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An Economic Analysis of Fish Demand and Livelihood Outcomes of Small-scale Aquaculture in Myanmar

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Executive Summary

Given that capture fishery production has either remained stagnant or declined globally, aquaculture has been responsible for the massive growth in the supply of fish to fulfill increasing demand and has also improved livelihoods. The development of the fishery sector, particularly aquaculture, has the potential to contribute to the Sustainable Development Goals (SDGs). New technologies and effective fishery management policies play critical roles in achieving this sector's contribution to the SDGs. Although aquaculture in Myanmar is dominated by large-scale fish farming, a larger number of small-scale aquaculture (SSA) households exist either legally or illegally because profitability and employment opportunities have enticed them to enter the sector. However, the potential of SSA farmers and their challenges are still overlooked. Even though Myanmar is one of the major consumers of fish and producers of aquaculture fish worldwide, to date, a holistic approach that considers the demand and supply side of Myanmar's aquaculture sector is rare.

The thesis focuses on two main topics. One topic is an analysis of the disaggregated fish demand system. Empirical evidence on whether the aquaculture sector can meet household demand through adequate availability of and accessibility to fish is vital to ensure household food and nutrition security and understand the future of the fish demand. The second main topic focuses on the two aspects of production based on SSA farms; production efficiency and impacts on welfare outcomes from the adoption of sustainable aquaculture (SA) technologies. To fulfill fish demand by increasing the supply of fish from farms, production efficiency of the farmers needs to improve to generate profitable in the face of lower fish prices that will accompany an increase in supply. In addition, traditional aquaculture production practices are risky and are not a long-term option for SSA farmers. Therefore, renewing or modifying productive resources and implementing new technologies may play critical roles in the development of a sustainable SSA sector. The study on the fish demand analysis in Chapter 2 relies on nationally representative data from the "Myanmar Poverty and Living Conditions survey (MPLCS) in 2015,". For the production side analysis in Chapters 3 and 4, primary survey data originate from 440 SSA households collected in three townships in Phyapon District, Ayeyarwady Delta region, Myanmar.

Chapter 2 estimates the demand parameters differentiated by fish supply sources (aquaculture, freshwater capture, marine capture, and dried fish) and household groups (wealth group and household location) in Myanmar using a three-stage budgeting framework,

combined with a Quadratic Almost Ideal Demand System (QUAIDS). The results reveal that fish demand from all sources of fish and household groups increases with income because fish is the second most crucial food commodity after rice in Myanmar. A substantial share of the increasing demand for all sources of fish is likely to come from poor and rural households with growing incomes due to their higher-income elasticity for all sources of fish. Moreover, less elastic price elasticity of demand in most cases for poor and rural households indicates that those households have less animal protein substitutes for fish available and accessible because fish is the cheapest form of an animal protein source in Myanmar. Due to the income responsiveness of aquaculture fish, its demand will grow faster than that of other fish sources. This study confirms that the rapidly growing aquaculture sector can compensate for the concurrent stagnation of capture fisheries production to fulfill the increase in the fish demand. The study's findings suggest that effective management policies and new technologies are essential to sustain the fish supply from capture fisheries and aquaculture. Intervention programs that sustainably increase aquaculture production will generate the most effective and significant effects on securing households food and nutrition security in the long-run.

Chapter 3 analyzes the current technical efficiency level of SSA farms and the link between women's level of participation in decision-making (WPDM) activities and the technical efficiency of fish farming using the two-stage double bootstrap data envelopment analysis (DEA) method. The results show that most SSA farming households are not technically efficient, performing in a range of 45%-60% below the production frontier. All the inputs used contain slacks, such that all of them are over-utilized in inappropriate ratios. This study reveals that while some of the households' socio-economic and production characteristics are significant shifters to enhance efficiency of fish farming, decision-making power of women at the household-level is found to significantly improve the level of technical efficiency through its effects on the ability of household members to allocate and organize resources optimally. This study highlights the vital need to promote intervention programs targeted at improving the technical efficiency of SSA farming households. Policies and intervention programs aimed at increasing productivity in the aquaculture sector would benefit by including women empowerment programs to reduce gender inequality and promote equity.

Chapter 4 evaluates the determinants and the impacts of SA technologies adoption on SSA households’ welfare outcomes using the endogenous switching regression (ESR) model. The significant value of the correlation coefficients between the error terms of the adoption decision and the outcome equations, as well as heterogeneity in the outcome variables between adopters and non-adopters, confirm that the ESR model is more appropriate than data pooling in a regression model. The model's actual and counterfactual results highlight that the adoption of SA technologies increases the SSA households' welfare outcomes, measured by fish yield per ha, Household Dietary Diversity Score (HDDS), and Total Food Consumption Score (TFCS). However, the actual adopters would benefit the most in terms of fish yield per ha and TFCS from adopting SA technologies because the average treatment effects of adoption on adopters are larger than that of non-adopters for these variables. The results highlight that household knowledge about aquaculture production and information sources are main drivers for the adoption decision and improving welfare outcomes. Therefore, appropriate policies targeting SSA development should emphasize the promotion of farmer's awareness and adoption of SA technologies by providing improved extension services.

This thesis' findings contribute to the current debate that the development of the aquaculture sector can help achieve some of the SDGs. In particular, aquaculture can help end hunger through increased food security by making fish more widely available and accessible by increasing the supply of fish. Moreover, aquaculture can improve gender equality and women's empowerment through creating employment opportunities linked to the aquaculture sector. Given the lower technical efficiency level and positive welfare impacts of SA technologies, it is recommended that the government and other development organizations disseminate information on the improved aquaculture practices and suitable input use through improved extension services to SSA farmers. Due to the dominance of a single fish species in the aquaculture sector, the government needs to support research and development programs in the hatchery sector for a new generation of species. Another recommendation is to reformulate the current "Farmland Law 2012" because it puts restrictions on converting agricultural land to fish ponds, which is preventing farmers entering the aquaculture sector legally. The above policy recommendations are crucial to achieve growth in the SSA sector and increase women's intra-household decision-making power, thereby opening the door to improve livelihoods.

Zusammenfassung

Während die Fangfischerei weltweit entweder stagniert oder zurück geht, ist es mittels Fischproduktion in Aquakulturen gelungen, die wachsende Nachfrage durch massive Steigerung des Fischangebots zu decken und eine Verbesserung der Lebensbedingungen zu ermöglichen. Die Entwicklung des Fischereisektors, insbesondere der Aquakultur, kann maßgeblich zur Erreichung der Sustainable Development Goals (SDGs, englisch für nachhaltige Entwicklungsziele) beitragen. Wie hoch dieser Beitrag ausfällt, wird von neuen Technologien und Fischereimanagementpolitiken abhängen. In Myanmar sind große Fischfarmen die vorherrschende Form von Aquakultur, doch gibt es auch eine wachsende Anzahl an Haushalten, die wegen der hohen Rentabilität und der Arbeitsplatzsituation – sowohl legal als auch illegal – Aquakultur in kleinem Maßstab (SSA, englische Abkürzung für small scale aquaculture) betreiben. Potenziale sowie Herausforderungen der SSA-Kleinbauern werden jedoch oft verkannt. Obwohl Myanmar einer der größten Fischkonsumenten und Produzenten von Aquakulturfischen weltweit ist, fehlt ein ganzheitlicher Ansatz, der sowohl die Nachfrage- als auch die Angebotsseite des Aquakultursektors berücksichtigt.

Die Arbeit konzentriert sich auf zwei Hauptthemen. Zuerst steht die Analyse des Fischnachfragesystems, disaggregiert nach verschiedenen Kriterien, im Fokus. Empirische Erkenntnisse darüber, ob der Aquakultursektor die Nachfrage der Haushalte durch eine angemessene Verfügbarkeit und Zugänglichkeit von Fisch befriedigen kann, sind entscheidend, um die Ernährungssicherheit der Haushalte zu gewährleisten und die Zukunft der Fischnachfrage zu verstehen. Das zweite Hauptthema konzentriert sich auf zwei Aspekte der Produktion von Fisch in kleinen Aquakulturen: Produktionseffizienz und Wohlfahrtseffekte durch die Einführung von nachhaltigen Aquakulturtechnologien. Um die Fischnachfrage durch ein höheres Angebot von Fisch aus Aquakultur zu befriedigen, muss die Produktionseffizienz von SSA verbessert werden. Nur so können die SSA-Kleinbauern trotz der niedrigeren Fischpreise, die mit einer Erhöhung des Angebots einhergehen, profitabel bleiben. Darüber hinaus sind die traditionellen Produktionsmethoden risikoreich und daher langfristig keine rentable Option für die SSA-Kleinbauern. Deswegen können Erneuerungen oder Modifizierungen von aktuellen Produktionsmitteln sowie die Einführung neuer Technologien eine entscheidende Rolle bei der Entwicklung eines nachhaltigen Aquakultursektors mit SSA-Kleinbauern spielen. Die Studie zur Analyse der Nachfrage nach Fisch in Kapitel 2 stützt sich auf national repräsentative Daten aus der "Myanmar Poverty and Living Conditions survey (MPLCS) in 2015". Für die produktionsseitige Analyse in den

Kapiteln 3 und 4 wurden Primärdaten erhoben mittels einer Befragung von 440 Haushalten, die Aquakultur in kleinem Maßstab in drei Gemeinden im Phyapon-Distrikt (Ayeyarwady-Delta-Region, Myanmar) betreiben.

Kapitel 2 schätzt die Nachfrageparameter aufgeteilt nach Fischversorgungsquellen (Aquakultur, Süßwasserfang, Meeresfang und Trockenfisch) und Haushaltsgruppen (Wohlstandsgruppe und Haushaltsstandort) in Myanmar unter Verwendung eines dreistufigen Budgeting Frameworks, kombiniert mit einem quadratischen fast idealen Nachfragesystem (QUAIDS, englische Abkürzung für quadratic almost ideal demand system). Die Ergebnisse zeigen, dass die Nachfrage nach Fisch aus allen Fischquellen und Haushaltsgruppen mit dem Einkommen steigt, da Fisch in Myanmar nach Reis das zweitwichtigste Nahrungsmittel ist. Ein wesentlicher Anteil der steigenden Nachfrage nach allen Fischquellen wird wahrscheinlich von armen und ländlichen Haushalten mit steigendem Einkommen kommen. Grund dafür ist deren höhere Einkommenselastizität für Fisch aus allen Produktionsformen. Außerdem deutet die geringere Preiselastizität der Nachfrage in den meisten Fällen für arme und ländliche Haushalte darauf hin, dass diesen Haushalten weniger tierische Eiweißsubstitute für Fisch zur Verfügung stehen, da Fisch die kostengünstigste Form einer tierischen Eiweißquelle in Myanmar ist. Durch diese starke Einkommensabhängigkeit wird erwartet, dass die Nachfrage nach Fisch aus Aquakultur deutlich schneller wachsen wird als die nach anderweitig produziertem Fisch. Diese Studie bestätigt, dass der schnell wachsende Aquakultursektor die gleichzeitige Stagnation des Fischfangs kompensieren und damit die gestiegene Nachfrage decken kann. Die Ergebnisse legen außerdem nahe, dass eine effektive Managementpolitik und neue Technologien notwendig sind, um das Fischangebot aus Fangfischerei und Aquakultur aufrechtzuerhalten. Besonders weitreichende Auswirkungen auf die langfristige Ernährungssicherung werden von Interventionsprogrammen erwartet, die die Aquakulturproduktion nachhaltig steigern.

Im dritten Kapitel wird das aktuelle technische Effizienzniveau der SSA-Kleinbauern und der Zusammenhang zwischen demselben und der Beteiligung von Frauen an Entscheidungsprozessen mit Hilfe einer zweistufigen Double-Bootstrap-Data-Envelopment-Analyse Methode analysiert. Die Ergebnisse zeigen, dass die meisten landwirtschaftlichen Haushalte, die kleinere Aquakulturen unterhalten, technisch nicht effizient sind und zwischen 45 % und 60 % unterhalb der Produktionsgrenze arbeiten. Zudem wird deutlich, dass einige der sozioökonomischen und produktionstechnischen Merkmale der Haushalte die Effizienz der Fischzucht signifikant beeinflussen. Auch das Mitspracherecht der Frauen auf Haushaltsebene verbessert signifikant das Niveau der technischen Effizienz, indem Ressourcen optimal verteilt und organisiert werden. Diese Studie unterstreicht die dringende Notwendigkeit, Interventionsprogrammen zu fördern, die auf die Verbesserung der technischen Effizienz von SSA-Kleinbauern abzielen. Strategien und Interventionsprogrammen mit dem Ziel die Produktivität in der Aquakultur zu steigern würden davon profitieren, wenn sie auch die Stärkung der Frauen zum Ziel machen und damit Ungleichheiten zwischen den Geschlechtern verringern.

Im vierten Kapitel werden die Determinanten und die Wohlfahrtseffekte auf Haushaltsebene der Einführung von nachhaltigen Aquakulturtechnologien mit Hilfe des endogenen Switching-Regressionsmodells (ESR) bewertet. Dass das ESR-Modell besser geeignet ist als eine gepoolte Regression, wird durch die folgenden zwei Aspekte deutlich; zum einen durch den signifikanten Korrelationskoeffizienten zwischen den Fehlertermen der Entscheidung, die neuen Technologien einzusetzen, und den Ergebnisgleichungen und zum anderen durch die Heterogenität in den Ergebnisvariablen zwischen Haushalten, die die Technologien einsetzen und denen die sich dagegen entscheiden. Die tatsächlichen und kontrafaktischen Ergebnisse des Modells zeigen, dass die Annahme von nachhaltigen Aquakulturtechnologien zu positiven Wohlfahrtseffekten auf alle SSA-Haushalte führt, gemessen am Fischertrag pro ha, dem Household Dietary Diversity Score (englisch für Score für die Ernährungsdiversität eines Haushalts) und dem Total Food Consumption Score (englisch für Score für den gesamten Lebensmittelkonsum eines Haushalts). Die Studie stellt auch heraus, dass das Wissen der Haushalte über Aquakulturproduktion und auch die Informationsquellen einen starken Einfluss auf die Entscheidung für oder wider die neue Technologie haben und auch für die Wohlfahrtseffekte entscheidend sind. Folglich sollten die Förderung des Bewusstseins der SSA-Kleinbauern und die Bereitstellung verbesserter Beratungsdienste fester Bestandteil von Politikstrategien sein, die auf die Entwicklung von Aquakulturen in kleinerem Maßstab abzielen.

Die Ergebnisse dieser Arbeit leisten einen Beitrag zur Debatte um die Frage, wie die Entwicklung des Aquakultursektors darauf hinwirken kann, einige der SDGs zu erreichen. Insbesondere kann die Aquakultur die Ernährungssicherung verbessern, indem sie durch erhöhtes Angebot Fisch in größerem Umfang verfügbar und zugänglich macht. Darüber hinaus kann die Aquakultur Geschlechtergleichstellung und die Rolle der Frau durch Schaffung von Beschäftigungsmöglichkeiten, die mit dem Aquakultursektor zusammenhängen, stärken. Akteuren wie der Regierung und Entwicklungsorganisationen wird empfohlen über optimale, angepasste Aquakulturpraktiken und den geeigneten Einsatz von Produktionsmitteln mittels verbesserter Beratungsdienste zu informieren. Da der Aquakultursektor bisher von nur einer Fischart dominiert wird, wird zudem geraten, Forschungs- und Entwicklungsprogramme zum Brüten und Züchten anderer, geeigneter Arten zu unterstützen. Eine weitere Empfehlung ist das aktuelle "Farmland Law 2012" neu zu formulieren, da es aktuell Einschränkungen für die Umwandlung von landwirtschaftlichen Flächen in Fischteiche vorsieht. Das hindert Landwirte daran, legal in den Aquakultursektor einzusteigen. Diese politischen Empfehlungen sind essentiell, um ein Wachstum im SSA-Sektor zu erreichen und das Mitspracherecht von Frauen innerhalb des Haushalts zu erhöhen und damit die Tür zu höheren Lebensstandards zu öffnen.

