the food for the entire family; therefore, we included screening questions regarding their family role and responsibility for food purchases. Of the 410 heads of household that we interviewed, only 10 said that they were not responsible for at least 50% of the food purchasing; these 10 respondents were thus excluded from the analysis.

Table 1. Descriptive statistics of the sample

Variable	Definition	%	Mean	Std. deviation
Age	Age of participants (years)		42.32	11.93
Education	Primary/elementary	24.15		
	Secondary	34.88		
	Higher secondary	13.17		
	College/University	27.80		
Monthly income	0–20,000 BDT	36.83		
	20,000–50,000 BDT	48.78		
	>50,000 BDT	14.39		
Monthly expenditure on food			7548	4026
Monthly expenditure on fish			3162	1873
Household size			4.68	1.71

1 USD = 83.10 Bangladeshi Taka (BDT)

Table 1 presents the descriptive statistics of the sample. The sample was not randomly drawn from the national population, but it was heterogeneous with respect to socioeconomic variables and food consumption. The mean age, household size, and income values are representative of the households in Bangladesh (HIES 2010). The mean age of the respondents was 42 years (range, 25–60 years). The average monthly household income was 32,700 Bangladeshi Taka (BDT). The average monthly household expenditure on fish consumption was 3162 BDT, or around 10% of monthly income.

3.2. Description of the choice experiment (CE)

The CE attributes were selected based on results from previous studies and knowledge about fish markets in Bangladesh. The attributes and their levels are presented in Table 2. To ensure that most consumers found fish that they would like to buy in at least some of the choice sets, we included four fish species[1] that are among the most sold in Bangladesh. Together, these

[1] The Latin names of the fish types are *Labeo rohita* (Rohu), *Catla catla* (Catla), *Heteropneustes fossilis/Clarias batrachus* (Singi/Magur) and *Pangasius pangasius* (Pangasius).

comprise 31% of the total fish market (DoF 2013). Rohu, Catla, and Live (Singi/Magur) are indigenous species in Bangladesh, whereas Pangasius is a foreign species.

The four price levels were set as 20% below average, average, 20% above average, and 40% above average market price. We also included origin (local or foreign), freshness (fresh or frozen), and production method (wild or farmed).

Table 2. Fish attributes, attribute levels, and coding in the choice experiment (CE)

Attributes	Level	Coding	
Retail price	170 BDT/kg	Continuous variable	
	210 BDT/kg		
	250 BDT/kg		
	290 BDT/kg		
Production method	Wild-caught	1	–
	Farm-raised	0	–
Origin	Local origin	1	–
	Foreign origin	0	–
Fresh	Fresh	1	–
	Frozen	0	–
Species	Rohu	1	0
	Catla	1	0
	Pangasius	1	0
	Live	1	0

3.3. Design of the experiment

The full factorial design had 128 ($4^2 \times 2^3$) possible combinations of different attributes and levels. A fractional factorial design (Kuhfeld et al. 1994) of 24 choice scenarios was created using STATA 13 (StataCorp LP, College Station, TX, USA).

The 24 choice scenarios were divided into four blocks (Kuhfeld 2010; Montgomery 2008; Nguyen et al. 2015) so that each respondent was presented with six choice scenarios. As shown in Figure 1, the respondents in each choice scenario were asked to choose between two fish alternatives and a none-of-the-above alternative (Hensher et al. 2005; Nguyen et al. 2015; Parker & Schrift 2011).

Alternative 1

Pangasius (*Pangasius pangasius*)
Price: 210/kg
Production method: Farm-raised
Origin: Foreign
Freshness: Fresh

I would choose ☐

Alternative 2

Rohu (*Labeo rohita*)
Price: 250/kg
Production method: Wild-caught
Origin: Local
Freshness: Frozen

I would choose ☐

Alternative 3: None of the above ……… ☐

Fig.1 Example of choice scenario

3.4. Econometric methods

We follow Train and Weeks (2005) and estimate a mixed logit model in WTP space. The utility that individual i derives from choosing alternative j in t-th choice situation is specified as a function of the fish price in BDT w_{ijt}, and different fish species and attributes x_{ijt}:

$$U_{ijt} = -\alpha_i w_{ijt} + \beta_i' x_{ijt} + \varepsilon_{ijt} \tag{1}$$

j = alternative 1, alternative 2, alternative 3 (no choice); $i = 1,\ldots\ldots\ldots I$; $t = 1,\ldots\ldots\ldots 24$.

where α_i and β_i are individual-specific coefficients for the fish price and different fish species and attributes, and ε_{ijt} is the random error that is an unobservable stochastic component. Following Train and Weeks (2005), we assumed the random error to be an i.i.d. extreme value with variance given by $\mu_i^2\left(\frac{\pi^2}{\sigma}\right)$, where μ_i is an individual-specific scale parameter. Train and Weeks (2005) show that dividing the utility (eq. 1) by μ_i results in a new error term with constant variance π^2/σ. Defining the utility $\lambda_i = \alpha_i/\mu_i$ and the WTP: $\gamma_i = \beta_i/\mu_i\lambda_i = \beta_i/\alpha_i$, the utility in equation (1) can be rewritten as:

$$U_{ijt} = -\lambda_i\left[w_{ijt} + \gamma_i' x_{ijt}\right] + \varepsilon_{ijt} \tag{2}$$

where λ_i is a price-scaling coefficient, γ_i' are WTP coefficients associated with the fish attributes and species, and ε_{ijt} is an i.i.d. type-one extreme value distributed error term. This WTP space specification has the benefit that fish attribute coefficients can be interpreted directly as marginal WTP for the attributes. The sign of the price-scaling coefficient should be negative, while the size has no direct economic interpretation. The WTP coefficients for the fish attribute are assumed to be normally distributed, while the price-scaling coefficients are assumed to be log-normally distributed (Balogh et al. 2016; Train & Weeks 2005). The latter induces the same sign of the coefficient for all individuals. Furthermore, we allowed for correlations between all random coefficients (Balogh et al. 2016; Hole & Kolstad 2012). The model was estimated with the Stata "*mixlogitwtp*" command (Hole 2015).

The WTP space specification has been applied in different fields, including food economics (e.g., Balogh et al., 2016), health economics (Hole & Kolstad 2012; Pedersen et al. 2014), and environmental economics (Balcombe et al. 2009; Scarpa et al. 2008; Train & Weeks 2005).

4. Results and discussion

In addition to the CE, the present study investigated fish consumption patterns and perceptions among consumers regarding different fish attributes.

4.1. Fish consumption patterns

With increased fish farming, food consumption patterns in Bangladesh have changed in recent years. From 2005 to 2010, the per capita consumption of fish increased by 17.58%, whereas the consumption of rice declined (HIES 2010). As shown in Table 3, the consumption of Rohu, Catla, and Live fish are positively correlated with income, whereas the consumption of Pangasius is negatively correlated with income. The low price of Pangasius makes it available to the poor (Alam 2011). Total household fish consumption was highest in the medium-income group, followed by the high and low-income groups.

Table 3. Monthly household fish consumption by income groups (quantity in kg)

Monthly income	*Rohu*	*Catla*	*Pangasius*	*Live (Singi/Magur)*	Total consumption
0–20,000 BDT	3.19	2.49	3.67	1.17	13.41
20,000–50,000 BDT	3.79	2.64	3.29	1.42	15.87
> 50,000 BDT	3.92	2.67	2.39	1.87	15.65
Average	3.54	2.58	3.40	1.44	14.55

4.2. Consumer attitudes to farmed and wild fish attributes

Given the increasing importance of fish farming, we wanted to compare consumer attitudes toward the attributes of farmed and wild fish. We therefore asked consumers to rate the importance of 14 attributes of farm-raised and wild fish on a 7-point Likert scale, with 7 indicating very important and 1 indicating not very important. Table 4 shows that the mean scores were higher than the midpoint of the scale for all attributes, which indicates that these attributes were important factors for respondents buying both farm-raised and wild-caught fish. Freshness and taste were the most important attributes for both farm-raised and wild fish, while fat content, bone content, and source of origin were among the least important attributes for both fish types. Price was considered the eighth most important attribute for both farm-raised and wild fish. The biggest differences found was for availability, which was the fourth most important attribute for farm-raised fish and the least important attribute for wild-caught fish.

Table 4. The importance of fish attributes in regard to purchase for consumption

Attributes	Farm-raised fish		Wild-caught fish	
	Mean score*	% of respondents indicating as very important	Mean score*	% of respondents indicating as very important
Freshness	6.43 (409)	94	6.49 (408)	93
Taste	6.12 (405)	86	6.46 (409)	93
Scale color	5.90(351)	78	5.94 (352)	79
Availability	5.80 (390)	75	4.76 (391)	51
Nutritive value	5.63 (353)	63	6.14 (365)	81
Health value	5.62 (361)	67	5.94 (382)	78
Size	5.61 (402)	68	5.21 (405)	62
Price	5.53 (405)	72	5.57 (405)	73
Medicine residues	5.50 (271)	65	5.23 (262)	59
Appearance	5.47 (397)	64	5.67 (400)	69
Smell	5.44 (377)	55	5.86 (382)	73
Fat content	5.00 (307)	47	4.86 (320)	40
Bone content	4.96 (347)	48	4.92 (353)	44
Source of origin	4.94 (369)	57	5.00 (359)	56

Figures in parentheses indicate the number of consumer respondents.
Note: * Based on a 7-point Likert scale, with 7 indicating very important and 1 indicating not very important.

Consumers were also asked about their level of concern regarding the environmental impact of fish farming, the overfishing of wild-caught fish, and the welfare of farm-raised and wild-caught fish. The results show that most consumers were concerned about the negative environmental impact of fish farming (61%) and the overfishing of wild-caught fish (56%). About 63% were concerned the welfare of farmed fish, and about 52% were concerned about the welfare of wild-caught fish.

4.3. Choice model results

Table 5 presents the results of the estimated mixed logit model in WTP space. In addition to the presented model, we also estimated a mixed logit model in preference space, as well as models with demographic effects. The preference space model gave similar WTP results, while no demographic variables were significant in any of the models.

Table 5. Estimated results from the model in WTP space with correlated coefficients

Attribute	Coefficients	Estimate	Std. error	*P* value
Wild	*Mean*	0.280	0.332	0.399
	Std. deviation	1.460**	0.641	0.023
Fresh	*Mean*	3.889***	1.294	0.003
	Std. deviation	3.796***	1.334	0.004
Local	*Mean*	2.629***	0.907	0.004
	Std. deviation	2.027**	0.793	0.011
Rohu	*Mean*	7.540***	1.862	0.000
	Std. deviation	6.493***	2.072	0.002
Catla	*Mean*	7.354***	1.815	0.000
	Std. deviation	6.606***	2.137	0.002
Pangasius	*Mean*	5.168***	1.352	0.000
	Std. deviation	8.976***	2.934	0.002
Live	*Mean*	8.091***	2.033	0.000
	Std. deviation	5.883***	1.916	0.002
Price	*Mean of ln (coeff.)*	-1.430***	0.323	0.000
	Std. deviation of ln (coeff.)	1.046***	0.158	0.000
Log-likelihood		-2058.92		
AIC		4205.85		
BIC		4508.65		
No. of choices		2400		

** and *** indicate significance at the 5% and 1% levels, respectively.

The model with correlated random coefficients was compared with a model with uncorrelated random coefficients using a likelihood ratio test. The test statistic, which is chi-square distributed with 36 degrees of freedom, is given by 2 × (2105.84 – 2058.92) = 93.84, that the hypothesis of uncorrelated random coefficients was rejected. Therefore, the presented model was estimated with correlated random coefficients.

The estimated coefficients in Table 5 show the WTP for different fish attributes in 100 BDT per kg. The estimates are large compared with market prices. As documented in several review papers on hypothetical bias in stated preferences (Harrison & Rutström 2008; List & Gallet 2001), survey respondents often display low sensitivity to prices, resulting in inflated WTP estimates. Harrison and Rutström (2008) found a hypothetical bias in 34 of the 39 valuation studies covered in their review. The large WTP estimates in Table 5 indicate a hypothetical bias. Hence, we discuss the results based on the relative differences between the WTP for the fish attributes and acknowledge that the estimated WTP values represents price premiums that are unlikely in the market.

All coefficients except for wild were significant. Although the coefficient for wild was positive as expected, it was not significant. This indicates that consumers are not willing to pay more for wild-caught than for farm-raised fish. This finding is not consistent with studies in many other countries, including the United States (Davidson et al. 2012), Japan (Uchida et al. 2014a), and France (Nguyen et al. 2015; Rickertsen et al. 2017), which reported that consumers were willing to pay more for wild-caught than for farm-raised fish. However, none of these studies was conducted in South Asian countries. Furthermore, the preferences for wild vs. farmed might differ based on closeness to coastal areas and the respondents' gender. Previous studies show that consumers with the strongest preference for wild seafood live in coastal areas (Davidson et al. 2012; Roheim et al. 2012; Wirth et al. 2007), and that consumers in the central part of the United States prefer farmed fish (Wirth et al. 2007). Women have also been found to have stronger preferences for wild fish compared with men (Clonan et al. 2012; Tomić et al. 2017). Our study was conducted in a non-coastal region of Bangladesh, and 92% of the heads of household interviewed were men, which could partly explain the lack of preference observed for wild fish. Another possible explanation is that consumers in Bangladesh, with its large production of farm-raised fish, consider farm-raised fish equally as good as wild fish.