List of Abbreviations

AD	Ayeyarwady Delta
AIDS	Almost Ideal Demand System
ARDC	Agricultural and Rural Development Corporation
ATT	Average Treatment Effect on the Treated
ATU	Average Treatment Effect on the Untreated
BCTE	Bias-Corrected Technical Efficiency
CDF	Cumulative Density Function
DEA	Data Envelopment Analysis
DID	Difference-in-Difference
DMU	Decision Making Unit
DOF	Department of Fisheries
ESR	Endogenous Switching Regression
FAO	Food and Agriculture Organization
FIML	Full Information Maximum Likelihood
GPI	Gender Parity Index
HDDS	Household Dietary Diversity Score
IAA	Integrated Aquaculture-Agriculture
IHLCA	Integrated Households Living Conditions Assessment
IMR	Inverse Mills Ratio
KMO	Kaiser-Meyer-Olkin
MFF	Myanmar Fisheries Federation
MMK	Myanmar Kyat
MOPF	Ministry of Planning and Finance
MPLCS	Myanmar Poverty and Living Conditions Survey
MPMPs	Modified Pond Management Practices
NGOs	Non-Government Organizations
OLS	Ordinary Least Squares
PCA	Principal Component Analysis
PDF	Probability Density Function
PSM	Propensity Score Matching
QUAIDS	Quadratic Almost Ideal Demand System

SA	Sustainable Aquaculture
SBM	Slack-Based Measurement
SDGs	Sustainable Development Goals
SFA	Stochastic Frontier Analysis
SPAITS	Scaling systems and Partnership for Accelerating the Adoption of Improved Tilapia Strains by Small-scale fish Farmers
SSA	Small-scale Aquaculture
TE	Technical Efficiency
TFCS	Total Food Consumption Score
UNDP	United Nations Development Programme
VFV Law	Vacant, Fallow and Virgin Lands Management Law
VRS	Variable Return to Scale
WEAI	Women's Empowerment in Agricultural Index
WELI	Women's Empowerment in Livestock Index
WPDM	Women's Participation in Decision-making
WPDMI	Women's Participation in Decision-making Index

Chapter 1: Introduction

1.1 Background

Achieving sustainable economic growth and ensuring the food and nutrition security of growing populations remain a challenge throughout the world. Persistent poverty, unemployment, and inequality are the main constraints for achieving food security and nutrition goals (FAO, 2018). Globally, the fisheries and aquaculture sector perform a significant and positive role in ensuring food security and livelihoods. While capture fishery production has been relatively stable, with some potential growth mainly in terms of inland capture globally, the significant growth in global production from the fishery sector since the early 1990s has been from aquaculture. Countries in Asia account for 89% of the share of world farmed aquatic animal production with an average production growth rate of 5.3% per year from 2001 to 2018. Developing and least developing countries often rely more on fish and other aquatic products for their nutritional security than developed countries. Among the fishery sector, the aquaculture sector provides 46% of total fish supply and 52% of total fish consumption globally. While fish consumption contributed 20% of per capita average animal protein intake globally, its contribution reached 50% or more in some developing countries in Asia and Africa (FAO, 2020).

As shown in Figure 1.1, Myanmar ranked 9th in the world in terms of aquaculture production in 2018 (FAO, 2020). Moreover, Myanmar ranked 10th in terms of fish and seafood consumption levels. In fact, fish consumption accounts for 50 % of animal sources of food in Myanmar (Belton et al., 2015). Additionally, the fishery sector is regarded as an essential contributor to fulfill people's protein requirement, provide food security, create employment opportunities, and generate income to a large number of rural dwellers and fishery communities (DOF, 2018). The significant contribution of fish consumption to daily nutrient intake reveals the importance of fish consumption to food and nutrition security of the households in Myanmar. The contribution of fish to nutrient intake is determined as follows: 17.5% of recommended protein intake for men and 21% for women, 55% of iron intake for men and 24.4% for women, 24.4% of calcium intake for men and women, and 50% of vitamin B12 intake for men and women (Youn et al., 2018).

Figures 1.2 and 1.3 show that dried and processed fish products constitute the largest share of fish expenditure and of the total quantity of fish consumption in Myanmar in 2005, 2010, and 2015.[1] Comparing fish consumption between 2005 and 2010, the average per capita fish consumption in 2010 was lower in 2005 across almost all fish categories. One possible reason is that Cyclone Nargis in 2008 adversely devastated the Delta region's capacity to produce fish (90 % of fish ponds areas are located in the Delta region). Most commercial aquaculture farms, including hatcheries and nurseries farms, were destroyed and 58 % of fishing households lost fishing gear and boats. Figure 1.7 shows that aquaculture production and area trends have significantly increased since 2000, but have remained stable in 2008 and 2011 due to Cyclone Nargis' effects. Moreover, Cyclone Nargis indirectly affected fishery resource depletion in estuaries and rivers, as well as caused a sharp reduction in the capture fisheries production. The socio-economic and ecological recovery from this Cyclone Nargis has been slow. Based on statistics from the Department of Fisheries (DOF), up until 2013 fish production from capture fishery sources were lower than they were before the cyclone hit in 2008. Many resource poor fishermen continued fishing with lower fish catches (Driel and Nauta, 2014). The result has been a cycle of poverty for many poor households who had to borrow the credit from informal sources with high interest rates to recover their losses or change their profession (Soe et al., 2020) .

Although the aquaculture sector has massive potential to contribute to household fish consumption in Myanmar, the production share of the aquaculture sector to total fishery production is still below that of captured fish because the aquaculture sector constitutes the smallest proportion towards total fish production areas compared to capture fishery sectors. Moreover, the aquaculture sector is dominated by a small number of fish species and there is less diversity in production technologies (DOF, 2018). Government support in Myanmar focuses on large-scale fish farming. Before Cyclone Nargis, the contribution of small-scale fish farming to livelihoods in rural communities was largely neglected by the Government. However, since Cyclone Nargis, some international organizations have attempted to promote the small-scale aquaculture sector in some areas through collaboration with the Department of Fisheries. Despite the apparent abundance of water resources and potential benefits that favor the development of the small-scale aquaculture (SSA) sector, the sector has still been restricted in terms of its development (Filipski and Belton, 2018).

[1] Data from 2005 and 2010 originates from the "Integrated Household Living Conditions Assessment Survey" (IHLCA), conducted by the United Nations Development Programme and Ministry of Planning and Economic Development. Data from 2015 is from the "Myanmar Poverty and Living Conditions survey" (MPLCS) in 2014/15," jointly conducted by the Ministry of Planning and Finance (MOPF) and World Bank. All datasets are nationally representative households' surveys of 18,660 households in 2005, 18,609 households in 2010, and 3,648 households in 2015.

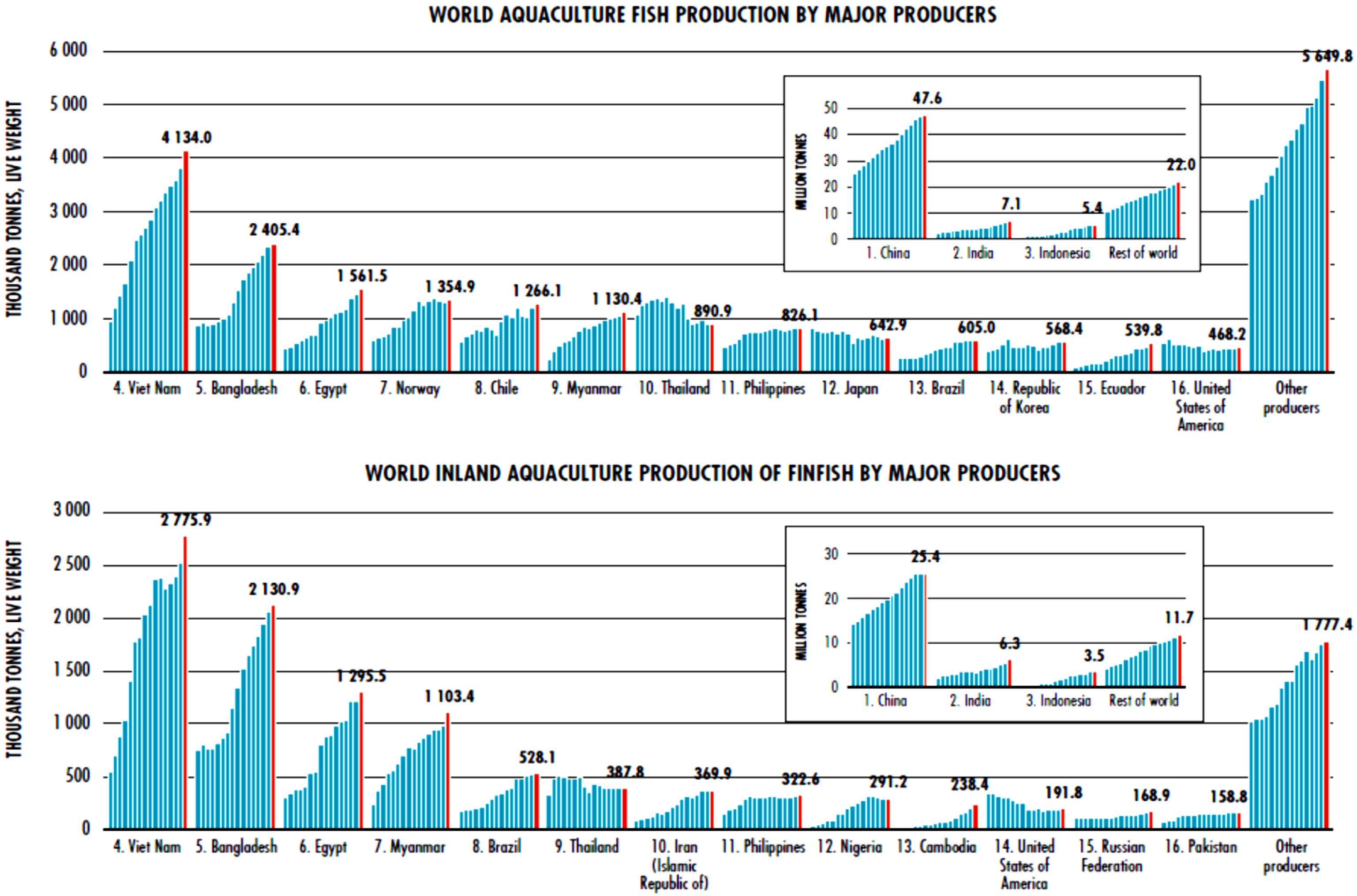

Figure1.1: World aquaculture fish production by major producers

Note: Columns for each entry represent aquaculture production for the years from 2003 to 2018.

Taken from FAO (2020)

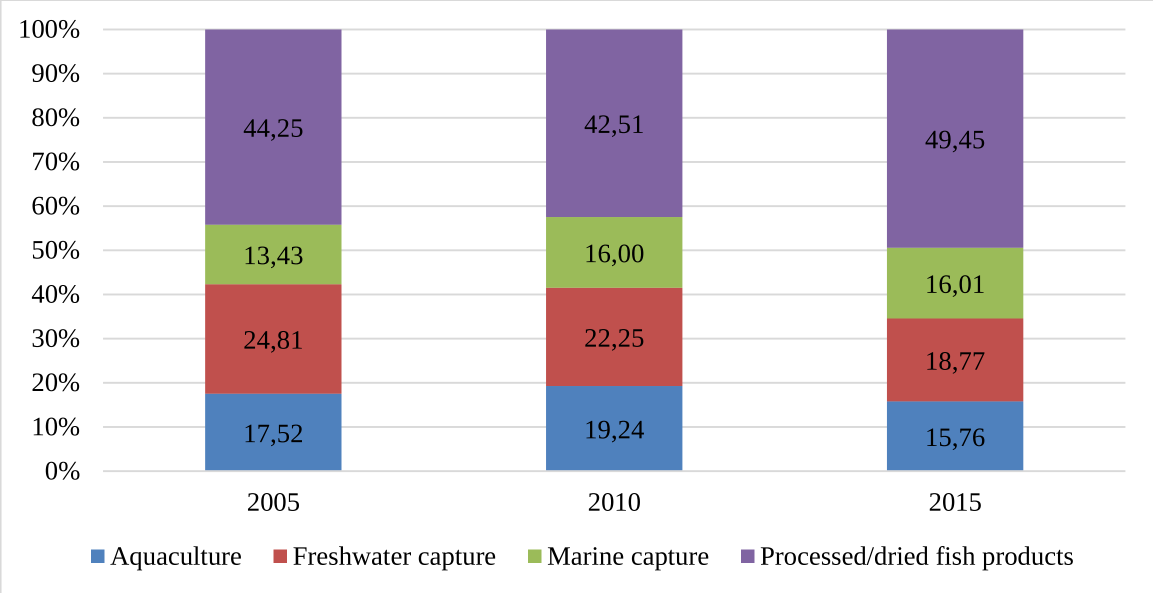

Figure 1.2: Share of fish consumption expenditure by source in 2005, 2010, and 2015

Source: Author's calculation from IHLCA 2005 and 2010 datasets and the MPLCS 2015 dataset

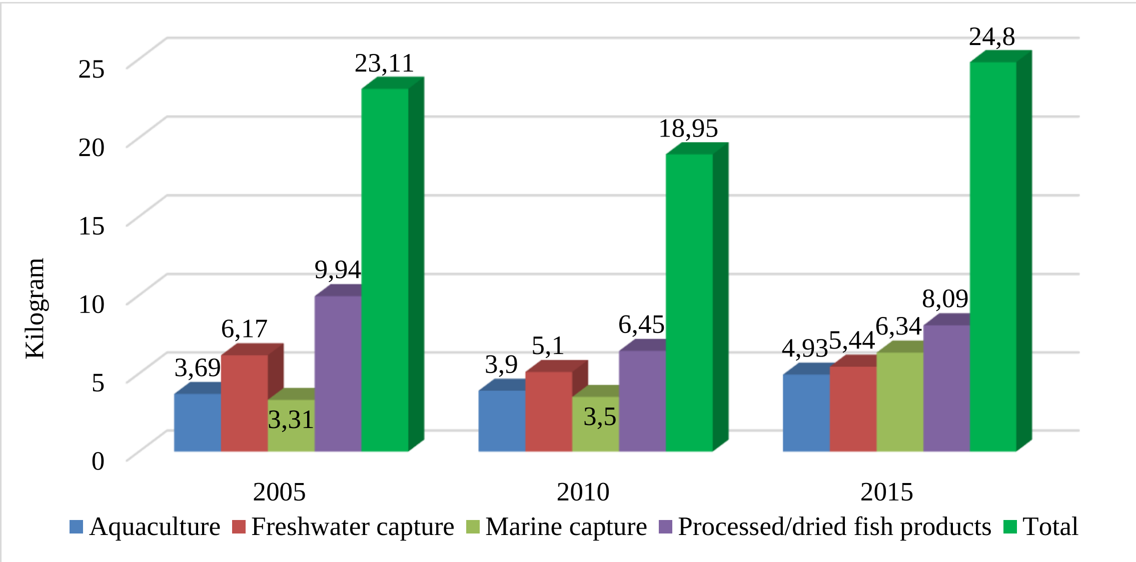

Figure 1.3: Annual per capita fish consumption by source in 2005, 2010, and 2015

Source: Author's calculation from IHLCA 2005 and 2010 datasets and the MPLCS 2015 dataset

In general, the development of the aquaculture sector can improve food security and reduce household poverty by enhancing food consumption, employment opportunities, and income through direct and indirect linkages (Belton et al., 2014). In developing countries, poverty reduction programs through the SSA sector remain compelling because most people reside in rural areas where agriculture, including aquaculture, is the primary income source through direct and indirect ways (Otsuka et al., 2016). Increasing income from fish farming reflects the current improvements of their welfare or may be transmitted inter-generationally as an indirect link. From the consumption link, an increase in the fish production leads to an increase in the farm household's fish consumption, availability of fish in the local market, and accessibility of fish due to lower prices for non-farm households (Steinbronn, 2009). The employment link through the aquaculture sector creates low skilled labor jobs for both family and hired labor through enterprises that are backward[2] and forward[3] on the value chain which would help in raising rural wages. This link leads to empowering women's roles because women's level of participation in aquaculture is relatively higher than that in the fisheries sector and agricultural sector (Kassam, 2013; Stevenson and Irz, 2009). In addition, aquaculture generates indirect income that increases household income, thus providing services and inputs for aquaculture production through the link to the market. Increased household income creates more demand for other food commodities. A summary of links in the development of the aquaculture sector is shown in Figure 1.4.

Regarding Filipski and Belton (2018), the average aquaculture farm in Myanmar generates much more direct and indirect income compared to the average agriculture farm. Compared to large-scale fish farms (ponds greater than 4.05 hectare (ha)), small commercial fish farms (ponds that are 4.05 ha or less) generate larger local spillover effects. This implies that small-scale commercial fish farms tend to use more local inputs, such as feed and manual labor, while large-scale fish farming is more likely to invest in capital intensive technologies. Landless households, especially poor households, capture most of the indirect effects through links to employment. The labor demand per acre of an aquaculture farm in Myanmar is four times higher than that of a crop farm. Moreover, aquaculture farms provide higher wages, especially for women, and thus lower the gender income gap. For one acre of small aquaculture farms,

[2] Eg. Hatcheries, nurseries, feed suppliers
[3] Eg. Harvesting, post-harvest handling, processing and marketing activities

56% of the generated total revenue is in the form of indirect income (spillover income), while that for large-scale fish farms is 50%.

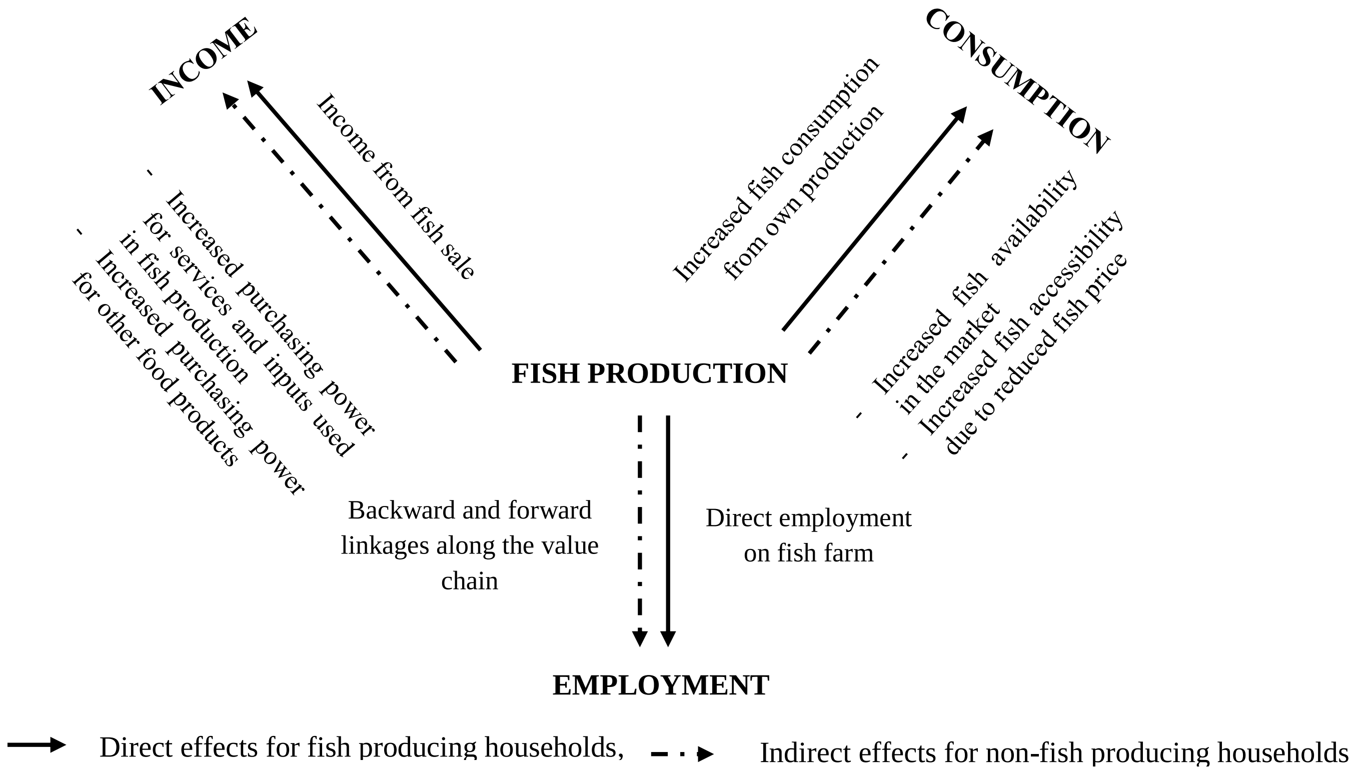

Figure 1.4: The contribution of the aquaculture sector to livelihood outcomes of fish farming households and non-farm households

1.2 Conceptual framework and outline of the thesis

In the context of the aquaculture sector in Myanmar, this thesis seeks to address specific knowledge gaps in the scientific literature and contribute to the current debate that the development of the aquaculture sector can help some sustainable goals by exploring the existing demand and supply conditions of the aquaculture sector. Before 2015, most of the literature related to aquaculture in Myanmar are gray literature, such as program or project reports, except for very few peer-reviewed articles on fish genetics (Aung et al., 2010) and four value chain studies (Joffre and Aung, 2012, 2014; Driel and Nauta, 2014; CBI, 2012). After 2015, the number of comprehensive working papers, research reports, and peer-reviewed articles on the technical and economic characteristics of the aquaculture sector in Myanmar increased (Belton et al., 2018, 2019; Tezzo et al., 2016, 2018; Filipski and Belton, 2018; Karim et al., 2020). However, to date, even though Myanmar is one of the major consumers of fish and producers of aquaculture fish worldwide, there is still the need for a description of the fish demand structure and the current state and potential of the small-scale fish farming sector in

Myanmar. In light of the widespread issue of demand and supply aspects of the aquaculture sector, this thesis focuses on disaggregated fish consumption patterns across household categories, determinants and implications of performance in the SSA sector, as well as corresponding livelihood outcomes. The conceptual framework of the thesis is illustrated and summarized in Figure 1.5. Below, we address the flow and causal links of the research topics, which correspond to the following three chapters of this thesis, as well as their main objectives and research questions.

In the following section, a brief overview is given about how Myanmar's aquaculture sector has developed in different policy regimes. Due to the stable trend of capture fisheries production and some potential growth from inland capture fishery source, the aquaculture sector is the only subsector in the fishery sector to increase production rapidly and sufficiently. However, there is no empirical evidence about how consumption patterns of disaggregated fish sources differ across household categories and whether development in the aquaculture sector can compensate for either concurrent stagnation or slow growth of capture fish production given the increase in household demand. Understanding the change in consumption patterns of households and their determinants is also critical to realize future fish demand. Information about demand parameters is useful for calibrating demand equations in fish foresight modeling studies to inform decision-making and policy to support sustainable fisheries and aquaculture development to positively contribute to the Sustainable Development Goals (SDGs). The factors mentioned above emphasize the importance of our first topic, namely the estimation of fish demand parameters for disaggregated fish sources by household groups. Most studies have estimated fish demand structures at the aggregate household-level, ignoring potential differences in consumption behavior across household categories. A study by Toufique et al. (2017) focuses on the difference in consumer fish demand, but fails to control for both endogeneity and sample selection bias derived from zero consumption observations. Chapter 2 of the thesis aims to close this research gap.

Despite the dominance of large-scale fish farming, the number of either legally or illegally operated small and medium ponds is significantly higher than shown in officially recorded data (Belton et al., 2015). These outcomes highlight that profitability and employment opportunities have enticed farmers to enter the sector informally (Belton et al., 2017; Norad, 2016). However, SSA farmers face several barriers compared to other aquaculture producing countries in Asia due to the existing land use policy that restricts the conversion of agricultural land into aquaculture fish ponds, as well as the lack of institutional support. To increase farmer's income with lower production costs and higher returns, measuring the production efficiency and investigating the determinants of inefficiency could be helpful for identifying suitable policy instruments. The relevant question of whether the current SSA sector can be made more efficient by achieving either the current output level with fewer inputs or a higher output level with the current level on inputs still remains unanswered. As an initial step to answering this question, this study focuses on an input-oriented approach that measures the level of technical efficiency that leads to inputs used more sparingly at a given level of output. Conceptually speaking, SSA's technical efficiency can be influenced by a combination of social, economic, and environmental characteristics of fish farming households. Although many previous studies have shown that fish producers' socioeconomic and production characteristics influence technical efficiency, the effect women's participation in decision-making (WPDM) on the technical efficiency of fish farming has not yet been examined. FAO (2018) reports that women play a significant role as laborers, managers, and/or decision-makers in the aquaculture production process and value chains. Prior studies in the agricultural sector have shown that women's empowerment indicators, including participation in the decision-making process, access to and control over the household resources, and freedom of movement, positively impact agricultural productivity, technical efficiency, and food and nutrition security of the households (Zereyesus, 2017; Seymour, 2017; Diiro et al., 2018). Information on the linkage between WPDM and technical efficiency could be applied for designing intervention programs and policies that have the goal to increase women's empowerment. Our research emphasizes the importance of exploring the relationship between WPDM as a measurement of women's empowerment and the technical efficiency of fish farming. Chapter 3 of the thesis tries to close this research gap.

Considering the impacts from the adoption of aquaculture technologies on productivity improvement, aquaculture standing-alone farms and traditional production practices are risky ventures and no longer an option for SSA farming households (Prein, 2002). FAO (2018) reports that renewing or modifying resources and assets used to produce goods and services and implementing innovative technologies is critical for increasing productivity. As mentioned above, SSA farming households in Myanmar face several barriers in their fish production activities due to the lack of institutional support and limited active extension services (World Bank and MOALI, 2019). In this regard, simple aquaculture production technologies based on local resources and expertise would likely bring about quick attainable and positive impacts on fish production by SSA farming households (Steinbronn, 2009). However, insights into what type of aquaculture technology is suitable for SSA farmers are still unclear. There are a vast number of studies about the determinants and impacts of the adoption of sustainable or improved technologies in the agricultural sector (cf. Asfaw et al., 2012; Khonje et al., 2018; Abdulai, 2016). However, none of these studies examined determinants of the adoption of sustainable aquaculture practices and its impact on the welfare outcomes of SSA households. Chapter 4 of the thesis tries to fill this research gap. It emphasizes sustainable aquaculture technologies (SA), namely Integrated Aquaculture-Agriculture (IAA) and Modified Pond Management Practices (MPMPs). In this chapter, we explore links between the adoption of SA technologies and household welfare outcomes, namely fish yield per acre, Household Dietary Diversity (HDDS), and Total Food Consumption Score (TFCS). Finally, in Chapter 5, we summarize the insights from the previous three chapters' main research findings and lessons drawn from our empirical work. The thesis ends with implications for research and policy, limitations of the study, and recommendations for future research.

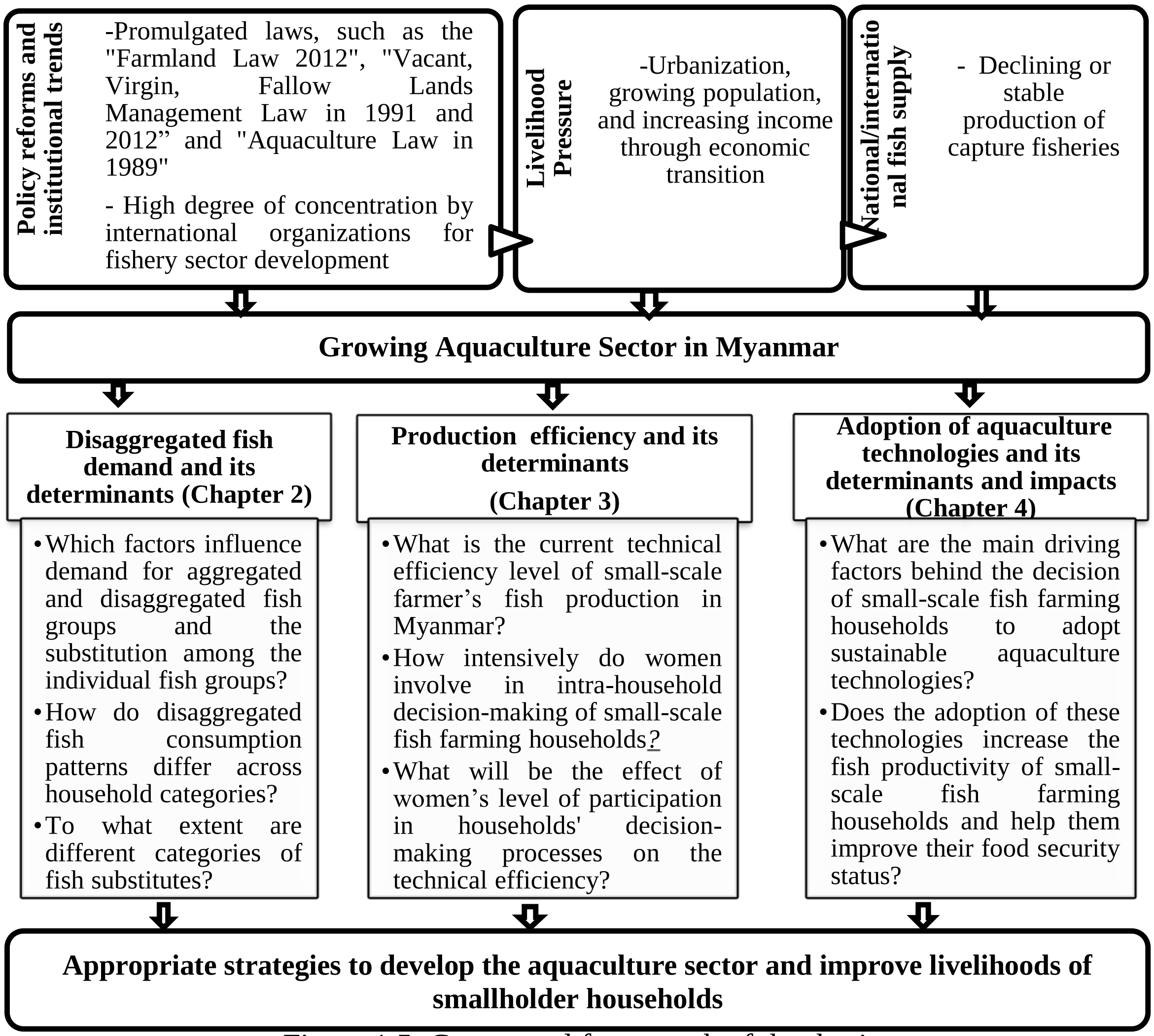

Figure 1.5: Conceptual framework of the thesis

1.3 Research objectives

This thesis focuses on three main objectives that are mentioned in three corresponding chapters. These main objectives are:

- To analyze fish demand differentiated by fish source, household wealth group, and household location;
- To analyze women's level of participation in decision-making as a measurement of women's empowerment and its implications on the technical efficiency of small-scale aquaculture farming households; and
- To assess the determinants of the adoption of sustainable aquaculture technologies and the impact of adoption on welfare outcomes of small-scale fish farming households.

1.4 Research questions

The following research questions emphasize the first objective, dealt with in Chapter 2, which explores the disaggregated fish demand system by wealth group (poor and non-poor households) and household location (rural and urban):

- Which factors influence demand for aggregated and disaggregated fish groups and the substitution among individual fish groups?
- How do disaggregated fish consumption patterns differ across household categories?
- To what extent are different categories of fish (aquaculture, freshwater capture, marine capture, and dried fish products) substitutes?

The second objective, dealt with in Chapter 3, explores technical efficiency and implications of women's level of participation in decision-making activities on SSA farming's technical efficiency. The chapter addresses the following questions:

- What is the current technical efficiency level of small-scale farmer's fish production in Myanmar?
- How intensively do women participate in intra-household decision-making of small-scale fish farming households?
- What will be the effect of women's level of participation in households' decision-making processes on technical efficiency?

The third research objective, dealt with in Chapter 4, examines the adoption of sustainable aquaculture technologies and impacts on their welfare outcomes for SSA farming households. The following research questions are addressed:

- What are the main driving factors behind small-scale fish farming households' decision to adopt sustainable aquaculture technologies?
- Does the adoption of these technologies increase fish productivity of small-scale fish farming households and help them improve their food security status?

1.5 Description of the study areas

The Ayeyarwady Delta (AD) region covers 35,140 square km. It is bordered by Bago region to the north, Yangon region to the east and the Bay of Bengal to the south and west (see Figure 1.6). The moderately high annual rainfall of up to 5,000 mm (Baroang, 2013) and flat topography are well suited to agriculture, including aquaculture (ADB, 2013). The abundant water resources favor productive fisheries (Baroang, 2013). The largest areas in this region have been cleared for paddy cultivation, followed by inland fish ponds. The Phyapon district in the AD region is located 131 km away from Yangon, the capital of Myanmar, and is comprised of four townships (Phyapon, Bogale, Daydaye, and Kyaiklatt). In Phyapon district, the total area is about 5,550 square km, including 450 villages and 298 village-tracts. Its total farmland area is approximately 3,400 square km. The total population in Phyapon district is 1.03 million with just 13.11% living in urban areas (MIP, 2015). This district has a high population density. Moreover, it is vulnerable to climate shocks, such as saltwater intrusion, flooding, and other severe weather changes because it lies only three meters above sea level (Driel and Nauta, 2014). Rising sea level, seasonal river runoff, and flooding after severe impacts of Cyclone Nargis in 2008 are significant sources of salinity in the AD region (Mu et al., 2015).

Myanmar's aquaculture sector is comprised of three subsectors: inland or freshwater, coastal or brackish water, and marine. Inland or freshwater aquaculture accounts for close to 95% of total aquaculture fish production (Belton et al., 2015). The Delta Zone, included Ayeyarwady, Yangon, Bago and Mon accounts for about 90% of total aquaculture pond areas (shown in Figure 1.8). Within the Delta Zone, the AD region accounts for an estimated 52% of the total aquaculture area (DOF, 2018). Among the AD region, Phyapon District has considerable potential to innovate and scale-out different SSA production systems given its high concentration of small-scale fish ponds. In Phyapon District, Phyapon, Kyaiklatt, and Daydaye townships were selected as the study areas and have total farm land areas consisting of 196326, 149787, and 189423 acres (GAD[4], 2018), respectively, and pond areas consisting of 9,194 acres, 1,074 acres, and 2,487 acres, respectively (DOF[5], 2018).