The WTP for fresh was large compared with the other WTP estimates. This is consistent with the importance of freshness shown in Table 4. The results regarding fresh fish are also consistent with studies in other countries, e.g., in relation to different fish in India (Debnath et al. 2012), aquatic products in China (Hu et al. 2014), wild-caught vs. aquaculture fish in Kenya (Musa et al. 2012), quality attributes of fresh seafood in France (Nguyen et al. 2015), and fish welfare in Denmark (Stubbe Solgaard & Yang 2011). According to Ahmad Hanis et al. (2013), freshness was the most important attribute among Malaysian marine fish consumers, followed by packaging and location. Freshness was also found to be an important attribute among Asian consumers in the northeastern region of the United States (Thapa et al. 2015).

Local production was also an important attribute among our participants. This is consistent with previous studies in other countries (e.g., Davidson et al., 2012; Uchida et al., 2014; Nguyen et al., 2015), which also found that consumers prefer locally produced over imported fish.

The estimated WTP was highest for Live (Singi/Magur) fish, followed by Rohu, Catla, and Pangasius. When asked about individual fish attributes, 78% of the respondents said that Live fish was very expensive, and 67% said that it had a very good taste. The WTP values for Rohu and Catla were nearly identical. These two fish species are known as major carps and are popular in South Asia. About 61% of consumers considered Rohu fish to have a very good taste, whereas only 32% felt the same about Catla fish. Pangasius is a relatively new species that was introduced from Thailand in 1989. It is comparatively cheap and popular among low-income consumers (Alam 2011). The overall consumers' perception of farm-raised Pangasius was negative, with 49% saying that they did not like it. This may explain the low WTP for Pangasius compared with other fish.

The standard deviations of the attributes in Table 5 were large and statistically significant, indicating a substantial amount of heterogeneity in consumer preferences for different attributes. We can also see the preference heterogeneity for each attribute and fish species using kernel density. Figure 2 shows the distribution of WTP for the attributes of freshness and local origin.[2] The large heterogeneity in WTP for freshness is reflected in the wide distribution. The distributions of fish species are shown in Figure 3. Pangasius had the largest standard deviation, which indicated a higher degree of heterogeneity in WTP compared with other species.

[2] The kernel density plots are based on 100,000 random draws from the coefficients of the WTP distribution of the model in WTP space (Hole and Kolstad, 2012).

4.4. Limitations of the study

This study do have some limitations. First, we used a hypothetical CE without actual purchases, which have resulted in inflated WTP values. As discussed above, previous studies find that enlarged WTP estimates is common in hypothetical studies (Harrison & Rutström 2008; List & Gallet 2001; Loomis 2011). Second, we did not include any substitutes to fish, which might have resulted in more fish choices in the CE than what can be seen in the markets. This could have resulted in enlarged coefficients for the fish species. Finally, we did not include all potential quality attributes, such as color (Alfnes et al. 2006), appearance, and texture (Thong & Olsen 2012). These limitations should be kept in mind when evaluating the results.

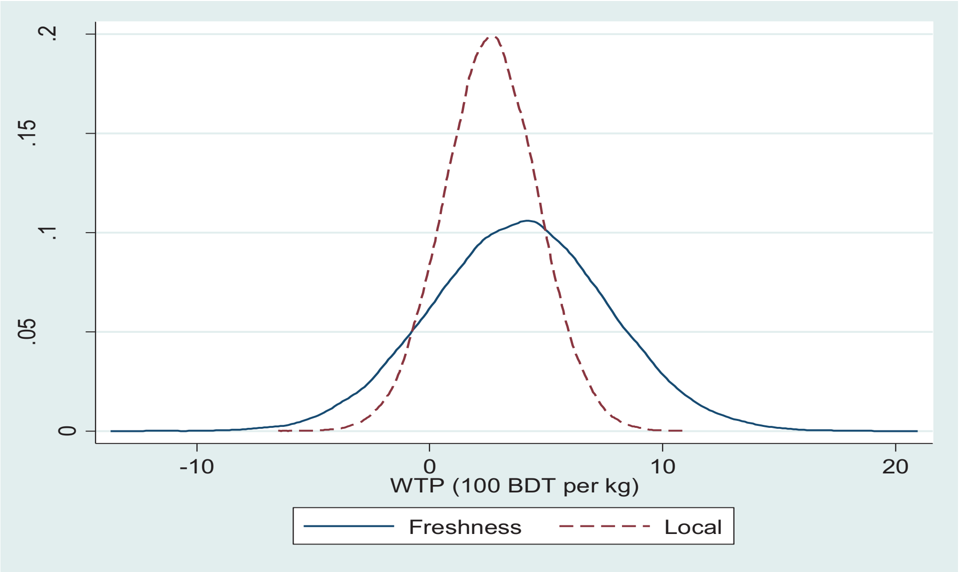

Fig.2 Willingness-to-pay (WTP) for the attributes of freshness and local origin

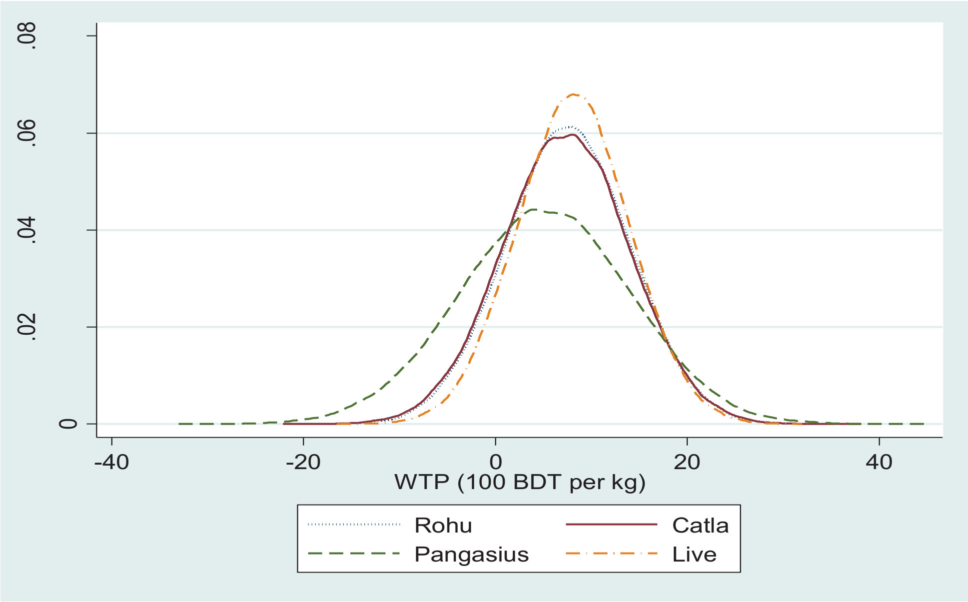

Fig.3 WTP for different fish species

5. Conclusion

Bangladeshi consumers on average are not willing to pay a significant premium for wild-caught fish. This is good news for the depleted fish stocks in and around Bangladesh. The lack of a premium for wild-caught fish means that the wild fisheries must compete with increasingly efficient aquaculture production on equal terms. Increased pricing pressure from farmed fish will likely reduce the profitability of overfishing practices in capture fisheries. This is also good news for aquaculture producers in the region, who can sell their products without a farmed-fish discount.

Applying a CE with a number of freshwater fish species enables us to investigate consumers' perceptions of both fish attributes and species. Product origin and fresh vs. frozen were identified as important determinants in consumers' choice decisions. The strong preference for freshness is consistent with results from other consumer studies in Asian countries. Bangladeshi consumers value local origin when it comes to both site of production (local origin) and species (indigenous). Consumer preferences for freshness, local origin, and indigenous species point in the direction of substantial local production of farmed fish in Bangladesh.

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Paper 4

Market integration for new aquaculture species: The whitefish market in Bangladesh

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Abstract

Aquaculture production has significantly increased global seafood supply due to an increased production of newly introduced species. Few studies have investigated how the market of new fish species is integrated with traditional species. This article examines the market interactions between new species such as pangasius, tilapia and traditional carps, and analyzes the market integration between regional markets in Bangladesh. The study employed both bivariate and multivariate cointegration approaches for monthly retail prices from July 2006 to October 2016, and also tested for The Law of One Price. The results indicate that the markets for the various species are partially integrated in the regional markets and that there is no price leader among the species. However, among the new species, the tilapia price determines the price of pangasius. Moreover, the on a species by species basis, the regional markets for rohu, pangasius, tilapia and silver carp are fully integrated, indicating a national market in Bangladesh. There is no market leader among the regional markets, which indicates that markets have their own power to transmit price information.

Keywords Cointegration, Law of One Price, market integration, weak exogeneity.

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1. Introduction

During the last decades, the global seafood supply has increased significantly, with increased aquaculture production as the main reason[2]. The rapid growth in aquaculture production has boosted the global per capita consumption, and the human consumption of farmed fish became greater than wild fish in 2014 (FAO 2016). The main reason for the increased aquaculture production is technical innovations leading to productivity growth (Anderson 2002; Asche 2008; Kumar & Engle 2016). However, the competitiveness of aquaculture can be further increased through the development of product and marketing strategies and predictable supply (Asche et al. 2009).

Market size is important for the efficiency of the price determination process (Sadoulet & De Janvry 1995). If the market size is limited, there will be few species and relatively high prices as natural production advantages will not be utilized. Alternatively, if the products compete in a large market, there will be a limited price pressure for increased production in a given region (Asche et al. 2001). A number of aquaculture species are farmed all over the world, and new species are being continuously introduced. Salmon and shrimp are the most successfully farmed species, and have been leading the global farmed seafood market for the last three decades. Recently, tilapia and pangasius are significantly increasing in global production, which introduces a new dimension in the market by supplying large quantities of farmed whitefish at very competitive prices (Asche et al. 2009; Kumar & Engle 2016). In this study, I will give particular focus to the market competition between these two successful new species with traditional species in the context of a developing economy: Bangladesh.

Whitefish is the largest segment in the global seafood market, and the number of aquaculture species has a significant impact on the whitefish market (Asche et al. 2009). A number of new species has entered this market since the early 1990s. Recently, new aquaculture species are increasingly entering this market. Pangasius and tilapia are the dominant species in terms of quantity. Recent studies found that pangasius is a price leader and competitor in the Russian whitefish market (Berg Andersen et al. 2009), and it is also important in Germany (Bronnmann et al. 2016). Development of aquaculture depends on increasing the amount of new market segments with higher quantities rather than higher price. This may limit the competition between different wild and farmed species (Asche et al. 2009). If the aquaculture sector is

[2] In 1974, the aquaculture production was only 7% of the total seafood supply. It has raised up about 50% of total seafood supply in 2014 (FAO 2016).

sufficiently large, wild and farmed product tend to be close substitutes with the same price determination processes (Asche et al. 2001). Some recent studies show evidence of market integration between farmed species and the traditional seafood market in addition to competition of wild and farmed products of the same species (Berg Andersen et al. 2009; Bronnmann et al. 2016; Nielsen et al. 2007). Hence, the new species entering the market can influence the price determination process.

In Bangladesh, the seafood market is an interesting case as an emerging market. Fish is a cheap and major source of animal protein for an increasing population (DoF 2016). Fish supply from aquaculture[3] has rapidly increased during the last two decades, and has gained market share. About 92% of aquaculture production is used for domestic consumption, and the farmed fish market has expanded 25 times in last three decades (Hernandez et al. 2017). With increased farmed fish production, the food consumption preferences have changed over recent years in Bangladesh. Recent experimental findings show that consumers are not willing to pay more for wild species than farmed (Alam & Alfnes 2017), which implies the possibility to expand farmed fish production. Bangladesh is rich in fish biodiversity with more than 250 different fish species, and most of them have a primary role for basic local food. Recent significant progress in the production of new farmed fish species such as pangasius, tilapia and silvercarp have introduced a new dimension in the supply chain. There are larger quantities being supplied and there is more access to fish products for consumers. There has been a rapid diversification of farmed fish consumption shifting from traditional carps to introduced species such as pangasius and tilapia (Hernandez et al. 2017). In 2016, the production of pangasius and tilapia were 13.01% and 9.73% of total fish supply respectively (DoF 2016). These fast growing new species go to local consumption and compete in the international whitefish market. Pangasius and tilapia are the quantity leaders in the global whitefish market (Asche et al. 2009). However, the market evolution of introduced aquaculture has not been studied for the South Asian market, although the technical aspects of pangasius and tilapia farming as well as the value chain has been studied extensively (Hernandez et al. 2017). The objective of this study is to test i) the market interaction or substitution between new species and traditional species particularly the pangasius, tilapia and carps, and ii) the market integration between regional markets for individual fish products to shed light on Bangladesh.

[3] In 1991, aquaculture fish production was limited and only 23.55% of total fish supply, which made up to 57% of total fish supply in 2016 in Bangladesh (DoF 2016).

Previous studies looking at different markets have found more or less integration between fish products e.g. whitefish in France (Asche et al. 2004), different fish species in Sweden (Blomquist 2015), tuna, whiting and hake in Spain (Jaffry et al. 2000).