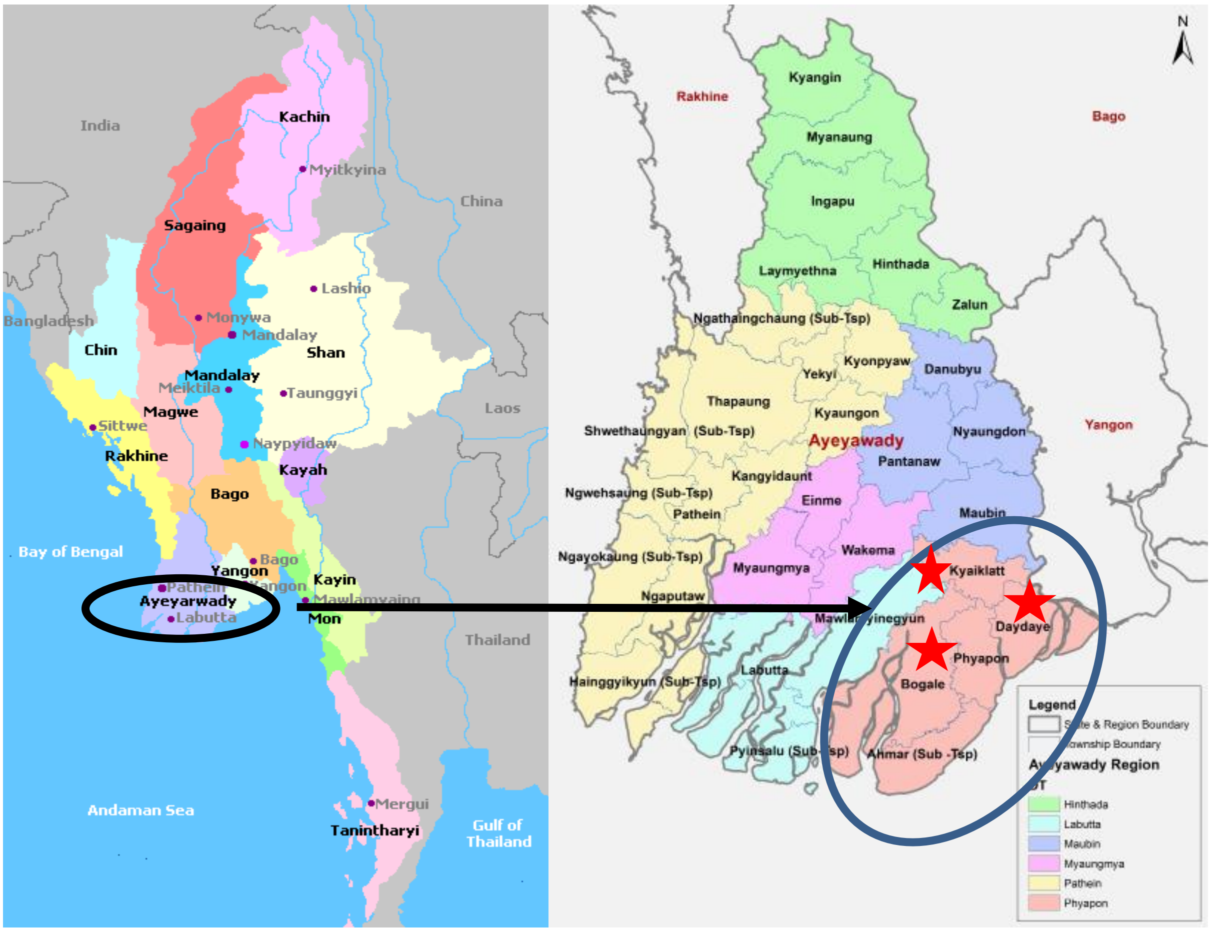

Figure 1.6: Maps of study areas in Phyapon district, Ayeyarwady Delta region
Source: MIP[6] (2015)

[4] General Administration Department, Pyapon District
[5] Department of Fisheries, Phyapon District
[6] Ministry of Immigration and Population

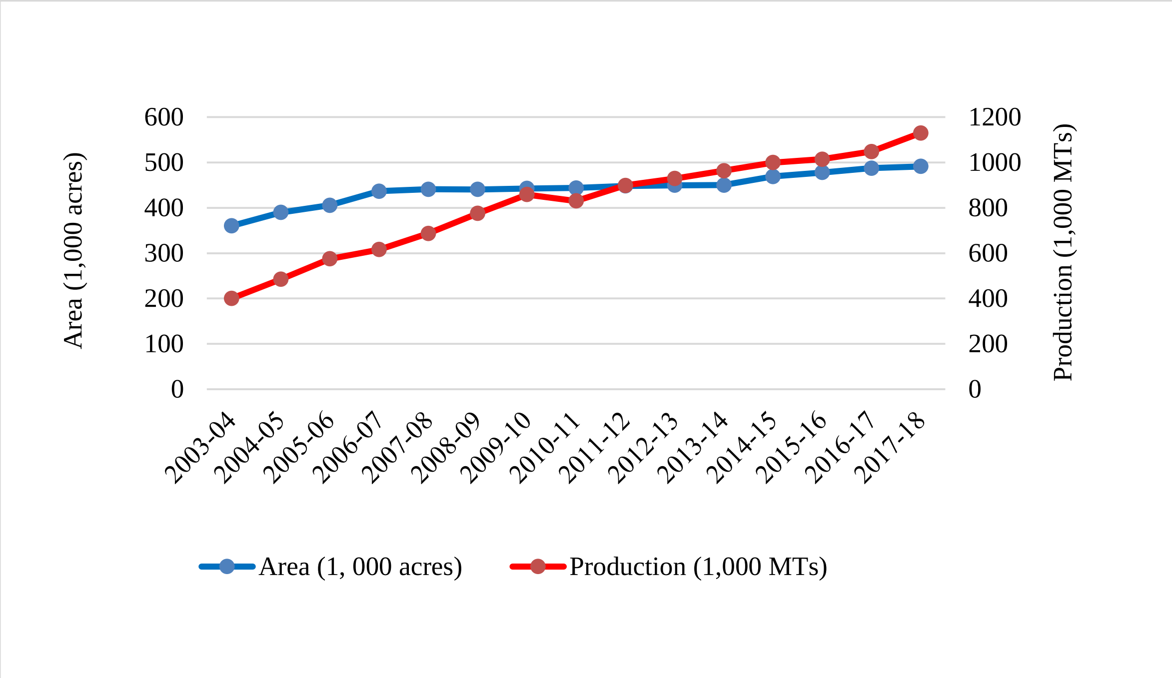

Figure 1.7: Aquaculture pond areas and production, 2003-2017
Source: DOF (2018)

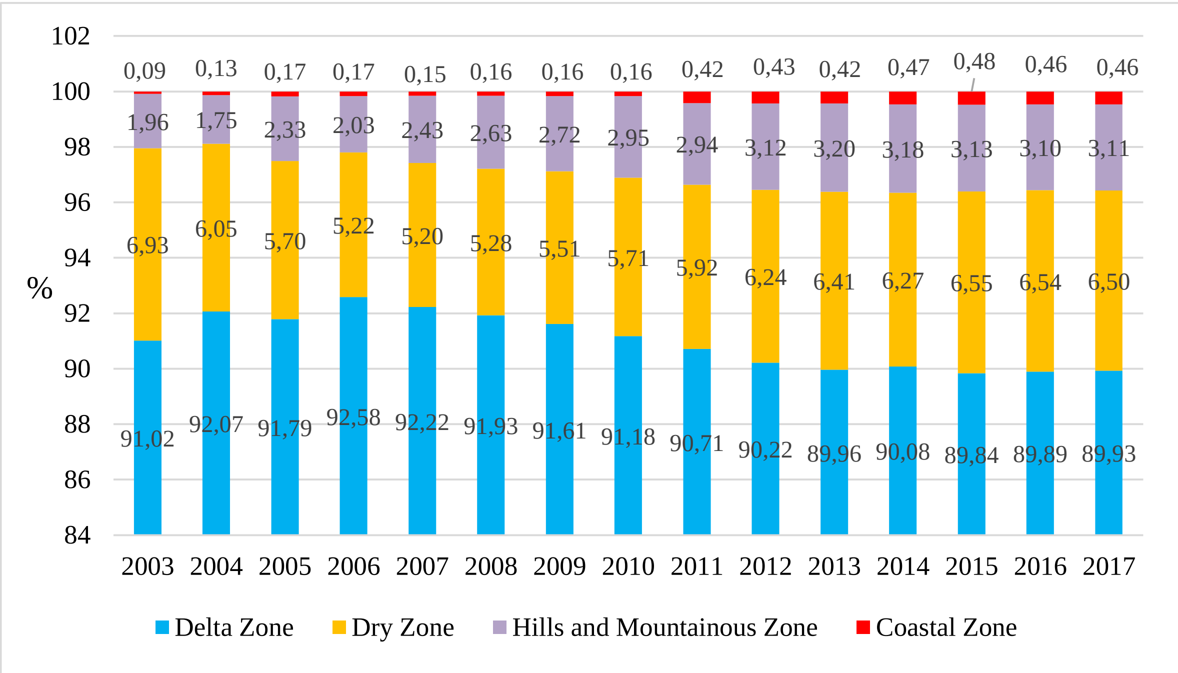

Figure 1.8: Share of fish pond areas by geographical zones, 2003-2017
Source: DOF (2018)

1.6 Data collection and methodology

Data used in this thesis originate from household surveys and other secondary data sources. The Department of Fisheries (DOF), Central Statistical Organization (CSO), and Food and Agricultural Organization (FAO) are the major secondary data sources on official statistics on fish production. Primary quantitative data for all studies were collected through a household survey. In addition, focus group discussions were conducted to garner more insights into opportunities and barriers to: development of the SSA sector, gender aspects in aquaculture production activities, and livelihood activities. The findings from the focus group discussions can help in the interpretation of the quantitative indicators. Detailed explanations of the sampling procedures and methods are presented in the subsequent chapters.

Household survey data for Chapter 2 originate from the "Myanmar Poverty and Living Conditions survey" (MPLCS) in 2014/15," jointly conducted by Ministry of Planning and Finance (MOPF) and World Bank. Data on household income, food, non-food consumption expenditure, and other demographic characteristics were extracted from MPLCS data. A three-stage budgeting framework, combined with the censored Quadratic Almost Ideal Demand System (QUAIDS) model, was applied. The analyses in Chapters 3 and 4 rely on survey data from 440 SSA households collected in three townships in Phyapon District, AD region during the baseline survey in 2019 for the SPAITS project.[7] Before conducting the baseline survey, enumerator training was held in Phyapon District by the project members from WorldFish and Hohenheim University. Afterwards, enumerators were trained on collecting data by using a tablet since survey data were collected via a mobile data collection Open Data Kit (ODK) platform. After this session, enumerators conducted a pilot survey in one village nearby using the electronic version of the questionnaire.

Data collected include different aspects of fish farming, such as social, economic, and environmental aspects, and the farmers' livelihood activities for integrated performance analysis. For examining the participation of different genders in aquaculture and household decision-making activities, questions about the main decision-makers in different household livelihood activities, such as pond management, harvest use, income allocation, and nutrition, and labor composition in fish farming activities, were included. For the second objective, a two-stage double Bootstrap Data Envelopment Analysis (DEA) was applied to estimate the

[7] SPAITS is an abbreviation for "Scaling systems and partnerships for accelerating the adoption of improved tilapia strains by small-scale fish farmers." For more information on the SPAITS project, see: worldfishcenter.org

bias-corrected technical efficiency scores and valid statistical inferences for the determinants of the technical efficiency analysis. Principal Component Analysis (PCA) was used to generate the WPDM index. For the third objective about technology adoption, we used the endogenous switching regression (ESR) model to calculate the actual welfare effects of the adoption of sustainable aquaculture technologies by controlling for selection bias issue on the adoption decision and welfare outcomes.

1.7 A brief history of the development of the aquaculture sector in Myanmar

Aquaculture sector development during each political regime is presented briefly in Figure 1.9. Details about the political and economic history of the four major policy regimes are reported in Hein and Belton (2017) and Tezzo et al. (2018). The Agricultural and Rural Development Corporation (ARDC) set up an Aquaculture Section in 1954. In 1956, 100 fish ponds were established by the ARDC. Aquaculture area expansion is based on the capture and nursery of wild-caught carp species. In the late 1950's, Tilapia species was introduced from Thailand and raised locally. In 1964, after introducing common carp species from Indonesia and Israel, the common carp culture rapidly expanded. Rapid growth in the aquaculture sector stemmed from the expansion of areas by early private and large-scale fish farmers, as well as from collaboration between private farmers and the Department of Fisheries (DOF). Therefore, the FAO was requested to initiate a captured fish breeding program in 1967, especially concerning the Rohu species, to supplement the collection of juveniles from wild resources (FAO and NACA, 2003). Moreover, around 1985, a large wealthy early fish farmer established private fish hatchery in Kayan by collaboration with DOF staffs privately and informally. This sector's annual growth rate reached 40% in 1988 due to the dominance of large-scale fish farms. The expansion of pond areas continued with the introduction of hybrid Clarias (in 1990) and Pangasius fish species (in 1994) (Joffre and Aung, 2017).

In late 1988, the industrialization of agriculture sector was promoted by the Government, which transferred the vacant, fallow, virgin lands and wastelands concession to the private sector for agriculture through "Wasteland Instructions (1991)"[8] by providing other supports such as the export permission up to 50% of the crop, tax exemptions for imported inputs, loans, and the government's infrastructure availability. Initially, these land concessions were intended to intensify and expand the rice cultivation program, but the program was not as successful as

[8] The main title is "Duties and Rights of the Central Committee for the management of cultivated land, fallow land, and wasteland" (Oberndorf, 2012, P.22).

expected due to unprofitable rice production. Because of this failure,[9] some rice cultivation in these concession lands were converted to fish pond operations through the "Aquaculture Law" enacted in 1989 (FAO and NACA, 2003). Due to the dominance of large-scale fish farming areas, aquaculture fish production reached 0.5 million MT with a production value of USD 1.231 billion in 2004 (Joffre and Aung, 2017; DOF, 2018). Land reforms in Myanmar in 2012, such as the "Farmland Law" and "Vacant, Fallow and Virgin Lands Management Law (VFV Law)",[10] have contributed to moving towards development of the aquaculture sector with a changing legal space surrounding land and leading to foreign investment. However, these changes have led to the weakening of tenure security for smallholder farmers due to restrictions on the converting the agricultural land to fish ponds. By 2017, more than 1 million metric tons of aquaculture fish were produced, representing 19% of total fish production (DOF, 2018). According to the FAO (2020), Myanmar's aquaculture sector is ranked 9th in the world among the major aquaculture producing countries in 2018 and 3rd in Southeast Asia.

1.8 Farm characteristics and management

1.8.1 Fish seed supply and stocking density

Despite the increasing number of "small and medium" fish operations that are legal or illegal under policy reforms, large-scale fish operations, including hatcheries, nurseries, and grow-out fish farms, are still the largest share of the market due their high concentration of technical skills and capital (Hein and Belton, 2017). Private hatcheries largely dominate the hatchery sector because the Government's hatcheries are mainly intended to replenish natural bodies of water (DOF, 2018). There are 39 private hatcheries and 26 government-owned hatcheries in Myanmar (Belton et al., 2015). According to the baseline survey results of the SPAITS project, Rohu, Catla, Pangasius, and Mrigal are the major carp species raised in the study areas. Among them, Rohu and Pangasius have been the dominant species because of its more affordable price and acceptable taste. In terms of the average fish yield, it was 5 tons/ha for small-scale farmers

[9] Okamoto (2009) notes that large areas of granted wasteland in the Delta region in the late 1990s was evidence of inefficient expansion of paddy areas. The main reason was that the Government invited construction and export companies and investors to invest in paddy cultivation in these land areas. However, most of these companies took advantage of their privileges and did not develop the rice production sector. Due to the failure of this intervention program, the aquaculture sector become an alternative investment program to contribute to economic development through the Aquaculture Law 1989.

[10] It prescribed "the mechanisms for converting Vacant, Fallow, and Virgin (VFV) lands into farmland through the application of permit by local farmers to secure a 'Permission Order' for the use of VFV lands". The VFV Law in 2012 is almost identical to the previous legislated rights and responsibilities of the central committee for fallow land, cultivable land, and wasteland management (1991) (Oberndorf, 2012, P.22).

during the SPAITS baseline survey in 2019, 3.8 tons/ha for fish farmers with less than 4.05 ha in 2017 (Belton et al., 2017), and 4.5 tons/ha for large-scale farmers in 2009 (Edwards, 2009).

In terms of average stocking density per hectare, the average stocking density of sampled farmers in the baseline survey was around 20,000 pieces/ha with average weight of 0.01kg and length of 5cm) per fingerling – this was significantly higher than that of the comprehensive survey results (3,334 fish/ha) by Belton et al. (2017). It implies that all sampled farmers during the baseline survey are small-scale farmers (with an average of less than 0.04 ha) and have received some input support, such as fingerlings and feed, from the project. Belton et al. (2017) confirm the finding that stocking density is negatively correlated with pond size.

1.8.2 Fish feed supply and culture techniques

Although fish farming operations have been growing because of some policy changes, most fish farmers still have barriers to sustainable aquaculture production due to an insufficient feed supply and the high cost of manufactured fish feed (Lay et al., 2011; Hishamunda et al., 2009). Myanmar's fish feed manufacturing is still behind other neighboring countries[11] with very few domestic companies, no government ownership,[12] and no foreign direct investment in the fish feed sector like there is in the livestock feed industry (DOF, 2018; Belton et al., 2015). In Myanmar, only seven feed mills out of 27 feed production plants produce fish feed (Lay et al., 2011) because fish feed production is separated from the livestock feed industry. Among domestic pelleted fish feed companies in Myanmar, "*Htoo Thit*[13] *and Shwe Taung-Ngwe Taung"* feed mills are significant feed producers (Norad, 2016). Due to the lack of competition domestically in this sector, the application of manufactured feeds in Myanmar is very low compared to other aquaculture producing countries in Asia, except for Cambodia (Mamun-Ur-Rashid et al., 2013; Hishamunda et al., 2009). About 80% of aquaculture production in Myanmar is still using traditional feeding practices and feeds, such as agricultural by-products

[11] In other neighboring countries, large numbers of domestic and foreign companies for fish and livestock feed manufacturing have been established to fill the insufficient feed production by competing with each other to attract the customers (Belton et al., 2015).

[12] Since 1998, the Government sold out or leased "all state-owned infrastructure related to the fishery sector, such as fishing vessels, ice-plants, processing plants, cold stores, fish-meal plants, and canning plants, to the private sector" (DOF, 2018, P. 6).

[13] Htoo-Thit company has a maximum production capacity of 450 metric tons/day, has produced feeds mostly for their own farm operation (Nelson, 2018). The company has practiced the contract system with small fish farmers by providing feeds and credit for buying juveniles and selling the fish back to the company because family members of this company have operated the following business activities together: hatcheries, nurseries, grow-out fish farms, feed milling and distribution, transportation, wholesale, other infrastructure and facilities for cold storage, ice plants, processing, distribution, and exports (Belton et al., 2015).

and waste, with a low production level. Moreover, the price of manufactured pellet feeds in Myanmar is among the highest in Asia (Belton et al., 2015). Furthermore, aquaculture in Myanmar is mostly based only on semi-intensive production technology instead of intensive technologies like other neighboring countries, such as India, Bangladesh, Vietnam, and Thailand (Belton et al., 2015). Dissemination of information and extension services with limited human resource capacity in Myanmar is relatively slow compared to that in other neighboring countries in the region (Edwards and Allan, 2004; Lay and Oo, 2011).

1.9 Institutional role

In the initial stage, fish culture has developed as an indigenous technology with little support and a slow response to opportunities from both the Government and international organizations. The FAO has been active for more than 50 years in Myanmar's fishery sector. After Cyclone Nargis in 2008, numerous donors funded projects (e.g., JICA, ACIAR, CGIAR, and WorldFish) have become more active to provide supports both in Cyclone affected areas[14] and fish culture. Additionally, since the Government reforms of 2011, some funding agencies and international organizations have shown a high degree of concentration for promoting research and development in Myanmar's fishery sector (DOF, 2018; Baran et al., 2017). Currently, WorldFish has been working on research and development programs with the Government and other partner organizations to develop an improved policy management for the development of the fisheries sector and to capture more social, economic, and environmental benefits for the long-term.[15] Eleven informal associations related to fishery sector development cooperate together to operate the business under the private sector's umbrella, Myanmar Fisheries Federation (MFF). However, the MFF is implemented under the support of the former military government. The MFF generally seeks to promote large-scale farming operations rather than small-scale activities because the most influential and active members of the MFF are large-scale aquaculture operations owners (Baran et al., 2017).

[14] Around 80% of inland fish farms in Myanmar are located in the Cyclone affected areas, namely in the Ayeyarwady Delta and Yangon regions.
[15] See the following website for more information: www.worldfishcenter.org/country-pages/Myanmar.

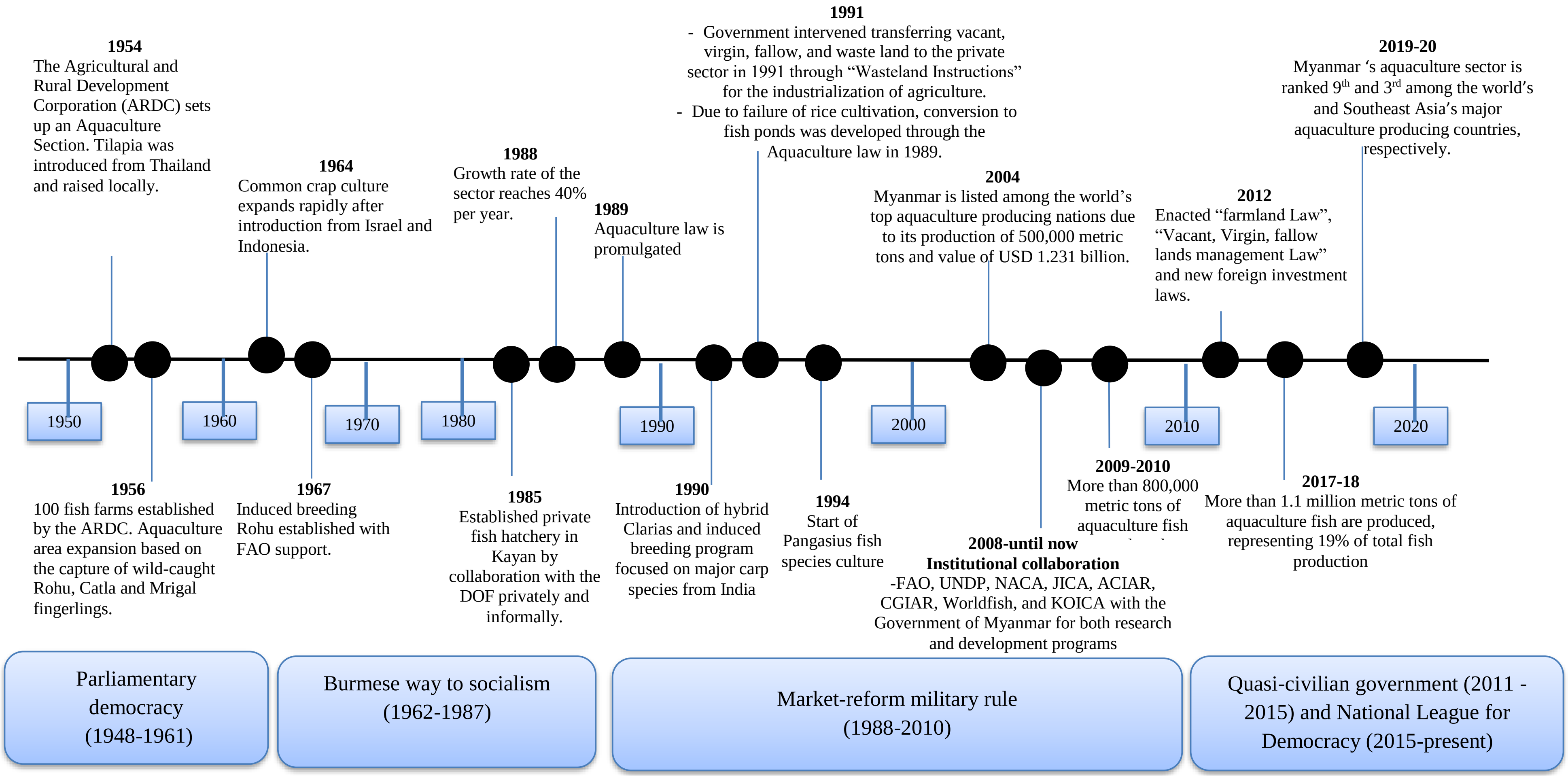

Figure 1.9: Timeline of the development of the aquaculture sector in Myanmar

Sources: DOF (2018), Joffre and Aung (2018), Tezzo et al. (2018)**,** Hein and Belton (2017), Belton et al. (2015) and FAO and NACA (2003)

1.10 Why does gender matter in the aquaculture sector?

Among the fishery sector, the aquaculture sector can be an engine for empowering women through employment opportunities and encouraging women and men in households to work or take care of aquaculture activities together. Women were actively involved in aquaculture activities and related links along the aquaculture value chain, especially in Asia. Most women laborers tend to concentrate on the household-based or subsistence fish farming system, such as feeding, stocking, managing the pond, and marketing products (FAO, 2016). There is empirical evidence in the major fish producing countries in Asia and Africa, such as Vietnam, Cambodia, Indonesia, Bangladesh, and Zambia, where women carry out 42 to 80%of all activities along the value chain (Williams and Hochet-Kinbongui, 2005; FAO, 2016; Ahmed et al., 2012). Generally, aquaculture and fishing activities in Myanmar are male-dominated activities, but women are also active labor in this sector, mainly in post-harvest activities, such as processing, marketing, stocking, and fertilizing, as well as in daily activities, such as feeding (FAO and NACA, 2003; Soe et al., 2020). Women's involvement in small-scale aquaculture activities may increase income and food security of the household because the cash from selling the surplus catch would flow directly to women due to their primary role in fish selling and processing (Aregu et al., 2017).

Moreover, empowering women, increasing their participation in decision-making activities, and improving their knowledge sharing is beneficial to households, as well as local and national economies (Morrison et al., 2007). The female respondents who involved in the focus group discussions during the baseline survey in 2019 report that women fulfill household duties and also support their husbands' main livelihood activity, such as by helping in post-harvest and routine management activities in small-scale aquaculture. Some female members, especially those who are spouses, report that they often bear the sole responsibility of farm and aquaculture production activities because their husband or adult male household members have left to work in the other locations that offer higher incomes. Therefore, women's involvement in income-generating activities, including small-scale aquaculture, to supplement household income enables their male counterparts to work elsewhere (Shelly and D'Costa, 2001). Therefore, promoting gender-inclusive technologies in small-scale fish farming would have a wide range of benefits for household livelihood outcomes (Aregu et al., 2017).

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Chapter 2: A Disaggregated Analysis of Fish Demand in Myanmar

Abstract

We estimate demand elasticities for fish in Myanmar by fish supply sources and household groups, using a multi-stage budgeting approach combined with Quadratic Almost Ideal Demand System (QUAIDS). Our findings show that fish demand from all sources and household groups has increased with income. A substantial portion of increasing demand for all sources of fish is likely to come from poor and rural households because the income elasticity of fish demand from all sources is higher for poor (0.40) and rural households (0.32) than non-poor (0.26) and urban households (0.29). Farmed-fish consumption is the most income-responsive in all household groups. Demand for fish tends to be less price elastic for poor and rural households in most cases because fish is their cheapest animal protein source, and substitutes are limited. Effective management policies and new technologies are essential to sustain fish supply from capture fisheries and aquaculture to meet the increasing fish demand in Myanmar.

Keywords: Fish demand elasticities, three-stage budgeting framework, QUAIDS model, Myanmar

2.1 Introduction

A large number of previous studies investigate the fish and seafood commodity demand structure (e.g., Bronnmann et al., 2016; Xie et al., 2009; Toufique et al., 2017; Chidmi et al., 2012) to provide policy advice and interventions in fisheries and aquaculture sub-sectors. Findings from these studies show that the income and expenditure elasticities of fish demand at the aggregate level in both developed and developing countries are positive and inelastic; however, disaggregated fish demand varies across fish species and countries. Furthermore, the fish demand estimation literature also shows that own-price elasticities of demand for aggregated and disaggregated fish groups are negative, while the magnitude of the price elasticity estimates of disaggregated fish species is mixed. This empirical evidence suggests that the estimation results' quality may depend on the statistical techniques, types of research dataset, and assumptions adopted (Okrent and Alston, 2011).

The most common problems related to the demand system estimations are endogeneity and sample selection bias derived from zero observations in the estimation procedure (Mackay and Miller, 2019). Furthermore, most studies have estimated fish demand at the aggregate household level, ignoring potential differences in consumption behavior across household categories. For example, Bronnmann et al. (2019); Dey et al. (2011); Kumar et al. (2005) have analyzed the fish demand system using multi-stage budgeting approaches in combination with QUAIDS model. Bronnmann et al. (2019) find that elastic expenditure and inelastic price elasticities of demand are found at aggregated fish level, but elastic price demand elasticity at the disaggregated level indicates that most fish are highly substitutable. Dey et al. (2011) and Kumar et al. (2005) have estimated the elasticities of fish demand for the households defined by income quantile to relate income with wealth status. Dey et al. (2011) report that among the different fish groups, income and price elasticities of high-value fish species demand are elastic across income quartile groups, but a large share of disaggregated fish species is expected to come from the poor households in the context of increasing household incomes. Kumar et al. (2005) find elastic income and inelastic price elasticities of demand for all disaggregated fish groups across the income quartile groups, but the share of disaggregated fish demand with the higher income is likely to vary across different sources of fish and the income quartile groups. Toufique et al. (2017) have studied the differences in consumer demand by rigorously defined wealth group. Findings are elastic income elasticity of inland capture and aquaculture fish groups for the poorest household and the inelastic price elasticity of demand of all sources of fish across the household groups, except for the marine capture fish source; nonetheless, their estimation does not address the endogeneity and sample selection bias issues. Bronnmann et al. (2019) highlights that ignoring the selection bias issue and quality-adjusted price tends to be less elastic demand estimates. In this study, we overcome these weaknesses by categorizing the households into explicit wealth groups and controlling for both endogeneity and selection bias using a multi-stage budgeting approach combined with the QUAIDS model.

Increasing poor households' fish consumption is a significant policy issue concerning food and nutrition security because fish is a major dietary component of households in many developing countries (Toufique et al., 2017). Furthermore, in Myanmar, the inclusion of nutrient-dense fish helps provide a more diverse dietary diet to that dominated by white rice (Scott et al., 2020). Elasticity estimates across household groups are essential to understanding fish demand responsiveness to changes in income and prices. This disaggregated information is needed to assess how economic policies and technological change influence fish distribution and households' food and nutrition security in developing countries. Besides, information about demand parameters is useful for calibrating demand equations in fish foresight modeling studies (e.g., Tran et al., 2017; Tran et al., 2019; Chan et al., 2019) to inform decision making and policy to support sustainable fisheries and aquaculture development to positively contribute to sustainable development goals. Income and price demand elasticities could also help private stakeholders along the fish supply chain adapt to consumer preferences changes during the economic development process.

In this chapter, we examine the household-level consumption behavior of different fish sources across household categories in Myanmar. Fish consumption is disaggregated into four groups (aquaculture, freshwater capture, marine capture, and dried fish) by source of production. Our research is the first in Myanmar to use the available household-level survey data to estimate fish demand elasticities across the household categories (wealth group and household location). The analysis raises the following research questions: what factors influence demand for aggregated and disaggregated fish groups and the substitution among the individual fish groups? How do the disaggregatd fish consumption patterns differ across the household categories? To what extent are different categories of fish (aquaculture, freshwater capture, marine capture, and dried fish products) substitutes? Based on these questions, the following hypotheses are tested:

- Expenditure and income elasticities of aggregated and disaggregated fish demand are higher in poor and rural household groups than in non-poor and urban household groups.

- The compensated own-price elasticity of fish demand from all sources is lower for poor and rural households than for non-poor and urban households.
- Aquaculture fish price changes trigger much larger changes in fish demand among poor and rural households.
- The compensated cross-price elasticities of demand across different sources of fish are higher for rural and poor households than for urban and non-poor households.
- Aquaculture fish can continue to compensate for the decrease in the availability of fish from the sources of capture fisheries.

Myanmar is an interesting developing country in the Southeast Asian region to study the fish demand system at the disaggregated level. With 70% of the population living in rural areas and relying on agriculture sector and fisheries as the primary source of income and livelihoods, the fishery sector plays an essential role in Myanmar's economic growth, job creation, and food and nutrition security (Soe et al., 2020). Myanmar ranks 9th among the top aquaculture-producing countries worldwide (FAO, 2020) and has one of the highest fish product and seafood consumption, ranking 10th out of 178 nations (Belton et al., 2015). Fish provides about 50% of animal-sourced food for household consumption and is a critical source of micronutrient supply in Myanmar(Belton et al., 2015), where more than 30% of the children under five years of age are stunted, and 25% of the children are underweight (WFP, 2020).