Market integration investigates to what extent prices are interrelated in different markets (Mafimisebi 2012). The extent of market integration dictates how the price is affected by economic and environmental shocks (Asche et al. 2012). If the markets are integrated, supply shocks will be weaker and finding a substitute for other fish products will be easier for consumers (Pincinato & Asche 2016). A well-linked market can optimize the allocation of goods and resources. Several studies on market integration have been conducted for different fish species e.g., shrimp (Asche et al. 2012; Pincinato & Asche 2016), salmon (Asche et al. 1999; Asche et al. 2005; Jaffry et al. 2000; Landazuri-Tveteraas et al. 2017), trout (Nielsen et al. 2007; Nielsen et al. 2009), tilapia (Norman-Lopez & Asche 2008; Norman-Lopez 2009; Norman-López & Bjørndal 2009), and catfish (Bukenya & Ssebisubi 2014).

In the whitefish market, studies in different countries have found integrated markets, such as in France (Asche et al. 2004), in European first hand markets (Nielsen 2005) and in Germany (Bronnmann et al. 2016). However, these studies have focused on large-scale well-functioning markets in developed countries. There is a knowledge gap for emerging markets in the developing countries. In this study, I analyze the relationship between traditional carps and introduced farmed fish, and further examine the price determination process for individual species among regional markets in Bangladesh.

To investigate market integration I utilize the Johansen cointegration procedure (Johansen 1988). This cointegration procedure allows to test market integration and price leadership. Empirical analysis is based on monthly retail prices from 2006 to 2016 for five major fish products; rohu, catla, pangasius, tilapia and silvercarp. Pangasius, tilapia and silver carp are introduced species whereas rohu and catla are traditional carps and known as Indian major carps. The findings of the study have implications for the market participants in the Bangladeshi seafood market who wish to observe which regional markets follow similar price trends. If the markets are integrated, then price information of these markets can be used for price determination i.e. price in one region can be used as a reference price for other regions. Moreover, the price of individual fish product should respond to the supply variation of the other fish products.

The paper is organized as follows: The next section provides a brief background and data description on fish products in Bangladesh. The third section presents the empirical methods, the fourth section reports the estimated results, and the final section includes the concluding remarks of the study.

2. Background and data description

To analyze the seafood market revolution in Bangladesh, it is important to know how the food consumption behavior of the consumers has changed due to the introduction of new products. For instance, it might be of interest to understand how the newly introduced aquaculture products can be entered in traditional food. In Asia, most of the farmed fish is sold and consumed in domestic markets. Urban consumption for farmed fish products is rapidly increasing with diversified consumption form staple food into high value non-staple food (Hernandez et al. 2017). In Bangladesh, the per capita consumption of fish has increased by 17.58%, whereas the consumption of rice has declined for the period 2005 to 2010 (HIES 2010). The increased fish consumption is a result of rapid expansion of aquaculture (Belton et al. 2014). Fish is the second most important food item after rice in terms of budget share in Bangladesh (Reardon et al. 2014). This shift towards higher value-added products is expected as the consumer purchasing power is increasing. In addition, there has been a rapid shift from home consumption (i.e. from one's own pond) to purchasing fish from the market, which implies the importance of commercial aquaculture rather than subsistence aquaculture (Hernandez et al. 2017). The expansion of commercial aquaculture keep down the fish price and increased fish consumption for extreme and moderate poor consumers in rural areas of Bangladesh (Toufique & Belton 2014). In the developed countries, most of the distribution of seafood take place in the retail distribution channels including supermarkets (Berg Andersen et al. 2009). In Bangladesh, retailers are the last intermediaries who sell the entire fish to ultimate consumers. Traditionally retailers have to buy the fish from local wholesalers.

The data set used in this study is the monthly retail[4] prices for the period July 2006 to October 2016. The data obtained from the Department of Agricultural Marketing, Ministry of Agriculture for four administrative divisions namely Dhaka, Chittagong, Rajshahi and Khulna.

[4] I used the retail price because the farmers direct involvement in the retail markets are increasing. Due to rapid growth in commercial aquaculture, increasing a new pattern in marketing system by direct participation of the farmers (Alam et al. 2012).

The price series is the average of all markets within the division (Sapkota et al. 2015). The data did not contain information on whether the fish products are fresh or frozen.

Table 1. Average prices (BDT/Kg) and Coefficient of variation (CV) for selected species at retail levels, 2006 to 2016

Market	Statistic	Rohu	Catla	Pangasius	Tilapia	Silver carp
Dhaka	Mean	229.42	195.12	107.94	122.75	112.14
	Std. deviation	43.53	44.36	19.87	21.60	28.76
	CV	18.99	22.73	18.40	17.59	25.64
Chittagong	Mean	217.76	212.21	100.40	129.05	122.07
	Std. deviation	54.82	57.43	19.81	20.22	33.69
	CV	25.17	27.06	19.37	15.66	27.59
Rajshahi	Mean	220.63	199.88	110.19	114.77	113.29
	Std. deviation	43.68	39.85	21.29	20.29	24.17
	CV	19.79	19.93	19.32	17.67	21.33
Khulna	Mean	211.10	173.99	115.97	113.37	105.38
	Std. deviation	43.05	35.51	15.59	18.69	22.92
	CV	20.39	20.40	13.44	16.48	21.74

1USD = 83.10 Bangladeshi Taka (BDT)

Five aquaculture fish products are considered in this study: rohu[5], catla, pangasius, tilapia and silvercarp. These species are among the 30 most highly and commonly consumed fish products in Bangladesh (DoF 2016). These species make a significant contribution to the total fish supply, constituting 42% of the total fish supply in Bangladesh (DoF 2016). Rohu and catla are known as traditional carps or Indian major carps and they are very popular in Indian sub-continent. Pangasius and tilapia are newly introduced farmed fish species, and have been commercially produced only in the last decade.

Table 1 shows the descriptive statistics of the price for each species and region. The coefficient of variation for silver carp fish was comparatively higher than other fish species for each region. These selected fish species are produced more or less all over the country. However, a large proportion (32%) is produced in the Dhaka region. The production of rohu and catla is comparatively high in the Rajshahi and Chittagong regions. For pangasius, a significant amount (64%) is produced in Dhaka region. A large proportion of silver carp is produced in the Rajshahi and Dhaka regions. In contrast, smaller quantities of tilapia are produced in Rajshahi. Hence, there is a possibility to trade different quantities between the regions. For rohu and

[5] The Latin name of the fish species are *Labeo rohita* = Rohu, *Catla catla* = Catla, *Pangasius hypophthalmus* = Pangasius, *Oreochromis mossambicus/ O. niloticus* = Tilapia, and *Hypophthalmichthys molitrix* = Silvercarp.

catla, the prices were for 1 kilogram (Kg) of whole fish measuring weight 1.5 to 2 kg. For others species, the prices were for 1 Kg of whole fish.

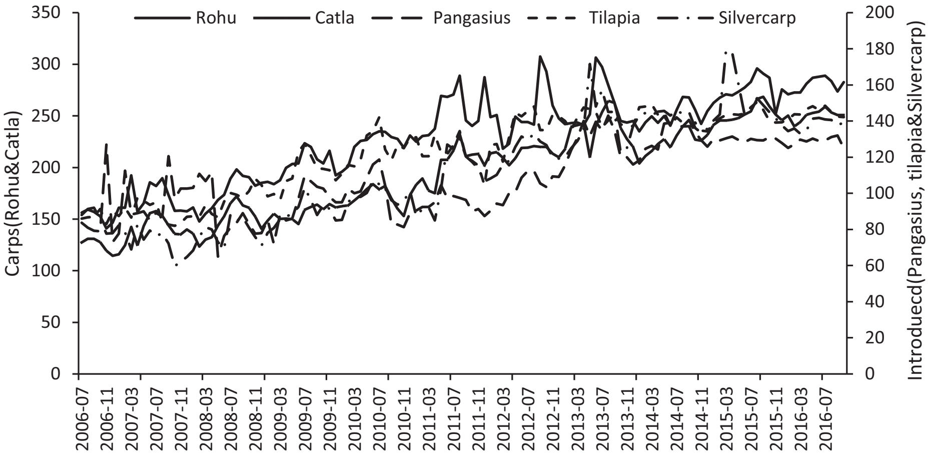

Figure 1. Monthly retail prices (BDT/Kg) of selected fish species in Dhaka

Figure 1 presents the prices (BDT/Kg) of rohu, catla, silver carp, pangasius and tilapia in Dhaka. The left vertical axis represents the traditional carp species such as rohu and catla, and the right vertical axis represents the newly introduced species such as silver carp, pangasius and tilapia. Overall, an increasing trend with fluctuations in prices for all species can be observed. There are spatial price differences among the regions for individual fish species. However, the price variation of pangasius, tilapia and rohu seems to be less compared to the price variation of catla and silver carp. To observe the price differences among the regions, the prices for each species in different regions are plotted in Figure 2a to 2e. These figures give an impression of the development of prices over time. All species prices show an increasing trend with fluctuations over time, however the prices are more volatile for rohu and catla.