Fish production for household consumption in Myanmar comes from three primary sources: aquaculture, freshwater capture, and marine capture fisheries. The fish preferred by the population comes from inland capture fisheries. Much of this production is processed into 'dried fish,' a term describing a range of fish products, including sun-dried fish and also pickled/fermented fish products. The latter are consumed with almost every meal in Myanmar to add taste to an otherwise bland white rice meal. Most aquaculture production comes from freshwater carps – mainly Rohu. Aquaculture production in the country has increased rapidly, threefold between 2003 and 2017, and at an average annual growth rate of roughly 13% since 2003, with pond area expansion of 36% during that same period (DOF, 2018). Aquaculture, 1.14 million tons per annum, now accounts for 36.5% of all fish produced in the country. Meanwhile, capture fisheries in Myanmar, both freshwater and marine, are in serious decline, contributing 1.1 million tons per annum from the marine sub-sector and 0.89 million t per annum from inland fisheries(FAO, 2020). Although Myanmar exports freshwater and marine capture fishery products to other countries, the majority of fish production is consumed in domestic markets (DOF, 2018). The exception being the high-value anadromous Hilsa fish, which is exported to many countries, mainly China and Thailand (Burcham et al., 2020).

2.2 Data and methods

2.2.1 Data description

This study relies on the data from the "Myanmar Poverty and Living Conditions Survey (MPLCS) in 2015", jointly conducted by the Ministry of Planning and Finance (MOPF) and the World Bank. The survey interviewed a stratified multi-stage sample of 3,648 households representing four agro-ecological zones and rural and urban areas in Myanmar. Of the total sampled households, 66 were dropped due to missing data, leaving 3,582 households for the analysis. In the food consumption module of the survey, food and fish consumption data were collected using a seven-day recall. Fish consumption data consists of 37 fish species; however, based on the previous literature, we follow Belton et al. (2015) to group household fish consumption into four groups, namely aquaculture, freshwater capture, marine capture fisheries, and dried fish products by source of production. Details of fish product classification by probable source of production are reported in Belton et al. (2015). Using the national poverty line figure, which was MMK 1,241 per day[16] or MMK 452,965 per year in 2015, we categorized the households as poor and non-poor.[17]

The proportion of households reporting zero fish consumption at the aggregated fish level in the past seven days was 6.34% for the whole sample, 4.87% for the poor group, 7% for the non-poor group, 7.26% for the rural regions, and 4.74% for the urban regions, respectively. At the disaggregated level, the proportion of the households consuming the dried fish for the overall sample was the highest, at 81.24% of total households, followed by aquaculture (43%), freshwater capture (40%), and marine capture (39%), respectively. This mirrors the fish preference by origin and type.

Patterns of fish consumption in Myanmar in 2015, drawing from the survey data, are reported in Table 2.1. A two-sample t-test was conducted to compare the average of fish consumption between geographical regions and among poor and non-poor groups. As reported in Table 2.1, non-poor households' fish consumption is significantly higher than that of poor households across all fish categories. Inequality of fish consumption between poor and non-poor households is most considerable for aquaculture and freshwater fish; consumption from

[16] USD 1 in January 2015 at the market exchange rate was worth MMK 1,025 (https://www.exchange-rates.org).
[17] For more details, see World Bank & Ministry of Planning and Finance (MPF) (2017)

these sources is around 1.5 times lower for poor households than non-poor households. Secondly, although urban household group consume more aquaculture fish than rural households, they consume smaller quantities of fish from other sources than rural households. The apparent tendency of urban people to consume aquaculture fish in larger quantities indicates a high degree of substitutability of aquaculture fish with capture fish(Belton et al., 2015). Overall, while dried and processed fish products are the most consumed, the smallest share of fish consumption is from aquaculture fish, irrespective of the household groups, except for the urban households. This finding implies that while aquaculture is dominated by a small number of fish species and a limited range of products, capture fishery sources are characterized by a much higher diversity of species and a more substantial proportion (63.5%) of total fish production in Myanmar.

Table 2.1: Annual per capita fish consumption in 2015 (kg/year)

	National	Poor	Non-poor	Sig	Rural	Urban	Sig
Average per capita fish consumption by all households (kg/yr) (N=3582)							
Aquaculture	4.62	3.26	5.23	***	3.45	6.65	***
Freshwater capture	5.10	3.44	5.84	***	5.76	3.93	***
Marine capture	5.94	6.40	6.00		6.54	4.88	***
Dried fish[a]	7.58	6.40	8.11	***	8.18	6.55	***
All fish	23.24	19.21	25.05	***	23.94	22.02	***

Notes: P-values less than 0.01, 0.05, and 0.1 correspond to ***, **, and *, respectively.

[a] Dried fish includes pickled and fermented fish products.

Source: Author’s calculation

2.2.2 Methodology for elasticity estimation

2.2.2.1 Analytical framework

Based on neoclassical demand theory, two popular econometric models are commonly used for demand and elasticity estimation: demand systems and single-equation models. The single equation models’ main weakness is that the adding-up restriction of the demand theory is violated, and such models are inconsistent with standard utility maximization (Okrent and Alston, 2011; Ecker and Qaim, 2011). On the other hand, demand systems consist of multiple simultaneous equations can reflect and incorporate the mutual interdependencies and substitution effects between several products of the consumer demand when the price changes and allow for the entire food demand system estimation with the theoretical restrictions derived from economic theory (Ecker and Qaim, 2011). However, the full demand system estimation is impractical if more than 100 food products are included in the dataset, as the parameters of the price elasticities increase with the square of the number of the food items (Deaton and Muellbauer, 1980; Edgerton, 1997 ; Gao et al., 1996). To solve this problem, a multi-stage budgeting framework approach is commonly used to analyze the household fish demand system. The usual assumption of this framework is that the consumer's decision on their total expenditure/income allocation to the commodity groups is performed based on price indices' information. In addition, the allocation of the expenditure within the food groups is independently performed of other food groups and then one is allowed to estimate the demand system independently at each stage and add up these elasticity estimations to total elasticities over the stages (Edgerton, 1997).

In this study, we apply a "three-stage budgeting process," in which a household allocates its total budget to food and non-food expenditure in Stage I. Conditional on Stage I allocation, a share of the total food expenditure is allocated to fish consumption in Stage II. In Stage III, conditional on the Stage II allocation, the total fish expenditure is further disaggregated into specified fish groups. In order to account for any measurement error problem, the predicted total food expenditure for each household derived from Stage I is used in the second stage, and the predicted total fish expenditure from Stage II is applied in the third stage instead of real expenditures. The purpose of using predicted expenditure is that the commodities' expenditure share is directly computed from the observed total food expenditures. Therefore, using the observed total food expenditures can be biased and inconsistent due to the probable correlation between the error term and total expenditure in the expenditure share equation (Edgerton, 1993; Zheng and Henneberry, 2010).

The cross-sectional data is often complicated with censoring the dependent variable created by zero expenditure for the food products. The nonnegative value of observed budget shares means that the dependent variable is censored (Heien and Wessells, 1990). Therefore, this censored data in the disaggregated level demand estimation must be accounted for to obtain consistent elasticity estimates and parameters. If households with zero consumption are excluded from the analysis, the assessment may be biased. Zero consumption may be due to either corner solution or abstention in the utility maximization problem of the household (Shonkwiler and Yen, 1999). While corner solutions result from the unaffordable prices of particular food products, abstention may be due to infrequent purchases. Moreover, the survey period was not long, so it is possible that households did not happen to purchase a particular food during the data collection period.

STAGE I - The total food expenditure function is estimated to be dependent on the Stone price index (SPI) for food commodities, annual income, and other household characteristics. The SPI for food is calculated as the average of the food price $\ln P_f^*$ as follows:

$$\ln P_f^* = \sum_{j-1}^{m} w_j \ln pfd_j \tag{1}$$

Where, w_j and pfd_j are the budget share of the commodity *j* and price of food commodity *j*, respectively. The functional form used in the first stage through OLS is specified as follows

$$\ln(M) = \propto_0 + \propto_1 \ln P_f^* + \propto_2 \ln I + \propto_2 (\ln I^2) + \sum_{i-1} \propto_i Z \tag{2}$$

Where *M* denotes annual total food expenditure (MMK), *I* is annual income (MMK), *Z* is a vector of socio-economic variables of the household that include family size, household head's age, the dummy variable for the household's location in either an urban or rural area, and the primary occupation of the household head. Both linear and quadratic forms of income variables are involved in the model. The purpose of the quadratic form of income is to capture the non-linearity of changes in total food expenditure across income.

STAGE II- Total food expenditure is allocated to aggregate fish spending as a portion by each household. The model for the aggregated fish expenditure through the OLS method is presented as follows.

$$\ln(F) = \propto_0 + \propto_1 \sum_{i-1}^{k} \ln pfd_i + \propto_2 \ln M + \propto_2 (\ln M^2) + \sum_{i-1} \propto_i Z \tag{3}$$

Where *F* denotes annual aggregated fish expenditure (MMK), pfd_j is the price of food commodities, *M* is the predicted annual total food expenditure obtained from Eq (2), and *Z* is a vector of socio-economic variables of the households, as mentioned in Eq (2). In order to control for the self-selection bias derived from the zero consumption of aggregated fish groups, the two-step procedure is applied. In the first step, a probit model is applied to estimate the probability that a sampled household will consume the fish. Based on the probit regression results, cumulative density function (CDF) and standard normal probability density function (PDF) are calculated, and then we compute the inverse Mills ratio (IMR) for each household. In the second step, IMR is incorporated as an additional explanatory variable to censor the latent variables in the aggregated fish expenditure function.

STAGE III- The linear expenditure form of the AIDS model is well adapted for the econometric estimation of expenditure and price elasticities, but it has been criticized for producing inconsistent and biased parameter estimations in most cases (Asche and Wessells, 1997). Banks et al. (1997) show that Engel's curve requires the quadratic expenditure term because Engel's curve is not always linear. To deal with this issue, the QUAIDS model is developed by including a quadratic expenditure term that can capture the non-linearity of food expenditure in the budget shares (Blundell et al., 1993; Banks et al., 1997). The QUAIDS model maintains all the relevant specifications of the AIDS model, which means that it(satisfies all the axioms of choice and exact aggregation over households) proposed by Deaton and Muellbauer (1980). Moreover, it has several advantages over the other demand analysis approaches. First, beyond the price and income effects, it captures the impact of the socio-economic characteristics on the budget share. Second, it considers econometric issues such as expenditure endogeneity and selection bias derived from zero consumption (Obayelu et al., 2009). Finally, it allows us to independently account for the household fish choices among the different sources of fish.

According to Banks et al. (1997), the QUAIDS model has the indirect utility function of the form

$$\ln V(p,m) = \left[\left\{\frac{lnm - lna(p)}{b(p)}\right\}^{-1} + \lambda(p)\right]^{-1} \quad (4)$$

where, $\frac{lnm-lna(p)}{b(p)}$ "is the indirect utility function of the price-independent generalized logarithmic (PLGLOG) preference demand system." Here, m denotes predicted household total fish expenditure, and *a(p)*, *b(p)* and $\lambda(p)$ are the vector of price p aggregator functions.

The former function ln *a(p)* is defined as

$$lna(p) = \alpha_0 + \sum_{i=1}^{4} \alpha_1 \ln p_i + \frac{1}{2}\sum_{i=1}^{4}\sum_{i=1}^{4} \gamma_{ij} \ln p_i \ln p_k \quad (5)$$

While *b(p)* is the Cobb-Douglas price aggregator;

$$b(p) = \prod_{i=1}^{4} {p_i}^{\beta_i} \quad (6)$$

In addition, the price aggregator function is defined as

$$\lambda(p) = \sum_{i=1}^{4} \lambda_i \, lnp_i \quad (7)$$

The expenditure share equation for each fish group in the QUAIDS model can be expressed as

$$w_i = \alpha_i + \sum_{j=1}^{4} \gamma_{ij} lnp_j + \beta_i \ln\left\{\frac{m}{a(p)}\right\} + \frac{\lambda_i}{b(p)}\left[ln\left\{\frac{m}{a(p)}\right\}\right]^2 \quad i = 1, \dots k \tag{8}$$

CENSORING

The two-step estimation procedure is used to control for selectivity bias derived from the zero-consumption expenditure in the disaggregated fish groups. Based on the probit analysis results, the CDF and the PDF are computed, and the IMR is calculated for each household in each budget share equation. IMR is incorporated in each budget share equation of the QUAIDS model. The budget share equation in Eq (8) is modified as follows

$$w_i = \alpha_{i0} + \sum_{k} \delta_{ik}\, s_{k,} + \sum_{j=1}^{4} \gamma_{ij} lnp_j + \beta_i \ln\left\{\frac{m}{a(p)}\right\} + \frac{\lambda_i}{b(p)}\left[ln\left\{\frac{m}{a(p)}\right\}\right]^2 + \pi_i IMR_i + \varepsilon_i$$

$$i = 1, \dots . k \tag{9}$$

In Eq (9), w_i is the budget share of the categorized fish sources, where the parameters $\delta_{ik,}\ \gamma_{ij,}\ \beta_i\ and\ \lambda_i$ are estimated, δ_{ik} is the effects of k_{th} demographic factors, γ_{ij} measures the effect of a change in the food commodity j price on the expenditure share equation of food commodity i and $\beta_i\ and\ \lambda_i$ measure the effect of the change in the total fish expenditure on the expenditure share of the disaggregated fish groups.

Economic theory imposes several restrictions on the parameters. For theoretical consistency, Eq (9) is estimated under the following restrictions:

a. Adding up condition

$$\sum_{j=1}^{4} \alpha_i = 1,\ \sum_{j=1}^{4} \delta_{ik} = 0, \sum_{j=1}^{4} \beta_i = 0,\ \sum_{j=1}^{4} \lambda_i = 0, and\ \sum_{j=1}^{4} \gamma_{ij} = 0, \tag{10}$$

b. Since demand functions have the homogeneous degree of zero

$$\sum_{j=1}^{4} \gamma_{ij} = 0\ \forall\ j, \tag{11}$$

c. Slutsky symmetry imposes that

$$\gamma_{ij} = \gamma_{ji} \tag{12}$$

In this study, the QUAIDS model is analyzed with the Nonlinear Seemingly Unrelated Regression (NLSUR) procedure in STATA (Poi, 2012). During this procedure, dropping one expenditure share equation is done to avoid an error in the covariance matrix due to a complete demand system, which is identically singular as the expenditure shares sum to one (Heien and Wessells, 1990). Afterward, the parameters for the dropped equation are computed with the help of additivity Eq (10), homogeneity Eq (11), and symmetry restrictions Eq (12).

2.2.2.2 Demand elasticities calculation

The formulas to estimate the elasticities from the QUAIDS model follow those of Banks et al. (1997). Eq (9) is differentiated concerning *lnm* and *ln pj*

$$\mu_i \equiv \frac{\partial w i}{\partial lnm} = \beta_i + \frac{2\lambda_i}{b(p_j)}\left[ln\left\{\frac{m}{a(p_j)}\right\}\right] \quad \text{and} \tag{13}$$

$$\mu_{ij} \equiv \frac{\partial w i}{\partial lnp_j} = \gamma_{ij} - \mu_i\left(\alpha_j + \sum_k \gamma_{jk}\, lnp_{k,}\right) - \frac{\lambda_i \beta_j}{b(p)}\left[ln\left\{\frac{m}{a(p)}\right\}\right]^2 \tag{14}$$

where, $lnp_{k,}$is a price index computed as the arithmetic average prices for k fish groups.

The expenditure elasticities for the fish category are given by

$$e_i = \frac{\mu_i}{w_i} + 1 \tag{15}$$

However, it is essential to note that the individual fish group's expenditure elasticity is computed based on total fish expenditure in the QUAIDS model, but it does not directly capture the consumer responsiveness to total food expenditure or income.

The uncompensated (Marshallian) price elasticity takes both income and price effects into consideration and is derived as

$$e_{ij}^{\mu} = \frac{\mu_{ij}}{w_i} - \delta_{ij} \tag{16}$$

where δ_{ij} indicates Kronecker delta, which takes the value of zero for cross-price elasticity (i≠j) and one for own-price elasticity (i=j).

From the Slutsky equation, compensated price elasticities (Hicksian) are obtained, which take only a price effect:

$$e_{ij}^{c} = e_{ij}^{\mu} + e_i w_j \tag{17}$$

2.3 Empirical results and discussion

2.3.1 Descriptive statistics of the variables

Descriptive statistics of the variables included in the three stages of estimation are presented in Table 2.2 The average income per year of the sampled households was MMK 3,689,440 (USD 3,600), of which MMK 2,409,627 (USD 2,351) was spent on food expenditure. On average, sampled households in the study spent 65% of their total income on food, of which the most substantial part (32.56%) was on rice (annual per capita rice consumption nationally is 168kg (Scott et al., 2020) followed by fish and fishery products (11.72%) and meat (10.58%). Among the fishery products, the dried fish products' proportion accounts for the largest share of total fish expenditure (47%). However, the unit price of dried fish is more than double that of freshwater fish. This price gap reflects water loss during the drying process, making it a concentrated source of nutrients (Belton et al., 2015). Moreover, total fish expenditure accounts for more than 50% of total animal-protein sources. It implies that fish represent a cheaper source of micronutrients than other animal sources of food, and then freshwater fish prices are 20% lower on average than that of meat price.

For demographic variables, the average family size in Myanmar was five persons, and the mean age of the household head was 51 years old. The average life expectancy in 2017 was 66 years. From the study sample, it is estimated that 37% and 63% of the sampled households lived in urban and rural areas, respectively. Regarding the wealth status of the sampled households, 31% were below the poverty line. The survey data shows that only 20% of the total sampled household heads worked in the agriculture sector as their primary occupation, and 80% of selected household heads chosen to work off-farm and non-farm income-generating activities as their main livelihood. This finding implies that Myanmar is characterized by a higher landlessness level (Belton et al., 2015). Off-farm labor and non-farm labor opportunities with higher wage rates are vital determinants of rural welfare.

Table 2.2: Summary statistics of variables used at various stages

Variables	Mean	Std. Dev.
Total household income per year (MMK/yr)	3,689,440	6,148,347
Total food expenditure per year (MMK/yr)	2,409,627	1,659,690
Total fish expenditure (MMK/yr)	263,736	319,422
Aquaculture fish expenditure (MMK/yr)	41,577	74,659

Freshwater capture fish expenditure (MMK/yr)	49,509	105,255
Marine capture fish expenditure (MMK/yr)	42,230	92,283
Dried fish expenditure (MMK/yr)	130,421	232,112
Prices of food products (MMK/kg)		
Rice	546	291
Pulses	1,420	1,105
Roots and tubers	597	225
Meat	4,916	23,131
Vegetables	771	255
Fruits	1,191	706
Fish	3,956	1,408
Aquaculture fish	2,795	1,847
Freshwater capture fish	2,910	2,203
Marine capture fish	3,650	2,023
Dried fish	7,060	2,046
Demographic variables		
Household size (No.)	5	2.14
Age of the household head (years)	51	14
Dummy=1 if households live in urban area, 0 if otherwise	0.37	0.48
Dummy=1 if any household above this poverty line, 0 if otherwise	0.69	0.46
Dummy=1 if the primary occupation of the household head is agriculture, 0 if otherwise	0.20	0.39
Budget share of fish groups	Percentage	
Share of aquaculture	0.19	-
Share of freshwater capture	0.18	-
Share of marine capture	0.16	-
Share of dried fish	0.47	-

Source: Author’s calculation

2.3.2 Stage I - Parameter estimations of the total food expenditure function

The findings of the first stage function are shown in Table 2.3. All explanatory variables included in the model are statistically significant. In this function, the foods’ price index is statistically significantly and negatively related to total food expenditure, which means that higher food prices lead to declining expenditure on food items. The annual income and its square term are significant variables, with the former having a positive sign and the latter a negative sign. This indicates that the responsiveness from total food expenditure to changes in income is nonlinear. As income rises, the total food expenditure tends to increase, but at a decreasing rate. These findings follow Engel's law and are consistent with empirical studies by Garcia et al. (2005) and Dey et al. (2011). The positive and significant sign of household size implies that an increase in the household size increases the total household food expenditure.

Additionally, the household head's age is significant with a positive sign, indicating that households with older heads consume more food products than households with younger heads. The location dummy variable's coefficient is significant with a negative sign, which is unexpected, indicating that rural households' food expenditure is higher than that of urban households. One possible explanation is that urbanization increases the share of total income on non-food items, so the share of total income on food declines. When the income increases, the rural households may find it difficult to spend the income on non-food items such as education, health, and recreation facilities due to their limited accessibility, while the urban households can easily access the non-food items. The household head who mainly works in the agriculture sector is significantly and positively associated with greater food consumption.

Table 2.3: Estimation results of the total food expenditure function in stage I

Variables	Coefficient	Robust S. E
Log household's annual income	4.893	0.378***
Log household's annual income squared	-0.134	0.013***
Ln Stone price index	-0.074	0.021***
Household size (No.)	0.006	0.002***
Age of the household head (years)	0.002	0.000***
Primary occupation of household head (1 =agriculture , 0=other)	0.034	0.011***
Household location (1=urban, 0=rural)	-0.078	0.009***
Constant	-28.531	2.760***
N	3,582	
R-square	0.87	

Notes: Log of total food expenditure is the dependent variable. S.E. is the standard error.

P-values less than 0.01, 0.05, and 0.1 correspond to ***, **, and *, respectively.
Source: Author's calculation

2.3.3 Stage II - Parameter estimations of the aggregated fish expenditure function

The estimation results of this stage are shown in Table 2.4. The coefficient of the total food expenditure and square terms of total food expenditure are insignificant. This finding indicates that total fish expenditure does not significantly respond to changes in total food expenditure. The positive own price parameter of fish indicates that an increase in average fish price may slightly decrease the household's quantity of fish consumption, but it would not lead to a decrease in fish expenditure, as it seems to be a staple food for the fish-eating population. The coefficient of the price of major food commodities, such as rice, pulses, roots and tubers, and fruits, are significant variables with a positive sign. It indicates that when the price of food commodities, particularly rice, is higher, the household's fish expenditure also increases because fish is the second most crucial food commodity after rice in Myanmar. The coefficient of the IMR is negative and significant in this stage, suggesting that correcting for selection bias derived from zero consumption is essential. The sign of the urban household's dummy variable is negative and statistically significant, showing that rural households consume more fish than urban households. The household head who works in the agriculture sector is positively and significantly associated with higher fish consumption, presumably because of the lower imputed costs for home-consumption and the accessibility and low transaction costs of acquiring fish in rural areas. The positive and significant sign of household size implies that an increase in family size increases the total household fish expenditure. Additionally, the household head's age is significant with a positive sign, indicating that households with older heads consume more fish than households with younger heads.

Table 2.4: Estimation results of the aggregated fish expenditure function in stage II

Variables	Coefficient	Robust S. E
Ln total food expenditure [a]	1.295	0.821
Ln total food expenditure squared [a]	-0.027	0.029
Ln price of fish	0.212	0.056***
Ln price of cereals	0.454	0.086***
Ln price of pulses	0.210	0.042***
Ln price of roots and tubers	0.167	0.054***
Ln price of fruits	0.095	0.039**
Ln price of vegetables	-0.021	0.060
Ln price of meat	-0.022	0.041

Inverse Mill's ratio	-6.794	0.059***
Household location (1=urban, 0=rural)	-0.185	0.041***
Household head's occupation (1 =agriculture, 0=other)	0.182	0.048***
Household size (No.)	0.030	0.008***
Age of the household head (years)	0.006	0.001***
Constant	-8.055	5.965
N	3,582	
R-square	0.90	

Notes: Log of total fish expenditure is the dependent variable. S.E. is the standard error.

[a] Estimated values obtained from stage I are used in this model.

P-values less than 0.01, 0.05, and 0.1 correspond to ***, **, and *, respectively.

Source: Author's calculation

2.3.4 Stage III – QUAIDS model parameter estimations of the disaggregated fish demand system

The QUAIDS model estimations of the four fish groups by household categories are presented in Table 2.5. In the demand system analysis at the household level, some households may pay the same prices for the food products and have the same income but have different food preferences and demographic characteristics. The square terms of total fish expenditure coefficients are statistically significant for all equations in almost all cases. These results imply that the responsiveness of categorized fish groups' expenditure share to total fish expenditure changes is nonlinear. Household size coefficients are significant for almost all equations across the household groups, but the sign of this variable varies across the disaggregated fish and household groups, showing different preferences in household fish consumption patterns. Although the sign of the household head's occupation variable varies across disaggregated fish groups and households, this variable is significantly associated with the consumption of specific fish groups in most cases. The IMRs are significant for all the equations across household groups. It implies that including the IMRs in the QUAIDS model to solve selection bias problem created by zero observations for disaggregated fish groups proved appropriate.

Regarding the findings mentioned above, the model yields expected results and in line with the theory for the different household groups and provide mostly statistically significant coefficient estimates at the 5% level or less. For the budget share type model estimated with cross-sectional household survey data, low R-square values (ranged from 0.37 to 0.65) are usual due to the large degree of stochastic variation in the dataset. The model also provides the root-mean-square error as the measurement of accuracy of predicted values of the model (ranging from 0.1 to 0.3). These values are acceptable when compared with other AIDS or the QUAIDS model estimation by Akbay and Boz (2007), Bronnmann et al. (2019), Ecker and Qaim (2011), and Mergenthaler et al. (2009).

2.3.5 Expenditure and income elasticity estimations at various stages

Expenditure and income elasticities calculated at different stages are shown in Table 2.6. In Stage I, the income elasticity of food demand is estimated, while food expenditure and the income elasticities of aggregated fish demand are estimated in Stage II. In Stage III, fish expenditure and income elasticities for disaggregated sources of fish are estimated by the household location and the wealth category. Income elasticity of food expenditure is positive across household categories, and its value is less than one. In addition, income elasticities for aggregated fish and disaggregated fish groups are less than their respective expenditure elasticities.

In Stage I, the average income elasticity of demand for total food expenditure at the national level is 0.73. In line with theory, this income elasticity in rural households (0.75) is higher than that in urban households (0.70). It indicates that rural households allocate proportionately more of their budget to food than urban households with a similar rise in income. A result that is in line with the theory is achieved for the wealth group. Poor households are found to have a higher income elasticity (0.89) than non-poor households (0.66). Regarding the elasticities results in Stage II, the food expenditure and income elasticities of total fish expenditure show the same pattern as in Stage I in household categories. All values are inelastic; that is, they range between 0 and 1, indicating that fish is a normal product among households in Myanmar. The magnitude of food expenditure and income elasticities shows that poor and rural households respond more than non-poor and urban households with an increased total food budget and income.

For all disaggregated fish groups in Stage III, income elasticities show the same pattern across the household categories as in Stages I and II; that is, they are less than one, indicating that they are normal goods. Among the different fish sources, aquaculture fish is the most income-responsive across household categories, followed by freshwater capture fish. It means that if income increases in Myanmar, aquaculture fish consumption will grow more rapidly than the consumption of fish from other sources. This significant result suggests that there are some opportunities for replacing stagnant and decreasing fish production from capture fishery sources by expanding the aquaculture fish supply to fulfill the required demand of the increasing population. Likewise, reducing the costs of aquaculture fish production with a corresponding decrease in market price is a development strategy that benefits more the poor and rural households. In other words, investment in aquaculture to increase supply and thereby reduce prices of aquaculture fish is pro-poor growth. Assuming that the real per-capita income in Myanmar continues to increase through economic growth, a large share of future fish demand for all sources of fish will come from poor and rural households. Overall, the hypothesis that poor and rural households have higher food expenditure and income elasticities than non-poor and urban households is true for both aggregated and disaggregated fish groups.

Table 2.5: Parameter estimations of the QUAIDS model

Variables		National		Poor		Non_poor		Rural		Urban	
		Coefficient	S. E	Coefficient	S. E	Coefficient	S. E	Coefficient	S. E	Coefficient	S. E
Constant	a1	-0.343***	0.102	-0.371**	0.172	-0.428***	0.126	-0.490***	0.093	0.392	0.210
	a2	-0.506***	0.093	-0.548***	0.139	-0.414***	0.126	-0.493***	0.116	-0.445**	0.179
	a3	0.108	0.084	0.089	0.160	0.177*	0.099	0.139	0.097	0.096	0.174
	a4	1.741***	0.067	1.829***	0.109	1.664***	0.089	1.844***	0.084	0.956***	0.169
Ln total fish expenditure	b1	-0.107***	0.022	-0.106***	0.037	-0.129***	0.028	-0.087***	0.021	-0.101**	0.046
	b2	-0.073***	0.020	-0.072**	0.030	-0.061**	0.028	-0.066***	0.025	-0.054	0.040
	b3	0.034*	0.018	0.028	0.034	0.041*	0.022	0.025	0.021	0.048	0.038
	b4	0.146***	0.013	0.149***	0.019	0.149***	0.018	0.128***	0.016	0.107***	0.036
Ln total fish expenditure squared	l1	-0.006***	0.001	-0.006***	0.002	-0.007***	0.002	-0.006***	0.001	-0.007***	0.003
	l2	-0.004***	0.001	-0.004**	0.002	-0.003**	0.002	-0.003**	0.001	-0.003	0.002
	l3	0.002*	0.001	0.002	0.002	0.002	0.001	0.000	0.001	0.003	0.002
	l4	0.008***	0.001	0.008***	0.001	0.009***	0.001	0.008***	0.001	0.007***	0.002
Ln prices	g11	0.038	0.025	0.015	0.040	0.085**	0.038	0.048**	0.019	0.105**	0.048
	g12	0.056***	0.010	0.062***	0.015	0.054***	0.016	0.026**	0.010	0.021	0.019
	g13	0.020	0.012	0.026	0.021	0.003	0.018	-0.015	0.010	-0.015	0.026
	g14	-0.114***	0.020	-0.103***	0.032	-0.141***	0.028	-0.059***	0.017	-0.111***	0.035
	g21	0.056***	0.010	0.062***	0.015	0.054***	0.016	0.026**	0.010	0.021	0.019
	g22	0.014	0.016	0.011	0.022	0.012	0.020	0.023	0.019	0.014	0.023
	g23	0.024***	0.009	0.023	0.015	0.016	0.011	0.048***	0.010	0.005	0.017
	g24	-0.094***	0.017	-0.097***	0.023	-0.082***	0.024	-0.097***	0.020	-0.040*	0.024
	g31	0.020	0.012	0.026	0.021	0.003	0.018	-0.015	0.010	-0.015	0.026
	g32	0.024***	0.009	0.023	0.015	0.016	0.011	0.048***	0.010	0.005	0.017
	g33	-0.062***	0.008	-0.067***	0.013	-0.055***	0.011	-0.072***	0.008	-0.009	0.021
	g34	0.018	0.014	0.017	0.025	0.036**	0.017	0.039***	0.014	0.019	0.019
	g41	-0.114***	0.020	-0.103***	0.032	-0.141***	0.028	-0.059***	0.017	-0.111***	0.035
	g42	-0.094***	0.017	-0.097***	0.023	-0.082***	0.024	-0.097***	0.020	-0.040*	0.024

	g43	0.018	0.014	0.017	0.025	0.036**	0.017	0.039***	0.014	0.019	0.019
	g44	0.190***	0.021	0.182***	0.033	0.187***	0.030	0.117***	0.024	0.133***	0.039
Household size (No)	eta11	-0.001	0.002	-0.007*	0.004	0.005*	0.003	0.000	0.002	-0.006*	0.003
	eta12	0.002	0.002	0.000	0.003	0.002	0.003	0.007**	0.003	-0.002	0.003
	eta13	0.005***	0.002	0.006	0.004	0.000	0.002	0.005**	0.003	0.007**	0.003
	eta14	-0.006**	0.003	0.001	0.004	-0.007**	0.003	-0.012***	0.004	0.002	0.004
Primary occupation of household head (1 =agriculture, 0=other)	eta21	-0.080***	0.012	-0.078***	0.024	-0.080***	0.014	-0.008	0.009	-0.110***	0.036
	eta22	0.045***	0.011	0.056***	0.019	0.042**	0.014	0.025*	0.013	0.050*	0.028
	eta23	0.017	0.010	0.043*	0.024	0.012	0.011	-0.010	0.012	0.013	0.029
	eta24	0.018	0.014	-0.020	0.030	0.027	0.017	-0.007	0.017	0.047	0.042
IMR	d1	0.151***	0.014	0.221***	0.024	0.117***	0.017	0.482***	0.012	-0.525***	0.027
	d2	0.448***	0.017	0.527***	0.023	0.407***	0.024	0.430***	0.024	0.512***	0.021
	d3	0.278***	0.012	0.277***	0.024	0.288***	0.013	0.319***	0.015	0.262***	0.019
	d4	-0.877***	0.024	-1.025***	0.040	-0.811***	0.031	-1.231***	0.031	-0.250***	0.039
R-squared		0.381***		0.416***		0.376***		0.598***		0.648***	
		0.464***		0.577***		0.419***		0.449***		0.533***	
		0.423***		0.462***		0.407***		0.441***		0.402***	
Root mean square		0.273		0.264		0.275		0.181		0.256	
		0.249		0.216		0.262		0.274		0.195	
		0.232		0.265		0.212		0.246		0.201	

Notes: P-values less than 0.01, 0.05, and 0.1 correspond to ***, **, and *, respectively. S.E. is the standard error.