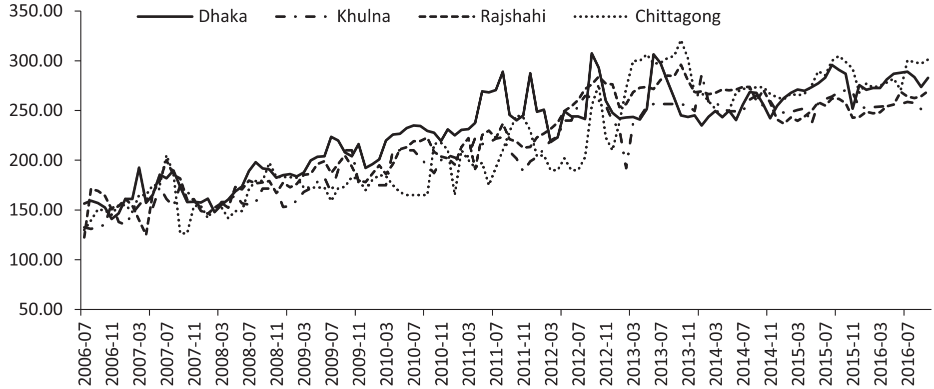

Figure 2.a Monthly retail prices (BDT/Kg) of rohu fish in Bangladesh

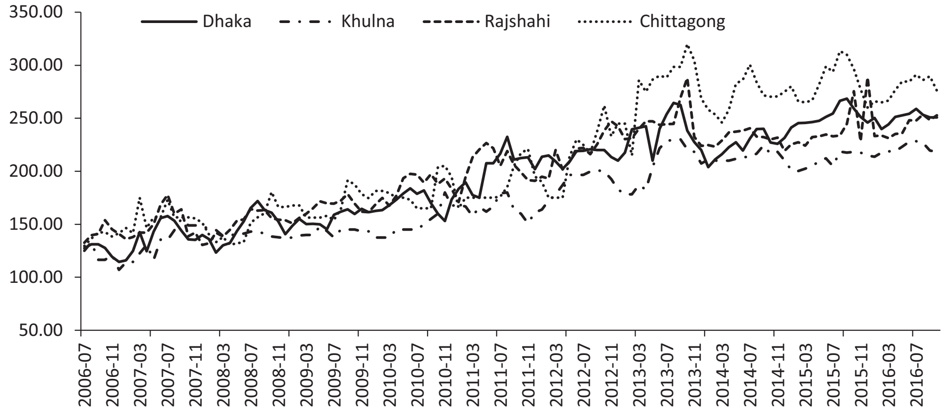

Figure 2.b Monthly retail prices (BDT/Kg) of catla fish in Bangladesh

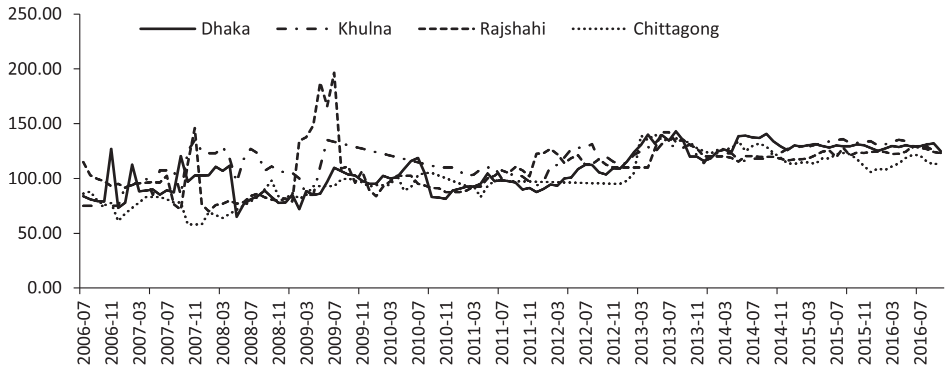

Figure 2.c Monthly retail prices (BDT/Kg) of pangasius fish in Bangladesh

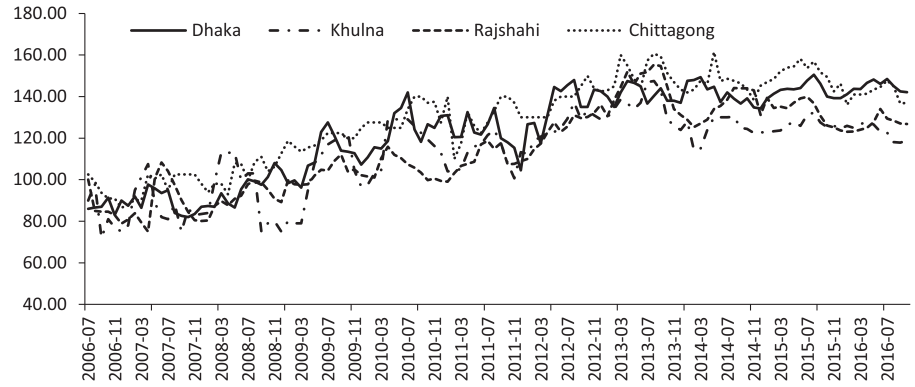

Figure 2.d Monthly retail prices (BDT/Kg) of tilapia fish in Bangladesh

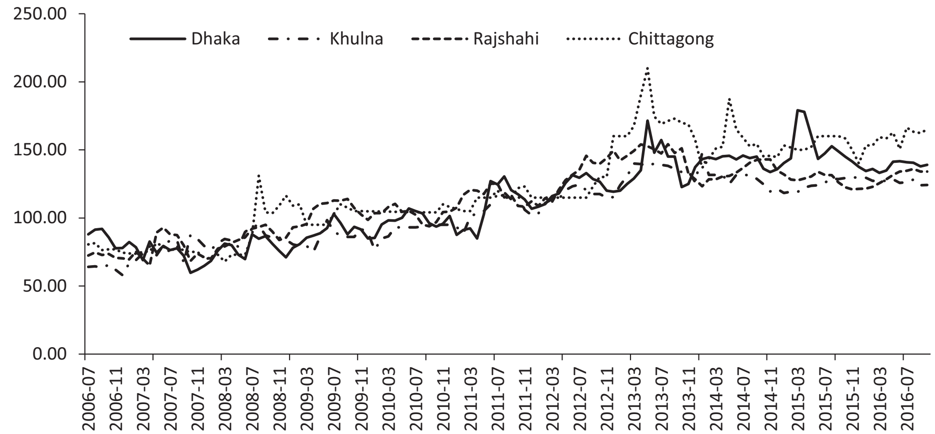

Figure 2.e Monthly retail prices (BDT/Kg) of silver carp fish in Bangladesh

Before investigating market integration, I have checked the time series properties of the price series. The presence of unit roots properties are tested using the most common approaches such as Augmented Dickey-Fuller (ADF) and KPSS. For the ADF test, the null hypothesis is that data series are nonstationary with alternative hypothesis of stationary. Appropriate lag length is set to achieve white noise in the error term (Asche et al. 2005). KPSS[6] test (Kwiatkowski et al. 1992) is the most common reversal of unit root tests, which specify a null hypothesis of stationary or trend stationary and an alternative of nonstationary. Both tests have been

[6] The lag length is selected using the combination of automatic bandwidth selection and quadratic spectral kernel option. Best performance was found for small sample using this option (Hobijn et al. 1998).

conducted with constant, trend and without constant for the level, and first difference for the price series. The results of the ADF and KPSS test are reported in Table 2.

Table 2. Unit root tests

Division	Species	Level (constant)		level (constant & trend)		1^{st}difference (without trend)	
		ADF	KPSS	ADF	KPSS	ADF	KPSS
Dhaka	Rohu	-1.989(4)	2.75^{**}	-3.079	0.464^{**}	-12.551^{**}	0.038
	Catla	-1.541(4)	3.01^{**}	-3.230	0.277^{**}	-10.741^{**}	0.034
	Pangasius	-1.801(5)	2.38^{**}	-3.110	0.176^{*}	-16.112^{**}	0.032
	Tilapia	-1.537(3)	2.79^{**}	-2.534	0.490^{**}	-12.841^{**}	0.076
	Silvercarp	-0.971(5)	2.90^{**}	-2.889	0.216^{*}	-11.457^{**}	0.043
Khulna	Rohu	-1.488(4)	2.98^{**}	-2.818	0.379^{**}	-12.778^{**}	0.086
	Catla	-1.011(1)	2.98^{**}	-3.114	0.159^{*}	-12.714^{**}	0.035
	Pangasius	-3.552^{*}(3)	1.40^{**}	-3.652^{*}	0.132	-11.836^{**}	0.109
	Tilapia	-2.327(1)	2.16^{**}	-3.583^{*}	0.304^{**}	-11.471^{**}	0.034
	Silvercarp	-1.966(3)	2.88^{**}	-2.110	0.388^{**}	-13.761^{**}	0.141
Chittagong	Rohu	-1.030(6)	2.90^{**}	-3.087	0.120	-10.949^{**}	0.020
	Catla	-1.250(3)	2.98^{**}	-3.274	0.183^{*}	-12.471^{**}	0.040
	Pangasius	-1.656(1)	2.42^{**}	-3.306	0.171^{*}	-11.229^{**}	0.043
	Tilapia	-1.929(3)	2.73^{**}	-1.775	0.534^{**}	-13.953^{**}	0.105
	Silvercarp	-1.300(1)	2.81^{**}	-3.129	0.192^{*}	-12.073^{**}	0.039
Rajshahi	Rohu	-1.466(1)	2.84^{**}	-3.112	0.436^{**}	-13.431^{**}	0.112
	Catla	-1.547(1)	2.95^{**}	-3.388	0.350^{**}	-14.621^{**}	0.040
	Pangasius	-2.658(3)	1.29^{**}	-3.603^{*}	0.051	-12.211^{**}	0.035
	Tilapia	-1.780(2)	2.68^{**}	-2.904	0.301^{**}	-10.286^{**}	0.051
	Silvercarp	-1.762(1)	2.60^{**}	-2.499	0.469^{**}	-10.656^{**}	0.081
Critical value at 5%		-2.889	0.463	-3.447	0.146	-2.889	0.463

**and * indicates statistical significance at the 1% and 5% level, respectively. Optimum number of lags were shown in the parentheses

The test results show that the null hypothesis of nonstationary for the price series cannot reject in level with constant and trend. However, in first difference form the null hypothesis of nonstationary are rejected for all price series. Therefore, I can conclude that the price series for different fish species are integrated of order one, i.e., *I* (1), and market linkage can be investigated using the cointegration test.

3. Methodology

In order to investigate the market linkage between different fish species, I tested for market integration. During the last two decades, market integration has been used as a typical approach to analyze the price relationship by focusing on cointegration and the Law of One Price (LOP). If the price of goods are determined within the same market, prices follow the same stochastic trend over time, forming a long-run relationship (Nielsen et al. 2009). The long-run relationship between the prices of fish species can be expressed in logarithm[7] as follows:

$$lnP_t^i = \alpha + \beta lnP_t^i + e_t \quad (1)$$

where P_t^i is the observed price of fish species i at time period t, and α is a constant term that captures transaction costs and quality differences between species; β determines the relationship between the market price of fish species. If $\beta = 0$, there is no relationship between the price of fish species and no substitution, while if $\beta = 1$, the LOP holds and the relative price is constant. In that case, species are perfect substitutes and markets are fully integrated. If $\beta \neq 0$ and $\beta \neq 1$, there is a relationship between prices but the relative price is not constant, In that case, species will be imperfect substitutes and the markets are partially integrated. Lags of the two price can be introduced into equation (1) to account dynamic adjustment, and then the long-run relationship has the same form as equation (1). For non-stationary price series, the regression of equation (1) often gives spurious results. It has often been noted to non-stationary price series. Hence, cointegration 'is a natural extension' to overcome this shortcoming (Asche et al. 2004). In this study, the prices have a unit root and integrated of order one. Therefore, cointegration tests are an appropriate tool, and the Johansen framework is the most common approach in this case, which has several advantages over the Engle and Granger cointegration method.

The relationship in equation (1) can be extended to any number of goods (Froot & Rogoff 1995), that produce a multivariate specification. However, the multivariate specification of the equation (1) does not provide any additional information. A multivariate approach for the LOP only indicates that the cointegration vector must sum to zero, or in a single equation the right hand side variable coefficients must sum one (Asche et al. 2005). If all variables are cointegrated in a bivariate relationship, a common stochastic trend will be identified by a multivariate system, and the systems should have $n - 1$ cointegration vectors (Hall et al. 1992). Multivariate models have some advantages over the bivariate specification. In the

[7] Logarithmic specification of market integration relationship has been proven to boost model specification and simple interpretation of parameter estimates. The LOP will fulfilled when prices of different fish species move together over time (Asche et al. 2004; Bronnmann et al. 2016).

multivariate system, it is only possible to estimate $n-1$ cointegration vectors and find out the exogenous variable if there is any[8].

The Johansen cointegration method is based on a vector autoregressive (VAR) form, but can be reformulated in an error correction model (ECM). The multivariate specification of this approach can be expressed as follows. Let X_t is a $n \times 1$ vector assuming unrestricted vector autoregressive (VAR) of the variables in the levels forms as

$$X_t = \Pi_1 X_{t-1} + \cdots + \Pi_k X_{t-k} + \Phi D_t + \mu + e_t \qquad (2)$$

where Π_i is a $n \times n$ matrix of parameters, μ is a constant term, and e_t is an error term i.e. $e_t \sim$ i.i.d $(0, \Sigma)$ and D_t is a vector of other deterministic components. The VAR system in equation (2) can be rewritten in ECM as follows;

$$\Delta X_t = \Gamma_1 \Delta X_{t-1} + \cdots + \Gamma_{k-1} \Delta X_{t-k+1} + \Pi X_{t-k} + \psi D_t + \varepsilon_t \qquad (3)$$

where $\Gamma_i = -(I - \Pi_1 - \cdots - \Pi_i)$, $i = 1, \dots\dots, k-1$ and $\Pi_i = -(I - \Pi_1 - \cdots - \Pi_k)$. The matrix Π is the long-run solution to the VAR model in equation (2). Assuming X_t is a vector of nonstationary $I(1)$ variables in equation (2), then the left-hand side and the first $(k-1)$ elements of equation (3) are $I(0)$, while ΠX_{t-k} must be stationary for the error term $\varepsilon_t \sim I(0)$ to be 'white noise'. The rank of Π, r, determines the number of linear combination of X_t are stationary. If the cointegration vectors are equal to the number of variables $(r = n)$, the variables in the level are stationary. If cointegration vector r is zero, so that $\Pi = 0$, then none of the linear combinations are stationary. When $0 < r < n$, indicating the existence of r cointegration vector, that is a single integrating factor or common factor exist among all price series (Asche et al. 1999). If so, Π can be factorize into $\Pi = \alpha\beta'$, where α contains the adjustment coefficient and β contains the cointegration vectors. The number of the cointegration vectors can be identified using the *maximal eigenvalue* test and the *trace* test (Johansen 1988).

The Johansen approach is flexible to impose restrictions for testing the hypothesis on the coefficients α and β, using likelihood ratio tests (Johansen & Juselius 1990). The LOP hypothesis is tested by imposing restrictions on the parameters in the cointegration vector. If

[8] For example, in bivariate cointegration if the price series 1 is exogenous for 2, but that 3 is exogenous for 1, but not for 2 then it is difficult to identify one exogenous variable. A multivariate test will able to identify the exogenous variable in the system if there is any. However, the multivariate models have some problems of dimensionality (Asche et al. 2005).

two price series in the X_t vector are cointegrated, then the rank of $\Pi = \alpha\beta'$ is equal to 1, and α and β are 2×1 vectors. Therefore, test of LOP is a test of whether $\beta' = (1, -1)'$. In the same market, if a group of goods exists; all the pairwise prices must be cointegrated. This also allows the LOP of multivariate test because there is a common stochastic trend with $n - 1$ cointegration vectors (Asche et al. 1999). In a system of n data series and r cointegration vectors, there will be $n - r$ stochastic trends (Asche et al. 2005). The LOP is tested by imposing restrictions on the β matrix which makes the columns sum to zero.

$$\beta = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ -1 & 0 & \cdots & 0 \\ 0 & -1 & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & -1 \end{bmatrix}$$

The α vector contains information about price leadership (Asche et al. 2005), the question of weakly exogenous in data series are tested by imposing zero rows in α vector. When there is one common stochastic trend in the system with many endogenous variables, there can be one exogenous variable at most. Therefore, there can be only one price leader. When the cointegration test identifies a common trend for all price series and the test of LOP is accepted, then the markets are closely integrated. If a common integrating factor is identified but the LOP is rejected then the markets are partially integrated and the products are imperfect substitutes (Nielsen et al. 2009).

4. Empirical results and discussion

In this study, data is available for the prices for five fish products including traditional and new species from markets in four regions in Bangladesh. The objectives were therefore to test market integration between traditional and newly introduced species, and the integration between regional markets for individual species to observe the price determination process. I present the results of the market integration test in two sub-sections. Given the large number of markets, I first conducted the pairwise bivariate co-integration test to identify common stochastic trends and find out whether the price series moves together over time or not[9]. The multivariate cointegration test was also conducted to find common stochastic trends and exogenous variables. The lag lengths were selected by minimizing Schwartz's information

[9] All cointegration tests have conducted with the unrestricted constant term to cointegration space, as there are linear trend in data. Seasonal effects were also tested and corrected using central seasonal dummies where needed.

criteria to whiten the error term. The Lagrange multiplier test for autocorrelation up to the 12 order is statistically insignificant everywhere, indicating white noise error.

4.1. Integration between traditional and newly introduced species

In Dhaka, the test statistics indicate that all combinations containing five fish species –rohu, catla, pangasius, tilapia and silver carp–are cointegrated, as the null hypothesis of zero cointegration vectors are rejected at the 1% significance level, while the hypothesis of one cointegration vector cannot be rejected. However, the tests of LOP restriction is rejected for most of the pairs except the pairs between rohu and pangasius, rohu and tilapia, catla and silvercarp, and pangasius and tilapia (Table 3). A multivariate test was carried out to clarify the relationship. The results suggest that there are four cointegration vectors and one stochastic trend in the system with five price series, whereas the LOP is rejected at the 1% significance level (Table 4). This implies that the markets for these fish species prices are not fully integrated. However, the LOP test cannot be rejected when considering only three fish species rohu, pangasius and tilapia This provides evidence that the market segments for rohu, pangasius and tilapia are highly integrated, and these three species can be aggregated into a single commodity based on the generalized composite commodity theorem (Asche et al. 2004).

In Chittagong, the null hypothesis of no cointegrating is rejected at the 1% significant level for all pairwise cointegration test, and we cannot reject the hypothesis of less than or equal to one cointegrating vector. This implies that the prices for different species in the Chittagong market compete in the same market. The LOP cannot be rejected for rohu and catla, rohu and pangasius, rohu and tilapia, catla and silvercarp, and pangasius and tilapia, but the hypothesis is rejected for the other ten combinations of prices. To clarify the long run relationship a multivariate cointegration test has carried out and found that the species of rohu, catla, pangasius, tilapia and silver carp are partially integrated (Table 4).

In Rajshahi, the null hypothesis of no cointegration is rejected for all the pairwise cointegration at the 1% level of significance, and the hypothesis of one cointegration vector cannot be rejected. The LOP holds for the combination of rohu and catla, rohu and pangasius, rohu and tilapia, rohu and silvercarp, catla and pangasius, catla and tilapia, catla and silvercarp, and pangasius and tilapia, but the hypothesis is rejected for the combination of pangasius and silvercarp, and tilapia and silvercarp (Table 3). The results of the multivariate test suggests that the species of rohu, catla, pangasius, tilapia and silvercarp are partially integrated as the LOP does not holds (Table 4).

In Khulna, the test results indicate that all combinations containing five species are cointegrated, which indicates a common stochastic trend between the species. The hypothesis of LOP is rejected for any combination of prices that includes rohu and pangasius, catla and pangasius, pangasius and tilapia, pangasius and tilapia, and tilapia and silver carp. This indicates that these fish species are not perfectly substitutable.

[Table 3 and 4 about here]

4.2. Integration between regional markets for individual fish species

Table 5 represent the results from the bivariate Johansen co-integration test between regional markets. For rohu, the null hypothesis of no cointegrating vectors is rejected at the 1% significant level for all combination markets, and the null hypothesis of less than or equal to one cointegrating vector ($P \leq 1$) cannot be rejected. This implies that these prices contain common trends among the markets. Tests for the restriction of LOP holds in each combination of markets. A multivariate specification of cointegration test was carried out in the system containing all four markets. The results suggest that there are three cointegration vectors in the system with four price series and a common stochastic trend. The multivariate test for the null hypothesis of LOP cannot be rejected (Table 6). Thus, Dhaka, Chittagong, Rajshahi and Khulna accordingly form a highly integrated market for rohu.

For catla species, the null hypothesis of no cointegration is rejected at the 1% level of significance for all six pairs of market combinations, which indicates that these prices contain a common stochastic trend. However, the restriction of LOP does not holds for all combinations. The test of LOP is rejected between Dhaka and Rajshahi, Chittagong and Rajshahi, and Chittagong and Khulna. The multivariate test of LOP is rejected at the 5% level of significance. This implies that these markets are partially integrated for catla species.

For pangasius, the null hypothesis of no cointegration is rejected at the 1% significance level for all combination markets, and we cannot reject the null hypothesis of less than or equal to one cointegrating vector ($P \leq 1$). This implies that these prices contain common trends among the markets. The LOP restrictions holds for all combinations except Rajshahi and Chittagong.

However, the Johansen multivariate test shows that LOP holds for the whole system. This implies that these markets are fully integrated for pangasius fish.

For tilapia and silver carp, the null hypothesis of no cointegrating vectors is rejected at the 1% significant level for all combination markets, and we cannot reject the null hypothesis of less than or equal to one cointegrating vector ($P \leq 1$). Tests for the restriction of LOP holds in each combination of markets. A multivariate specification of the cointegration test was carried out in the system containing all four markets. The results suggest that there are three cointegration vectors in the system with four price series and a common stochastic trend. The multivariate test of the null hypothesis of LOP that holds for the whole system cannot be rejected (Table 6). Thus, Dhaka, Chittagong, Rajshahi and Khulna accordingly form a highly integrated market for tilapia and silvercarp.

The central market hypothesis can be investigated by testing for exogeneity. The result of the weak exogeneity tests in bivariate models are rejected in most of the cases (Table 3 & 5). Some markets are exogenous in some relationships but not in others, which shows ambiguity and they do not provide a clear conclusion. A multivariate test was also conducted to clarify any price leadership. The test shows that weak exogeneity can be rejected for all markets (Table 4&6). This indicates that there is no market leader among the regional markets.

[Table 5 and 6 about here]

5. Conclusions

The supply of farmed fish products in Bangladesh have increased from both traditional and newly introduced species, whereas the percentage share of capture fisheries are reducing. The aim of this paper was to investigate whether the farmed new fish species such as pangasius and tilapia compete with several traditional carp species, and how the price is determined among the regional markets in Bangladesh. The results are particularly interesting for several reasons. First, there is little knowledge about the fish markets in developing countries, particularly the growing aquaculture industries in Asia. Second, this study provides an empirical contribution for competition between the new species and traditional species of farmed fish, as well as price relationship among the regional markets. The results shows that new aquaculture fish such as pangasius and tilapia compete with traditional carps in the same market, although the LOP does not hold for all combinations of prices. Therefore, these fish products are not perfect substitutes for each other. However, pangasius, tilapia and rohu are perfect substitutes in Dhaka; and pangasius, tilapia, rohu and catla can be substituted for one another in Rajshahi. This indicates that the consumers perceive these newly introduced fish and traditional fish as substitutes. In addition, based on exogenous tests, we find that some fish products are exogenous in some relationships but not in others, which shows ambiguity and they do not provide a clear conclusion. The multivariate test shows that none of the fish prices are exogenous, indicating that there is no price leader in the farmed fish market. Hence, the price determination process can be influenced by factors common to all species (Asche et al. 2005). However, the most interesting findings is that if only pangasius and tilapia compete in the market then the increased production of tilapia can determine the price of pangasius.

In this paper, we also investigated the integration between the regional fish markets for individual species. The results show that the regional markets are integrated for all fish products. This indicates a common stochastic trend for the regional markets. The result of the multivariate test shows that the LOP holds for rohu, pangasius, tilapia and silver carp. This implies that markets for these fish species are fully integrated and they do not represent independent prices. In the short run, the price may possibly vary but it must maintain equilibrium in the long run across the regional markets. Moreover, we find that none of the market prices are exogenous, indicating that there is no price leader in the regional fish markets. This indicates that the price information flow is not transmitted between the markets, each market has their own power to transmitted price information (Aruga & Li 2016).

The findings of the study have an implication for market participants such as producers, suppliers and other stakeholders to understand how fish products will likely move among regional markets, and which prices are interrelated to other market prices. It also provides useful information for policymakers to create efficient marketing strategies for distribution.

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Table 3. Bivariate Johansen cointegration and exogeneity test between species prices within region

Markets	H_0: rank = P	Trace test	LOP	Test for exogeneity	Trace test	LOP	Test for exogeneity
Dhaka					***Chittagong***		
Rohu	$P = 0$	28.902**	7.866(0.005)**	6.357(0.011)*	35.538**	3.059(0.080)	12.696(0.000)**
Catla	$P \leq 1$	3.004		4.187(0.040)*	2.820		1.873(0.171)
Rohu	$P = 0$	28.219**	2.329(0.127)	3.343(0.067)	28.036**	3.027(0.081)	6.064(0.013)*
Pangasius	$P \leq 1$	3.740		18.540(0.000)**	2.409(S)		14.619(0.000)**
Rohu	$P = 0$	40.448**	0.347(0.555)	22.993(0.000)**	20.419**	3.317(0.068)	14.487(0.000)**
Tilapia	$P \leq 1$	3.590(S)		12.452(0.000)**	2.821		0.880(0.348)
Rohu	$P = 0$	25.758**	7.210(0.007)**	13.391(0.000)**	34.003**	4.713(0.029)*	21.284(0.000)**
Silvercarp	$P \leq 1$	1.818		5.662(0.017)*	1.632		4.781(0.028)*
Catla	$P = 0$	29.716**	8.608(0.003)**	1.038(0.308)	22.225**	4.375(0.026)*	10.717(0.001)**
Pangasius	$P \leq 1$	2.261		23.434(0.000)**	1.750		4.034(0.044)*
Catla	$P = 0$	24.965**	4.985(0.025)*	13.972(0.000)**	24.574**	9.480(0.002)**	15.264(0.000)**
Tilapia	$P \leq 1$	2.529		4.892(0.027)*	2.370		4.463(0.034)*
Catla	$P = 0$	27.412**	1.576(0.209)	9.471(0.001)**	27.712**	0.967(0.324)	15.904(0.000)**
Silvercarp	$P \leq 1$	1.536(S)		16.822(0.000)**	1.668		3.690(0.054)
Pangasius	$P = 0$	28.767**	2.282(0.130)	20.223(0.000)**	24.627**	3.487(0.061)	11.622(0.000)**
Tilapia	$P \leq 1$	4.187*(S)		0.039(0.841)	2.217		4.934(0.026)**
Pangasius	$P = 0$	33.213**	13.393(0.000)**	26.313(0.000)**	29.925**	11.647(0.000)**	19.922(0.000)**
Silvercarp	$P \leq 1$	2.200		0.560(0.453)	1.457		3.832(0.050)
Tilapia	$P = 0$	28.204**	11.816(0.000)**	5.200(0.022)*	21.359**	12.175(0.000)**	7.375(0.006)**
Silvercarp	$P \leq 1$	2.138		13.560(0.000)**	1.965		5.667(0.17)

(*Continued*)

Table 3. *Continued*

Markets	H_0: rank = P	Trace test	LOP	Test for exogeneity	Trace test	LOP	Test for exogeneity
Rajshahi					***Khulna***		
Rohu	$P = 0$	41.777^{**}	0.095(0.756)	$9.177(0.002)^{**}$	18.558^{*}	0.149(0.699)	$4.894(0.026)^{*}$
Catla	$P \leq 1$	2.145		$10.121(0.001)^{**}$	3.213		1.224(0.268)
Rohu	$P = 0$	29.976^{**}	1.027(0.310)	$4.637(0.031)^{*}$	23.715^{**}	$9.103(0.002)^{**}$	0.279(0.597)
Pangasius	$P \leq 1$	6.122^{*}(S)		$12.908(0.000)^{**}$	5.045^{*}		$13.345(0.000)^{**}$
Rohu	$P = 0$	21.164^{**}	3.671(0.055)	$6.867(0.008)^{**}$	24.572^{**}	1.518(0.217)	$7.153(0.007)^{**}$
Tilapia	$P \leq 1$	3.602		0.634(0.425)	4.906^{*}		$4.000(0.045)^{*}$
Rohu	$P = 0$	28.412^{**}	1.816(0.177)	$16.072(0.000)^{**}$	35.290^{**}	1.046(0.307)	$11.550(0.000)^{**}$
Silvercarp	$P \leq 1$	3.660		0.025(0.875)	4.125^{*}		$11.224(0.000)^{**}$
Catla	$P = 0$	21.767^{**}	3.652(0.056)	0.915(0.338)	23.104^{**}	$10.485(0.001)^{**}$	0.316(0.574)
Pangasius	$P \leq 1$	2.224		$15.680(0.000)^{**}$	2.522		$15.337(0.000)^{**}$
Catla	$P = 0$	17.892^{**}	3.187(0.074)	$5.116(0.023)^{**}$	22.538^{**}	2.549(0.110)	$4.174(0.041)^{*}$
Tilapia	$P \leq 1$	2.275		$4.985(0.025)^{*}$	3.619(S)		$7.811(0.005)^{**}$
Catla	$P = 0$	30.627^{**}	1.864(0.172)	$20.426(0.000)^{**}$	27.859^{**}	0.578(0.446)	$11.042(0.000)^{**}$
Silvercarp	$P \leq 1$	3.247		0.272(0.601)	3.168		$6.776(0.009)^{**}$
Pangasius	$P = 0$	23.782^{**}	1.693(0.193)	$14.684(0.000)^{**}$	22.917^{**}	$4.922(0.026)^{*}$	$9.041(0.002)^{**}$
Tilapia	$P \leq 1$	3.723		1.588(0.207)	6.014^{*}(S)		0.190(0.662)
Pangasius	$P = 0$	24.170^{**}	$4.364(0.036)^{*}$	$16.252(0.000)^{**}$	17.180^{*}	$10.105(0.001)^{**}$	$9.743(0.001)^{**}$
Silvercarp	$P \leq 1$	3.308(S)		1.259(0.261)	3.392		2.149(0.142)
Tilapia	$P = 0$	30.003^{**}	$6.801(0.009)^{**}$	$11.758(0.000)^{**}$	24.145^{**}	$4.385(0.036)^{*}$	3.838(0.050)
Silvercarp	$P \leq 1$	4.139^{*}(S)		0.015(0.899)	5.897^{*}(S)		$5.038(0.024)^{*}$

**and * indicates statistical significance at 0.01 and 0.05 level, respectively. () = P-value, S indicates corrected using central seasonal du

Table 4. Multivariate cointegration test between species

Markets	H_0: rank = P	Trace test	AR-test	LOP	Test for exogeneity
Dhaka					
Rohu	$P = 0$	125.450**	1.406(0.167)	19.351(0.000)	108.27(0.000)
Catla	$P \leq 1$	75.970**	1.351(0.182)		105.84(0.000)
Pangasius	$P \leq 2$	41.553**	1.540(0.124)		119.84(0.000)
Tilapia	$P \leq 3$	17.074*	0.757(0.564)		109.25(0.000)
Silvercarp	$P \leq 4$	2.276	0.846(0.591)		107.16(0.000)
Chittagong					
Rohu	$P = 0$	122.260**	1.003(0.451)	17.013(0.001)	104.15(0.000)
Catla	$P \leq 1$	78.550**	0.442(0.942)		112.380(0.000)
Pangasius	$P \leq 2$	41.910**	0.671(0.773)		111.670(0.000)
Tilapia	$P \leq 3$	20.224**	0.494(0.914)		101.340(0.000)
Silvercarp	$P \leq 4$	1.595	0.766(0.682)		100.331(0.000)
Rajshahi					
Rohu	$P = 0$	156.030**	1.033(0.426)	11.848(0.018)	124.63(0.000)
Catla	$P \leq 1$	85.979**	0.754(0.694)		127.92(0.000)
Pangasius	$P \leq 2$	50.197**	0.825(0.624)		137.52(0.000)
Tilapia	$P \leq 3$	23.661**	1.052(0.407)		130.50(0.000)
Silvercarp	$P \leq 4$	3.375	1.083(0.381)		126.03(0.000)
Khulna					
Rohu	$P = 0$	96.179**	1.188(0.302)	9.515(0.049)	78.228(0.000)
Catla	$P \leq 1$	63.880**	1.943(0.038)		70.904(0.000)
Pangasius	$P \leq 2$	33.370*	0.991(0.463)		85.325(0.000)
Tilapia	$P \leq 3$	14.450	3.499(0.000)		76.477(0.000)
Silvercarp	$P \leq 4$	3.079	1.247(0.262)		80.132(0.000)

**and * indicates statistical significance at 0.01 and 0.05 level, respectively

() = P-values

Table 5. Bivariate Johansen cointegration and exogeneity test between regional markets for individual fish species

Markets	H_0: rank = P	Trace test	LOP	Test for exogeneity	Trace test	LOP	Test for exogeneity
Rohu					***Catla***		
Dhaka-	$P = 0$	19.356**	1.758(0.184)	4.550(0.032)*	23.746**	1.687(0.193)	2.528(0.111)
Chittagong	$P \leq 1$	3.137		4.913(0.026)*	1.661		14.885(0.000)**
Dhaka-	$P = 0$	26.430**	0.368(0.544)	5.667(0.017)*	28.336**	4.418(0.035)*	8.552(0.003)**
Rajshahi	$P \leq 1$	2.668		11.744(0.000)**	1.720		12.760(0.000)**
Dhaka-	$P = 0$	38.543**	0.624(0.429)	13.542(0.000)**	18.421**	2.243(0.134)	3.928(0.047)*
Khulna	$P \leq 1$	3.269		18.119(0.000)**	2.070		10.396(0.001)**
Chittagong-	$P = 0$	21.898**	1.244(0.264)	11.613(0.000)**	17.497*	4.077(0.043)*	10.353(0.001)**
Rajshahi	$P \leq 1$	1.480		3.059(0.017)	1.970		1.228(0.267)
Chittagong-	$P = 0$	26.150**	2.821(0.093)	11.584(0.000)**	21.031**	7.404(0.005)**	4.058(0.044)*
Khulna	$P \leq 1$	2.741		11.180(0.000)**	2.155(S)		11.815(0.000)**
Rajshahi-	$P = 0$	45.639**	0.099(0.752)	13.361(0.000)**	21.434**	0.005(0.98)	4.349(0.037)*
Khulna	$P \leq 1$	2.539		22.368(0.000)**	2.596(S)		11.281(0.000)**
Pangasius					***Tilapia***		
Dhaka-	$P = 0$	17.125*	0.759(0.383)	7.176(0.007)**	38.595**	3.448(0.063)	7.824(0.005)**
Chittagong	$P \leq 1$	2.326		2.143(0.143)	2.812		19.866(0.000)**
Dhaka-	$P = 0$	27.557**	0.346(0.556)	12.150(0.000)**	29.165**	0.007(0.978)	6.663(0.009)**
Rajshahi	$P \leq 1$	4.851*(S)		7.418(0.006)**	2.048		17.427(0.000)**
Dhaka-	$P = 0$	41.282**	2.822(0.093)	9.741(0.001)**	27.016**	1.458(0.227)	8.343(0.003)**
Khulna	$P \leq 1$	10.670**		9.348(0.002)**	4.431(S)		8.232(0.004)$^{*'*}$
Chittagong-	$P = 0$	25.842**	2.886(0.089)	4.360(0.036)*	29.735**	1.442(0.229)	12.358(0.000)**
Rajshahi	$P \leq 1$	2.445		19.2641(0.000)**	1.700(S)		13.379(0.000)**
Chittagong-	$P = 0$	23.171**	8.764(0.003)**	4.641(0.031)**	26.532**	0.005(0.942)	10.630(0.000)**
Khulna	$P \leq 1$	3.720		12.943(0.000)**	3.116(S)		7.973(0.004)**
Rajshahi-	$P = 0$	30.803**	3.214(0.073)	0.106(0.744)	20.986**	0.921(0.337)	6.013(0.014)**
Khulna	$P \leq 1$	5.486*		19.631(0.000)**	1.918(S)		11.465(0.001)**

Table 5. *Continued*

Markets	H_0: rank = P	Trace test	LOP	Test for exogeneity
Silvercarp				
Dhaka-	$P = 0$	21.790^{**}	0.557(0.455)	$11.320(0.000)^{**}$
Chittagong	$P \leq 1$	1.786		$6.596(0.0102)^{*}$
Dhaka-	$P = 0$	20.071^{**}	1.555(0.212)	$11.134(0.000)^{**}$
Rajshahi	$P \leq 1$	2.198		2.929(0.087)
Dhaka-	$P = 0$	22.224^{**}	3.948(0.096)	$10.472(0.001)^{**}$
Khulna	$P \leq 1$	3.139		2.771(0.096)
Chittagong-	$P = 0$	21.535^{**}	3.651(0.056)	$12.886(0.000)^{**}$
Rajshahi	$P \leq 1$	2.560		1.615(0.203)
Chittagong-	$P = 0$	20.673^{**}	$4.627(0.031)^{*}$	$10.217(0.001)^{**}$
Khulna	$P \leq 1$	3.468(S)		2.990(0.083)
Rajshahi-	$P = 0$	27.250^{**}	0.174(0.676)	$7.445(0.006)^{**}$
Khulna	$P \leq 1$	4.455^{*}(S)		$15.504(0.000)^{**}$

**and * indicates statistical significance at 0.01 and 0.05 level, respectively. () = P-values

S indicates corrected using central seasonal dummies.

Table 6. Multivariate Johansen test between regional markets

Markets	H_0: rank = P	Trace test	AR-test	LOP	Test for exogeneity
Rohu					
Dhaka	*P= 0*	81.094**	0.668(0.778)	2.369(0.499)	69.744(0.000)
Chittagong	$P \leq 1$	41.747**	0.882(0.567)		72.010(0.000)
Rajshahi	$P \leq 2$	20.142**	0.894(0.556)		67.749(0.000)
Khulna	$P \leq 3$	2.192	1.614(0.099)		61.948(0.000)
Catla					
Dhaka	*P= 0*	60.647**	1.293(0.234)	9.598(0.022)*	48.619(0.000)
Chittagong	$P \leq 1$	35.621**	0.291(0.989)		52.356(0.000)
Rajshahi	$P \leq 2$	18.084*	0.726(0.722)		46.234(0.000)
Khulna	$P \leq 3$	1.770	1.875(0.046)*		54.373(0.000)
Pangasius					
Dhaka	*P= 0*	68.162**	0.729(0.719)	7.789(0.050)	58.690(0.000)
Chittagong	$P \leq 1$	36.615**	0.883(0.566)		48.419(0.000)
Rajshahi	$P \leq 2$	15.753*	0.585(0.848)		51.480(0.000)
Khulna	$P \leq 3$	2.477	0.198(0.034)*		62.044(0.000)
Tilapia					
Dhaka	*P= 0*	85.928**	0.947(0.504)	3.856(0.274)	71.364(0.000)
Chittagong	$P \leq 1$	49.167**	0714(0.733)		74.661(0.000)
Rajshahi	$P \leq 2$	22.990**	0.997(0.457)		73.555(0.000)
Khulna	$P \leq 3$	2.047	1.148(0.331)		74.470(0.000)
Silvercarp					
Dhaka	*P= 0*	72.993**	1.144(0.332)	5.422(0.143)	61.198(0.000)
Chittagong	$P \leq 1$	45.093**	0.959(0.491)		66.544(0.000)
Rajshahi	$P \leq 2$	22.161**	1.000(0.447)		53.835(0.000)
Khulna	$P \leq 3$	2.846	0.836(0.602)		56.036(0.000)

**and * indicates statistical significance at 0.01 and 0.05 level, respectively

() = *P*-value

Appendices

Appendix A

The Interview schedule for the study

On

Production risk, farmer's risk perceptions and management strategies for aquaculture farming in Bangladesh

Sample/ farmer code No.____________

1. **Information of the Respondent:**

Name:________________________Village:____________________Upazila:___________
District:______________Age(years):_________Mobile number:______________________
Occupation*: Main:……….. Secondary:…………
[* Fish farmer =1, Agriculture = 2, Service = 3, Business = 4, others = 5]
Education (year of schooling):………… Social status**:……………….
[**Local leader = 1, Teacher = 2, Common person = 3, other (specify) =4]
Member of any organization/cooperative***:…… If yes, then from how many years:……..
[***NGO member=1, Member of farmers' cooperative=2, Member of cooperative society=3, Member of union council=4, Active member of a political party=5, others (specify) =6]

2. **Information about fish farming:**

i. When did you start aquaculture farming (Year)?
ii. What you have done with this land before start aquaculture farming?
[Agriculture = 1, unused land = 2]
iii. How distance of your farm from your residence (km)
iv. Who is the owner of the farm: [Own =1, lease/rent =2, others = 3]
v. If farm is not operated by single owners then, what percentage yours?
vi. If pond is in lease, then the lease value per decimal (Tk.) per year
vii. If pond is own, then how much would you get from lease value (Tk.) per year?
viii. What is the present sale value of the pond per decimal (Tk.)?
ix. What is culture system*/model
[* Integrated =1, extensive =2, semi-intensive =3, intensive =4]
x. Type of culture [Traditional =1, semi-improved =2, Improved =3]

3. Soil and water quality (pond characteristics)

Items	Response (Yes = 1, 0 for otherwise
Have you ever had a dispute over the ownership or leasing period of land	
Have you been test the water color and quality	
If yes then how(specify):	
Soil quality (Infertile/poor =1, fertile/good =2, highly fertile/very good =3)	
Water color (clear=1, Muddy=2 , Greenish=3)	
Use of water (Fish culture only=1, Fish culture and household use=2)	
How many years you are culture fish in this pond (Years……………….)	
Length of farming/Duration of fish culture (Days/months……………..)	
Number of cycle culture last years (……………………………………..)	
Do you drain out water after each cycle of production?	

4. Sources of income

Total household annual income (Tk.) …………………………

Non-farm and off-farm income sources

Income generating activities	No of HH member involved	Last year income(TK.)	Who participates in this activities
Govt. services of farmers himself &household members			
Private services of farmers himself &household members			
Labor selling for agriculture			
Labor selling for non-agriculture			
Business (medium and large)			
Small /petting trading/grocery shop keeping			
Remittance (in country and abroad)			
Money lending			
Land leased and /or mortgage out			
Handicrafts			
Pension and other govt. benefit			
Others (specify)			

Reasons for involving non-farm and off-farm activities (from 1= do not agree to 5 = fully agree)

Reasons	Please circle only one degree for each reason				
Increase family income	1	2	3	4	5
Increase standard of living/family wellbeing	1	2	3	4	5
Reduction of income risk from fish farming	1	2	3	4	5
Utilization of working capacity	1	2	3	4	5
Desire to work on something else	1	2	3	4	5
To help others /participation in social works	1	2	3	4	5
Other (specify)	1	2	3	4	5

PART I: Cost and Return of Fish Production (September-March 2013)

5. Investment cost for pond / cage / others enterprise

How much money did you spend for gher/pond construction at the beginning of farming…………………

items	Quantity (No.)	Own				If rented, total cost(Tk.)
		Purchase cost (Tk.)	Purchase year	Durability (years)	% used	
Bamboo/wood/rope						
Shallow tube well/pump						
Drum/fishing trap						
Feeding tray						
Boat						
Net (for harvesting)						
Gher/pond house						
Equipment repairing						
Others						

Dyke/Pond preparation	Quantity (Kg/No.)	Price (Tk.)
Machine cost for pond drying/ and pack clear		
Lime		
Others (specify)		

6. Information about fingerlings

Species	No. of pond	Total Pond area (dec.)	*Sources	Depth of water (fit)		Quantity Kg or Number	Price Tk./ (kg or100 fingerlings)	Average size(cm/inch)
				wet	dry			
Talapia (……								
Rui								
Catla								

*Sources: Own hatchery/nursery =1, directly from government hatchery/nursery =2, directly from private hatchery/nursery = 3, purchase from private traders =4, 5= others

7. Feed cost

Traditional feed

Feed name					Total cost (Tk.)
	Qty	Price/unit	Qty	Price/unit	
Cow dung					
Fish meal					
Rice bran					
Wheat bran					
Boiled rice					
Snail as feed					
Rice or wheat flower					
Mustered oil cake					
Homemade feed					
Mixture feed					
Gas tablet					
Bleaching powder					
Others					

Commercial pellet feed

(1= sinking, 2 = floating, 3 = both [ ])

Feed name	Quantity	Price/unit	Total cost (Tk.)	Feed company	Feed quality*
Nursery					
Cramble					
Starter -I					
Starter-II					
Grower					

*Feed quality: 1 = high quality, 2 = medium quality, 3 = low quality

8. Cost of labour:

****Temporary labor**

Species	**Digging of pond**			**Repairing/preparation**			***Intercultural operation**			**Harvesting**			**Marketing**		
	Family	Hired		Family	Hired		Family	Hired		Family	Hired		Family	Hired	
	Qty	Qty	price	Qty	Qty	price	Qty	Qty	price	Qty	Qty	price	Qty	Qty	price

*Intercultural operation includes procurement to fry/fingerlings, applying fingerlings, fertilizer, and guarding fish

[1]Price is Tk. /man-days

****Permanent labor**

Labor type	No of labor	Effective months spent	Salary/month
Male			
Female			
Family labor:			
Male			
Female			

9. Production and return by species

Species	1st harvest		2nd harvest		3rd harvest		Total harvest		Closing stock	
	Qty	Price/kg	Qty	Price/kg	Qty	Price/kg	Qty	Price/kg	Qty	Price/kg
Talapia										
Rui										
Catla										

10. Do you have access to **credit or loan / credit**? Yes or No……………………….

11. Did you take the **credit or loan**? Yes or No………How much (Tk.)…………….

Sources	Amount borrowed (Tk.)	Interest rate (%)	Interest paid (Tk.)
Bank			
NGO			
Dadandar			
Relatives			
Others			

12. Did you **repaying loan/ credit**? Yes or No…………… If yes, then response your degree of loan repayment ability (Highly capable=1, Capable=2, Not capable=3)………

13. Contact with extension agents, training and information for farming

Items	Response (Yes=1, 0 for others)	Frequency in the last six months	
		Freq. to visit your farm	Freq. of visit by you
Do you have any contact with GO or NGOs extension offices			
Upazila fisheries officer			
BFRI			
Do you have experience with the followings			
Method demonstration			
Group discussion			
FFS training program			
Other training (specify)			
Watching fisheries related programs in television /radio			
Participation national program (fish fair, rally etc.)			
Had access to fish feed and other inputs (Y or N)			
Has information on farm technology (Y or N)			
Had access to marketing information (Y or N)			
Do you get any training on fish culture (Y or N)			
If yes then duration……………… Source of training………………..			
How fish farming experience acquired: Self-study=1, Friends& neighbors=2, NGOs=3, Demonstration plot=4, Others (specify)=5			
Do you think that this type of farming is more profitable than others (Y or N)			
Do you want to convert more land into pond or gher (Y or N)			

14. Farmers perception on beneficial and environmental effect of fish farming

Positive perception about the profitability [Yes or No] if yes then level (from very few=1 to very high=5 scale) [ ]

Positive perception about its environmental effect [Yes or No] if yes then level (from very few=1 to very high=5 scale) [ ]

Positive perception about its nutritional diversity effect [Yes or No] if yes then level (from very few=1 to very high=5 scale) [ ]

Positive perception about biodiversity effect [Yes or No] if yes then level (from very few=1 to very high=5 scale) [ ]

PART II: Information about sources of risks in fish farming

In the following questions, please indicate the impact and the frequency of the following risk factors on you farm production

For consequences or impact, (from 1 to 5) 1-indicates least significant to 5-most significant impacts on farm production

For frequency, (from 1 to 5) 1-indicates rarely happen to 5-almost certain

22. R1: The consequences (impact) and frequency of risk factors related to pond location and pond preparation

	Risk factors	Consequences (1-5)	Frequency (1-5)
	Pond located outside the planning area		
	Pond located nearby flood affected area		
	Do not treat the pond before fingerlings stocking		
	Low quality of soil		
	Low quality of water (high turbidity…..)		
	Land tenure system/tenure conflict		

22. RM1: Please indicate the effectiveness of the following risk management strategies in controlling risk factors related to pond area and pond preparation *(from 1- not effective at all to 5-highly effective)*

Risk factors	Risk management strategies	Effectiveness (1-5)	
Pond located outside the planning area	Locate pond in planning area		
Pond located nearby flood affected area	Locate less flood affected area/flood protection		
Do not treating the pond before fingerlings stocking	Strictly treat the pond before stocking		
	Attending extension workshop/training		
Low quality of soil	Improve soil quality		
Low quality of water	Treat water before fingerlings stocking		
Land tenure system			

For consequences or impact, (from 1 to 5) 1-indicates least significant to 5-most significant impacts on farm production

For frequency, (from 1 to 5) 1-indicates rarely happen to 5-almost certain

23. R2: The consequences (impact) and frequency of risk factors related to fingerlings

	Risk factors	Consequences (1-5)	Frequency (1-5)
	Low quality of fingerlings (not healthy)		
	Fingerlings with unknown origin/unknown trader		
	Timely supply and price of fingerlings		
	Fingerlings infected by disease		
	Over (density) stocking fingerlings		
	Use undersize/ oversize fingerlings		

23. RM2: Please indicate the effectiveness of the following risk management strategies in controlling risk factors related to fingerlings *(from 1- not effective at all to 5-highly effective)*

Risk factors	**Risk management strategies**	**Effectiveness (1-5)**	
Low quality of fingerlings (not healthy)	Select good quality of fingerlings		
	Buy fingerlings from reliable sources		
Fingerlings with unknown origin	Only buy fingerlings from certified producers		
Timely supply and price of fingerlings	Timely supply of fingerlings		
	Fair price of fingerlings		
Fingerlings infected by diseases	Careful checking the fingerlings when buying		
Over (density) stocking fingerlings	Attending training or workshop		
	Strictly follow the recommended guide		
	Reduce density of fingerling stocking		
Use undersize fingerlings	Attending extension workshop/training		
	Use large size of fingerlings		

For consequences or impact, (from 1 to 5) 1-indicates least significant to 5-most significant impacts on farm production
For frequency, (from 1 to 5) 1-indicates rarely happen to 5-almost certain

24. R3: The consequences (impact) and frequency of risk factors related to feed &feeding and use of chemical &medicines

	Risk factors	**Consequences (1-5)**	**Frequency (1-5)**
	Low quality of feed		
	Overfeeding cause pollution and waste accumulation		
	Using chemical and medicines improperly		
	Price variation of feed and chemicals		
	Limited knowledge about usage of chemical, fertilizer and medicines		
	Using wrong sources of consultancy in using chemical and medicines		

24. RM3: Please indicate the effectiveness of the following risk management strategies in controlling risk factors related to feed & feeding and use of chemical &medicines *(from 1- not effective at all to 5-highly effective)*

Risk factors	**Risk management strategies**	**Effectiveness (1-5)**	
Low quality of feed	Choose the good brand of feed		
	Buying feed from reliable dealers		
	Checking prohibited substances (hormone, chem.)		
Overfeeding cause pollution and waste accumulation	Use only factory made (pallet) feed		
	Strictly follow recommended doze from expert		
Using chemical and medicines improperly	Attending workshop/training		
	Use labors with aquaculture knowledge		
Price variation of feed and chemicals	Appropriate price policy		
Limited knowledge about usage of chemical, medic	Attending workshop/training		
	Use labors with aquaculture knowledge		
Using wrong sources of consultancy in using chemical and medicines	Consult people who have knowledge with aquaculture veterinary		
	Use labors with aquaculture knowledge		
	Attending workshop/training		

25. R4: The consequences (impact) and frequency of risk factors related to diseases, aquaculture & community environment, and harvesting of fish

	Risk factors	Consequences (1-5)	Frequency (1-5)
	High dead rate due to disease		
	Low awareness of disease prevention by farmers		
	Farm have no reserve area for waste water and mud treatment		
	Inappropriate size of harvested fish		
	Inappropriate method of harvesting cause reduction of fish quality and weight		
	Fish yield variability		

25. RM4: Please indicate the effectiveness of the following risk management strategies in controlling risk factors related to diseases, aquaculture &community environment, and harvesting *(from 1- not effective at all to 5-highly effective)*

Risk factors	Risk management strategies	Effectiveness (1-5)	
High dead rate due to disease	Well manage water environment in pond		
	Apply medicine, chemicals to prevent disease		
	Preventing disease by regular checking and observation pond		
	Reduce over density of fingerlings stocking		
Low awareness of disease prevention by farmers	Attending workshop or training		
Farm have no reserved area for waste management	Use certain area for waste and mud treatment		
Inappropriate size of fish harvest	Production contract with predetermined size		
	Collect information about favourable size		
Inappropriate method of harvesting cause reduction of fish quality	Sale contract with processor		
	Attending workshop/training		
Fish yield variability	Strictly follow recommended technical guide from expert		

26. R5: The consequences (impact) and frequency of risk factors related to marketing and business issues

	Risk factors	Consequences (1-5)	Frequency (1-5)
	Fish price variability		
	Inaccessibility to the market		
	Weak enforcement in conducting sale contract with processors/Aratder/middlemen		
	Exploitation from middlemen		
	Lack of storage and transportation facilities		
	Uncertainty and technical barriers about foreign market		
	Uncertainty about future price and demand		
	High costs of operating inputs/farm equipment		
	Wages of labor/hired labor cost		
	Changes in consumer preferences		

26. RM5: Please indicate the effectiveness of the following risk management strategies in controlling risk factors related to marketing and business issues *(from 1- not effective at all to 5-highly effective*

Risk factors	Risk management strategies	Effectiveness (1-5)	
Fish price variability	Sale contract with middlemen/processor		
	Association of fish farmers		
	Available market information		
	Increase cooperative marketing		
Inaccessibility to the market	Market monitoring		

	Available market information		
Weak enforcement in conducting sale contract with processor	Farmers' cooperative association		
Exploitation from middlemen	Removal of influence of middlemen		
Lack of storage and transportation facilities	Establish storage facilities		
	Improve transportation facilities		
Uncertainty and technical barriers from foreign markets	Apply quality management strategies (HACCP)		
Uncertainty about future price and demands	Research for consumer demand and prices		
High cost of operating inputs/ farm equipment	Produce at lowest possible costs		
High wages of labor/hired labor cost	Use of family labors		
Changes in consumer preferences	Collecting information on consumer preferences		
	Product diversification		

For consequences or impact, (from 1 to 5) 1-indicates least significant to 5-most significant impacts on farm production
For frequency, (from 1 to 5) 1-indicates rarely happen to 5-almost certain

27. R6: The consequences (impact) and frequency of risk factors related to financial issues

	Risk factors	Consequences (1-5)	Frequency (1-5)
	Under financing by own capital		
	Under financing by credits from bank/institutions		
	Supply of private capital (debt, equity)		
	Supply of microcredit from NGOs		
	High interest rate of loans		
	Low credit availability		

27. RM6: Please indicate the effectiveness of the following risk management strategies in controlling risk factors related to financial issues

Risk factors	Risk management strategies	Effectiveness (1-5)	
Under financing by own capital	Reduce farm size to appropriate scale		
	Increase solvency ratio		
	Increase personal saving		
Under financing by credit from bank/institutions	Make credit arrangement before farming		
	Solvency-debt management		
	Assurance of bank loans		
Supply of private capital (debt, equity)	Off-farm work		
	Investment in off-farm activities		
Supply of microcredit from NGOs	Assurance of available microcredit		
High interest rate for loans	Use economic consultant services		
Low credit availability	Increase personal saving		
	Share ownership of equipment/partnership		

For consequences or impact, (from 1 to 5) 1-indicates least significant to 5-most significant impacts on farm production
For frequency, (from 1 to 5) 1-indicates rarely happen to 5-almost certain

28. R7: The consequences (impact) and frequency of risk factors related to natural risks

	Risk factors	**Consequences (1-5)**	**Frequency (1-5)**
	Drought/lack of water supply in dry season		
	Flood		
	Polluted water		
	Disease infected and polluted water supply		

28. RM7: Please indicate the effectiveness of the following risk management strategies in controlling risk factors related to natural risks

Risk factors	**Risk management strategies**	**Effectiveness (1-5)**	
Drought/lack of water supply	Crop insurance		
	Choose location nearby good water sources		
Flood	Regular checking and enforcing the pond		
	Spatial diversification		
	Insurance against production loss		
Polluted water	Treat water before stocking fingerlings		
Disease infected and polluted water supply	Treat water before stocking fingerlings		

Appendix B

The Interview schedule for the study

On

Consumption, Consumer preferences and Willingness to pay for fish attributes

Sample No.____________

<u>1. Information of the Respondent</u>:

Name:___________________________Village:_____________________Upazila:_________

District:____________________ Mobile number:_______________________

1. **<u>Personal and household characteristics</u>**

i) Age (years):

ii) Occupation*: Main:……….. Secondary:………….

[* Agriculture =1, Fish &Livestock =2, Govt. Service =3, Private Service =4 Business =5, Full-time paid worker =6, Part-time paid worker =7, Retired person =8, Others =9 please specify……………………………………..]

iii) Education (year of schooling):………… Social status**:………………

[**Local leader = 1, Teacher = 2, Common person = 3, other (specify) =4]

iv) Marital status: Single ☐ Married ☐

v) Gender: Male ☐ Female ☐

vi) How many people live in your household?...................... Male ☐ Female ☐

Please specify number with age:1…………2………...3…………4………..…5…………

vii) Household income per month (Taka):…………..

Your per month income (Taka):…………………...

i) Income from other household member (specify relation with you) (Taka):………………

ii) Income from other household member (specify relation with you) (Taka):………………

viii) Who in your household is deciding what food to buy? Check **<u>one or more</u>** boxes.

Yourself ☐ Your wife ☐ Your husband ☐ Someone else (specify…………) ☐

ix) Are you the main persons for grocery shopping in your household (the person responsible for at least 50% of food purchased for household)? Yes ☐ No ☐

On a scale from 1 to 7, where 1 means you strongly **DISAGREE** and 7 means you strongly **AGREE**, how much do you agree with the following statements?

Check <u>in one</u> box per line

i) In what kind of produced fish do you prefer for consumption at your household

Check <u>in one</u> box

	Strongly dislike 1	2	3	4	5	6	Strongly like 7
Fish produced in farm / aquaculture pond……..	☐	☐	☐	☐	☐	☐	☐
Fish caught/ Capture from river, floodplains, Boar, or Bill…………	☐	☐	☐	☐	☐	☐	☐

ii) Which of the following attributes you think when you buy fish for consumption?

On a scale from 1 to 7, where 1 means **not very** important and 7 means **very** important.

Check <u>in one</u> box per line

	Not very important 1	2	3	4	5	6	Very important 7	Do not know 8
Farm fish/ Fresh water aquaculture/pond aquaculture fish								
Freshness………………………...	☐	☐	☐	☐	☐	☐	☐	☐
Taste……………………………..	☐	☐	☐	☐	☐	☐	☐	☐

Nutritive value…………………..	☐	☐	☐	☐	☐	☐	☐	☐
Price……………………………..	☐	☐	☐	☐	☐	☐	☐	☐
Appearance………………………	☐	☐	☐	☐	☐	☐	☐	☐
Fish size..………………………..	☐	☐	☐	☐	☐	☐	☐	☐
Smell……………………………..	☐	☐	☐	☐	☐	☐	☐	☐
Bone content..……………………	☐	☐	☐	☐	☐	☐	☐	☐
Fat content...……………………..	☐	☐	☐	☐	☐	☐	☐	☐
Healthy to eat/safe to eat……….	☐	☐	☐	☐	☐	☐	☐	☐
Farming conditions..……………..	☐	☐	☐	☐	☐	☐	☐	☐
Availability……………………..	☐	☐	☐	☐	☐	☐	☐	☐
Concern over medicine residues…	☐	☐	☐	☐	☐	☐	☐	☐
Source of origin………………….	☐	☐	☐	☐	☐	☐	☐	☐
Scale color……………………….	☐	☐	☐	☐	☐	☐	☐	☐
Wild caught/ Capture from river, floodplains, Boar and Bill								
Freshness………………………...	☐	☐	☐	☐	☐	☐	☐	☐
Taste……………………………..	☐	☐	☐	☐	☐	☐	☐	☐
Nutritive value……..…………..	☐	☐	☐	☐	☐	☐	☐	☐
Price……………………………..	☐	☐	☐	☐	☐	☐	☐	☐
Appearance………………………	☐	☐	☐	☐	☐	☐	☐	☐
Fish size..………………………..	☐	☐	☐	☐	☐	☐	☐	☐
Smell……………………………..	☐	☐	☐	☐	☐	☐	☐	☐
Bone content..……………………	☐	☐	☐	☐	☐	☐	☐	☐
Fat content...……………………..	☐	☐	☐	☐	☐	☐	☐	☐
Healthy to eat/safe to eat…..……	☐	☐	☐	☐	☐	☐	☐	☐
Farming conditions..……………..	☐	☐	☐	☐	☐	☐	☐	☐
Availability……………………..	☐	☐	☐	☐	☐	☐	☐	☐
Concern over medicine residues…	☐	☐	☐	☐	☐	☐	☐	☐
Source of origin………………….	☐	☐	☐	☐	☐	☐	☐	☐
Scale color……………………….	☐	☐	☐	☐	☐	☐	☐	☐

2. Attitudes towards different specific fish

i) On a scale from 1 to 7, where 1 means strongly **DISAGREE** and 7 means strongly **AGREE**, how much do you agree with following statements about **PANGUS**?

Check in one box per line

	Strongly Disagree 1	2	3	4	5	6	Strongly Agree 7	Do not know 8
Pangus is good in taste……………	☐	☐	☐	☐	☐	☐	☐	☐
Pangus has good nutritive value…	☐	☐	☐	☐	☐	☐	☐	☐
Pangus is fatty food………………	☐	☐	☐	☐	☐	☐	☐	☐
Pangus fish is healthy/ safe to eat…	☐	☐	☐	☐	☐	☐	☐	☐

Pangus is very expensive………..								
Pangus gives you good value for money……………………………								

iii). On a scale from 1 to 7, where 1 means strongly **DISAGREE** and 7 means strongly **AGREE**, how much do you agree with following statements about **Ruhi?**

Check <u>in one</u> box per line

	Strongly Disagree 1	2	3	4	5	6	Strongly Agree 7	Do not know 8
Ruhi is good in taste…………….								
Ruhi has good nutritive value..….								
Ruhi is fatty food………………..								
Ruhi fish is healthy/safe to eat….								
Ruhi is very expensive………..								
Ruhi gives you good value for money……………………………								

iv). On a scale from 1 to 7, where 1 means strongly **DISAGREE** and 7 means strongly **AGREE,** how much do you agree with following statements about **Katla?**

Check <u>in one</u> box per line

	Strongly Disagree 1	2	3	4	5	6	Strongly Agree 7	Do not know 8
Katla is good in taste……………								
Katla has good nutritive value.…								
Katla is fatty food………………								
Katla fish is healthy/safe to eat…								
Katla is very expensive………..								
Katla gives you good value for money……………………………								

v. On a scale from 1 to 7, where 1 means strongly DISAGREE and 7 means strongly AGREE, how much do you agree with following statements about **Live fish (Magur, Singi)?**

Check <u>in one</u> box per line

	Strongly Disagree 1	2	3	4	5	6	Strongly Agree 7	Do not know 8
Good in taste……………………								
Good nutritive value……………								
Fatty food………………………								
Healthy/safe to eat……………..								
Very expensive………..								
Gives you good value for money……………………………								

<u>Attitudes towards contribution to livelihoods and food security</u>

4. On a scale 1 to 7, where 1 means strongly DISAGREE and 7 means strongly AGREE about the following statement?

Check <u>in one</u> box per line

	Strongly Disagree 1	2	3	4	5	6	Strongly Agree 7	Do not know 8
Farm fish/ Fresh water aquaculture/pond aquaculture fish								
Improved nutrition supply……….	☐	☐	☐	☐	☐	☐	☐	☐
Improved livelihood status………	☐	☐	☐	☐	☐	☐	☐	☐
Increased economic solvency……	☐	☐	☐	☐	☐	☐	☐	☐
Made fish easily available……….	☐	☐	☐	☐	☐	☐	☐	☐
Wild caught/ Capture from river, floodplains, Boar and Bill								
Improved nutrition supply……….	☐	☐	☐	☐	☐	☐	☐	☐
Improved livelihood status………	☐	☐	☐	☐	☐	☐	☐	☐
Increased economic solvency……	☐	☐	☐	☐	☐	☐	☐	☐
Made fish easily available ………	☐	☐	☐	☐	☐	☐	☐	☐

5. Attitudes toward fish farming and environmental aspects

i) On a scale from 1 to 7, where 1 means you strongly **DISAGREE** and 7 means you strongly **AGREE**, how much do you agree with the following statements?

Check <u>one box</u> per line.

	Strongly disagree 1	2	3	4	5	6	Strongly agree 7	Do not know 8
Farmed fish is healthy food………	☐	☐	☐	☐	☐	☐	☐	☐
Wild fish is healthy food…………	☐	☐	☐	☐	☐	☐	☐	☐
Farmed fish is safe to eat…………	☐	☐	☐	☐	☐	☐	☐	☐
Wild fish is safe to eat……………	☐	☐	☐	☐	☐	☐	☐	☐
I am concerned about the negative environmental impact of the fish farming…………………………	☐	☐	☐	☐	☐	☐	☐	☐
I am concerned about the overfishing impact of catching wild fish……….	☐	☐	☐	☐	☐	☐	☐	☐
I am concerned about environmental sustainability of fish farming……………………..	☐	☐	☐	☐	☐	☐	☐	☐
I am concerned about environmental sustainability of catching wild fish……………..	☐	☐	☐	☐	☐	☐	☐	☐
I am concerned about the welfare of fish farming…………………	☐	☐	☐	☐	☐	☐	☐	☐
I am concerned about the welfare of wild caught fish………………	☐	☐	☐	☐	☐	☐	☐	☐

SECTION FOR CHOICE EXPERIMENT

Block 1

Choice set 2, Option		Choice set 4, Option		Choice set 7, Option	
Choice set 10,Option		Choice set 17, Option		Choice set 24, Option	

Block 2

Choice set 1, Option		Choice set 5, Option		Choice set 9, Option	
Choice set 15, Option		Choice set 16, Option		Choice set 20, Option	

Block 3

Choice set 13, Option		Choice set 18, Option		Choice set 19, Option	
Choice set 21, Option		Choice set 22, Option		Choice set 23, Option	

Block 4

Choice set 3, Option		Choice set 6, Option		Choice set 8, Option	
Choice set 11, Option		Choice set 12, Option		Choice set 14, Option	

N M B U

20.04.2017

FORM 4.7 Errata

Correcting formal errors in the PhD thesis (cf. section15.3-2 in the PhD regulations)

The PhD candidate may after submitting the thesis apply to correct formal errors in the thesis. An application to correct formal errors must be submitted no less than four (4) weeks before the disputation. Such an application can be made only once.

Thesis title:	Aquaculture in Bangladesh: Essays on production variability, consumer preferences and market integration

Page number	Para-graph	Change from	Change to
Paper 2		EndNote Style T&F Standard Chicago AD	Harvard_X2_UMB_eng
Page 100-102	Fig 1-2e	Kg/Taka	BDT/Kg
Page 99			1 USD = 83.10 BDT
Page 111			Alam, M. A. & Alfnes, F (2017)

This form will be signed by the PhD candidate and the main supervisor and must be sent to the faculty for approval. The approved errata must be archived in the PhD candidate's doctoral archive and must be attached to the final thesis print version as the last page of the thesis.

Date and signature:

PhD candidate (Author):	06.02.2018 ,

Main supervisor:	9.2.18 Frode Alfnes (co-supervisor)

Errata approved by the faculty: Yes ☑ No ☐

For the faculty:	

Md Akhtarul Alam

Akhtarul Alam was born in Rangpur, Bangladesh. He holds a B.Sc. in Agricultural Economics and a M.Sc. in Agricultural Statistics from Bangladesh Agricultural University. He also holds International Master of Science in Rural Development form Ghent University, Belgium in 2011. Alam is currently an Assistant Professor at Bangladesh Agricultural University.

The thesis investigated aquaculture farming in Bangladesh on four issues; (1) production risk and technical efficiency, (2) farmers' risk perceptions and risk management strategies, (3) consumer preferences for fish attributes, and (4) market integration of aquaculture products. Paper 1 investigates the production variability of tilapia fish farming by means of two main possible sources: production risk and technical inefficiency. There are significant production risks and technical inefficiencies exist in tilapia farming. Paper 2 assess farmers' attitudes towards risk and their risk management strategies. It shows that the most important perceived sources of risk were fish-diseases, fish price variability, low quality of feed and fingerlings, flood and credit constraints. The most important strategies to mitigate risks were the supply of good quality feed and fingerlings, diseases prevention, crop insurance, increasing personal savings, and assurance of bank loans.

Paper 3 examines Bangladeshi consumer preferences toward wild-caught and farm-raised fish, fresh vs frozen, local vs and foreign species. Using a choice experiment the study found that on average, consumers were willing to pay more for indigenous fish than foreign fish species. They preferred domestic production to imported fish, and fresh to frozen fish. However, Bangladeshi consumers were not willing to pay a significant premium for wild-caught fish. Paper 4 investigates the market integration between regional markets in Bangladesh and between traditional carps and the non-indigenous species pangasius and tilapia. Results show that the species are partially integrated on the regional markets and that there is no price leader among the species in the market. Furthermore, the integration test between regional markets show that the regional markets for rohu, pangasius, tilapia and silvercarp are fully integrated. This implies that all prices follow the same stochastic trend in the regional markets.

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