Source: Author’s calculation

Table 2.6: Estimated expenditure and income elasticities in various stages

	National	Poor	Non-poor	Rural	Urban
Income elasticity of food expenditure (Stage I)	0.73	0.89	0.66	0.75	0.70
Food expenditure elasticity of fish expenditure (Stage II)	0.42	0.45	0.40	0.42	0.41
Income elasticity of fish expenditure (Stage II)	0.31	0.40	0.26	0.32	0.29
Income elasticity of demand for the disaggregated fish groups (Stage III)					
Aquaculture	0.57***	0.72***	0.46***	0.76***	0.54***
Freshwater capture fish	0.48***	0.44***	0.45***	0.63***	0.38***
Marine capture fish	0.21***	0.30***	0.10***	0.30***	0.17***
Dried fish	0.19***	0.19***	0.17***	0.24***	0.15***

Notes: To calculate the income elasticity of aggregated fish expenditure in Stage II, we must multiply the food expenditure elasticity of aggregated fish demand with the income elasticity of food expenditure demand. If the income elasticity of demand for food expenditure and the food expenditure elasticity of aggregated fish demand are 0.73 and 0.42, respectively, the income elasticity of aggregated fish demand is 0.31. To calculate the income elasticities of disaggregated sources of fish in Stage III, we multiply the fish expenditure elasticities of disaggregated sources of fish with the income elasticity of food expenditure demand in Stage I and the food expenditure elasticity of aggregated fish demand in Stage II, respectively. Suppose the income elasticity of food expenditure demand and the food expenditure elasticity of aggregated fish demand are 0.73 and 0.42, respectively, and the fish expenditure elasticity of aquaculture fish is 1.87. In that case, the income elasticity of aquaculture fish demand is 0.57.

P-values less than 0.01, 0.05, and 0.1 correspond to ***, **, and *, respectively.

Source: Author's calculation

2.3.6 Compensated own-price elasticities of disaggregated fish demand

Table 2.7 represents the compensated own-price elasticities estimation for the disaggregated fish groups by household categories because they capture only the price effect on the consumption and keep the utility constant. The compensated own-price elasticity of fish demand from all sources, except freshwater capture fish, at the national level, is elastic and in the range of 1.07 to 2.22. The compensated own-price elasticity of freshwater capture fish is close to one. Elastic demand indicates that as fish prices rise, demand for fish will decline at a higher rate. Therefore, households at the national level will reduce their fish consumption, except for freshwater capture fish, by a disproportionately larger quantity in response to price increases.

Regarding the wealth group, the compensated own-price elasticity of demand for all sources of fish, except for the freshwater capture fish, is lower for poor households than that for non-poor households. It implies that although the non-poor households can afford to pay the higher price of fish, they tend to respond quickly to higher price changes. This is because they have more substitutes available to them due to their ability to pay more. It is important to note here that the poor's lower responsiveness to increases in fish prices indicates that fish, except high-value species, is the cheapest form of animal protein and that the number of animal protein substitutes for fish at that price range is limited. We observe that the hypothesis that the own-price elasticities of demand for poor households are lower than that for non-poor households is validated for aquaculture and marine capture fish sources.

In terms of compensated own-price elasticities by household location, the gap between urban and rural households is relatively small for the capture fishery sources. This is not the true for aquaculture fish source, for which aquaculture fish price elasticity of demand is much lower in urban areas than in rural areas. The hypothesis that fish demand is more responsive to changes in its own price in urban areas than in rural areas is observed for the capture fishery sources. but is rejected for aquaculture. Additionally, the hypothesis that aquaculture fish price changes trigger much larger fish demand changes among the poor and rural households is rejected. As already noted in Table 2.1, urban households consume a significant amount of aquaculture fish, compared with other fish sources. It implies that as urbanization proceeds and incomes grow, urban areas will increase the aquaculture fish market share due to the declining share of fish capture from rivers, lakes, and the sea (Belton et al., 2015).

Table 2.7: Compensated price elasticities of demand for the disaggregated fish groups

Disaggregated fish groups	National	Poor	Non-poor	Rural	Urban
Aquaculture	-1.07***	-1.19***	-1.24***	-1.26***	-0.14
Freshwater capture fish	-0.93***	-0.96***	-0.82***	-0.75***	-0.86***
Marine capture fish	-1.69***	-1.43***	-1.88***	-1.51***	-1.73**
Dried fish	-2.22***	-2.35***	-2.35***	-2.27***	-1.65***

Notes: P-values less than 0.01, 0.05, and 0.1 correspond to ***, **, and *, respectively.

Source: Author's calculation

2.3.7 Compensated cross-price elasticities

Compensated cross-price elasticity analyzes the change in one product demand as a result of changes in the price of another product. Table 2.8 presents the compensated cross-price elasticities for disaggregated sources of fish. Other than the dried fish source group, the compensated cross-price elasticities for other sources of fish are positive with below and above unity, indicating a weak substitution effect (less than unity) and strong substitution effect (above unity) between these fish groups. The results show that the demand for aquaculture fish is significantly influenced by the price changes in marine capture and dried fish. The positive and above unity compensated cross-price elasticities indicate that an increase in the price of marine capture and dried fish products will lead to a higher-than proportionate rate increases in the aquaculture fish demand for all household groups, except for the urban households concerning the marine capture fish price. These findings reveal that households in Myanmar would turn towards purchasing more farmed fish in the face of higher marine capture and dried fish prices. This finding is similar to the observation in Bangladesh, where Toufique et al. (2017) find that aquaculture fish demand is substantially affected by marine capture fish's price. In contrast, the significant and negative compensated cross-price elasticities of demand for all household groups are found in the dried fish group, but its elasticity values are below unity, showing weak complementary effects with the marine capture fish source. An increase in the price of marine capture fish source will cause a less-than proportionate decrease in the dried fish products demand. It implies that processed or dried fish products consist of a mix of fish and shrimp from the freshwater and marine capture fishery sources, but marine capture fishery sources account for the largest share of those products (Belton et al., 2015).

Regarding the household location, the extent of substitution among the fish groups is greater in most cases for the rural households than urban households, showing that the range for changing of fish demand from many different sources is higher for the rural households. The more substantial substitution across the sources of fish for rural households could be a reflection of the greater availability of fish species in the local market, probably the nature of the inland fishery, and the predominance of the aquaculture fish ponds in the rural areas. Regarding the cross-price elasticities for household wealth group, the cross-price elasticities of aquaculture fish demand for the non-poor groups are higher than those of poor groups. It implies that the higher diversity of capture fish species and dried fish products offers very cheaper fresh or dried small-fish species to the poor households despite the average price of capture fish and dried fish is moderately higher than the aquaculture fish. When the price of high-valued capture and dried fish species increases, non-poor households will substitute those fish species with aquaculture fish instead of low-valued or small-fish species.

Table 2.8: Compensated cross-price elasticities of demand for the disaggregated fish groups

Disaggregated fish groups	National	Poor	Non-poor	Rural	Urban
Aquaculture					
Freshwater capture fish	0.12	0.13	0.25	-0.08	0.02
Marine capture fish	1.34***	1.42**	1.58***	1.40***	0.87*
Dried fish	3.70***	3.83***	4.27***	5.22***	1.95**
Freshwater capture fish					
Aquaculture	0.26**	0.32	0.11	0.12	0.69
Marine capture fish	1.03***	1.09***	0.89***	0.98***	0.94
Dried fish	2.42***	2.48**	2.07**	1.79***	1.91
Marine capture fish					
Aquaculture	0.47***	0.45***	0.42**	-0.04	-0.06
Freshwater capture fish	0.46***	0.40***	0.29**	0.42***	0.34
Dried fish	-0.90	-0.56	-0.93	0.26	-1.38
Dried fish					
Aquaculture	0.18	0.17	0.33*	0.29**	-0.15
Freshwater capture fish	0.16	0.13	0.13	0.18	0.17
Marine capture fish	-0.41***	-0.38	-0.48***	-0.28***	-0.39****

Notes: P-values less than 0.01, 0.05, and 0.1 correspond to ***, **, and *, respectively.

Source: Author’s calculation

A caveat about the results is that using cross-sectional food consumption survey data at the household level for the demand analysis has limitations in terms of accuracy. Firstly, recalls of food consumption captured all food that has entered the household, but did not account for food that was not consumed by family members. Some food might be given to hired laborers or guests, fed to animals, or wasted. It can result in the overvaluation of food intake, particularly among wealthy households (Bouis, 1994). Secondly, food consumption surveys at the household level do not collect the intra-household consumption data, so it is assumed that food is equally distributed among the household members. Thirdly, there are issues with food commodities prices because many datasets do not include food prices directly. Those prices are obtained from the unit prices or average prices by dividing the expenditure on a product by the amount consumed. If the survey captures the market prices of individual food items at the community level, the estimation results could be more accurate. Although we are aware of the drawbacks mentioned above of the survey data, individual-level food consumption data is hardly available for developing countries. Our analysis can provide practical and vital information on the consumer demand situation, particularly fish demand. Besides, there is mitigation to the shortcoming. Due to the short recall period (seven days) in this survey, respondents should be able to remember the precise amount consumed and expenditure, whereas they might not be able to do so with a longer recall period. Furthermore, this study focuses on the demand for four primary fishery sources in Myanmar instead of individual fish species. Therefore, potential problems in the results should be minimized, as long as there is no systematic bias in the reporting of prices between all sources of fish.

2.3.8 Simulation analysis

According to the fish price data at the national level, the real price of fish from capture fishery sources increased by around 20% on average between 2015 and 2019(CSO, 2019). In this section, the results of a simulation analysis of how the quantity of farmed-fish consumption per household at the national level changes if household income or prices of other fish sources increase by 20% and 40% while keeping other factors constant are presented. The simulation results are shown in Table 2.9. Scenarios I through IV simulate a price for all non-aquaculture fishery sources increase of 20%, and scenario V simulates an income increase of 20%. The results reveal that the households' quantity of aquaculture fish consumption per year would rise from the base level of 18.71 kg to 19 kg, 19.11 kg, 19.63 kg, 20.05 kg, and 20.31 kg, respectively. When the household's income and prices of capture and dried fish increase by 40%, the quantity of aquaculture fish consumption per household per year will increase to between 19 kg and 22 kg. Therefore, we conclude that the domestic market for aquaculture fish has considerable potential for long-term growth with urbanization, improved communication, and increased incomes.

Table 2.9: Simulation results for fish prices or income increasing by 20% and 40%

	Aquaculture
Base - annual aquaculture fish consumption per household (kg/year)	18.71
Fish price or household income increase by 20%	
Scenario I: freshwater capture fish price increase	18.75
Scenario II: marine capture fish price increase	19.11
Scenario III: dried fish price increase	19.63
Scenario IV: freshwater and marine capture and dried fish price increase	20.05
Scenario V: income increase	20.31
Fish price or household income increase by 40%	
Scenario I: freshwater capture fish price increase	19.00
Scenario II: marine capture fish price increase	19.50
Scenario III: dried fish price increase	21.00
Scenario IV: freshwater and marine capture and dried fish price increase	22.00
Scenario V: income increase	22.00

Source: Author’s calculation

2.4 Conclusions and policy recommendations

The rapidly growing aquaculture sector and concurrent stagnation of capture fishery production are observed globally. Myanmar is one of the major consumers of fish worldwide at an annual 30kg per capita, and its fish demand has been increasing rapidly over the years, but no study has investigated its fish demand parameters at the household level in particular. In this chapter, *a multi-stage budgeting framework* combined with the QUAIDS model is applied to provide the micro-level evidence of fish demand in Myanmar using household survey data from 2015. The methodological issues of conducting demand analysis using cross-sectional household survey data, such as endogeneity and sample selection bias, are addressed in this study.

Income elasticity of aggregated and disaggregated fish groups demand is positive and less than unity in all cases, showing that all sources of fish in Myanmar are normal necessary goods. This trend is a reflection of the fact that all consumers in Myanmar frequently consume different fish species. A significant share of fish consumption is likely to come from poor and rural households due to their higher-income elasticity of demand. In the context of increasing household incomes, there will be a substantial increase in aquaculture fish demand in Myanmar, indicating that aquaculture production pressure will grow. If the fish supply from aquaculture does not respond to an increase in fish demand and household income, the fish price will increase. This will affect food security of the households to a greater extent. Poverty alleviation programs that increase household income are more likely to have a positive impact on household fish consumption, which, in turn, can positively contribute to household food and nutrition security.

Compensated own-price elasticities by all household groups reveal a downward-sloping demand curve for all sources of fish. Aquaculture and marine capture fish groups support the hypothesis that fish demand tends to be less elastic price elasticities for poor household group compared to non-poor household group. It reflects that those households have less animal protein substitutes for fish available and accessible to them because fish, except high-value fish species, is the cheapest form of animal protein sources. We observe the growing farmed-fish market in urban areas because aquaculture fish demand is the least responsive to changes in its own price in urban households compared to other fish sources. Furthermore, a price-elastic fishery market indicates that this fishery sector has the potential to increase the revenue of the producers if the production increases that will accompany the falling price (Dey et al., 2011; Bronnmann et al., 2016; Toufique et al., 2017). We also observe a strong significant substitution of aquaculture for marine capture and dried fish products (both marine and freshwater) in all household categories. As there is evidence of a declining trend in capture fishery production, the aquaculture sector can fulfill consumer demand through its rapidly growing production.

In order to sustainably increase farmed-fish production to secure food and nutrition security, the subsector needs to be more competitive and smallholder inclusive with accompanying land-use regulatory reforms. In addition, there needs to be a higher diversity of fish species under aquaculture with improved services and new production technologies for small-scale farmers who will play a critical role in aquaculture sector development. Moreover, the development and improvement of inputs, mainly fish seed and feed, by collaboration with government and private sector actors should be a major priority. Sustainable production from capture fishery sources can be achieved through improved monitoring control and surveillance (MCS) that help to reduce illegal, unreported, and unregulated (IUU) fishing and reinforce better capture fishery management and governance. Although aquaculture sector development would have played an essential role in the households' food and nutrition security, sustainable production from all fish production sources will be more beneficial than merely the growth of one sub-sector. Moreover, investments and development in fish marketing and distribution systems are also essential to bridge the supply-demand gap and ensure households' accessibility with affordable prices. Therefore, policies and intervention programs to support better access to the conditions mentioned above are crucial to achieving fish supply growth, hence fulfilling the increasing households' fish demand.

A potential field of future research is to disaggregate the consumption data in the four groups of fishery sources into smaller subgroups based on main species (e.g., Rohu, Hilsa, and low-value species) within each group and its nutrient contribution (e.g., vitamins, minerals, and essential fatty acids). Panel or longitudinal data can also be used to track the change in demand elasticities over time. Considering that malnutrition and food insecurity remain considerable problems in Myanmar, in addition to the fishery sector, it is also vital to examine the complete food and nutrient demand system. The empirical results could be fed into a multi-market partial equilibrium simulation model for further policy analysis. In addition, the information can also be applied in policy analysis to evaluate the food and nutrition security situation and implement appropriate intervention programs for economic development and reducing undernutrition.

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Chapter 3: Women's Level of Participation in Decision-making: Implications for Technical Efficiency of Small-scale Aquaculture in the Ayeyarwady Delta Region of Myanmar

Abstract

Efficient use of inputs is crucial for sustainably increasing aquaculture productivity and profitability as well as sustaining rural livelihoods in developing countries. A few studies have shown that women's level of participation in decision-making as a measurement of women empowerment can influence technical efficiency among crop farmers. However, rigorous empirical evidence on input use efficiency and the effect of women's decision-making power on technical efficiency of fish production in small-scale aquaculture households is inadequate. Using data from 440 smallholder aquaculture households in the Delta region of Myanmar, this study: (*a*) measures technical efficiency and (*b*) examines the effect of the women's participation in decision-making (WPDM) on technical efficiency. Two-stage double bootstrap Data Envelopment Analysis (DEA) is applied to adjust for bias and serial correlation of efficiency scores. Results reveal that most small-scale fish-farming households are not technically efficient, performing in a range of 45%-60% below the production frontier. All the inputs used contain slacks such that all of them are over-utilized in inappropriate ratios. Regarding the findings of the regression analysis, we observe a positive and significant relationship between the WPDM and technical efficiency. Additionally, aquaculture production practices particularly polyculture and climate change adaptation strategies are also significant shifters to enhance the efficiency level. The findings indicate the vital need to promote interventions programs targeted at technical efficiency improvement of small-scale fish farming households. Policies and intervention programs aimed at aquaculture fish productivity improvement would benefit by including intervention programs to promote equity and reduce gender inequality.

Keywords: Input use efficiency, women, decision-making, data envelopment analysis, small-scale aquaculture, Myanmar

3.1 Introduction

The economic reforms in Myanmar that began in 2012, targeted at poverty reduction and rural development, introduced new agricultural policies promoting diversification of smallholder agriculture, including fish farming (NESAC, 2016). Prior to the reforms, small-scale fish farming was almost non-existent (Driel and Nauta, 2014; Edwards, 2005). The number of small and medium scale aquaculture producers has since then rapidly expanded (Belton et al., 2015). Most recently, Karim et al. (2020) showed that the entry cost of small-scale fish farming is low because farmers can modify paddy fields and/or utilize unused lands in the backyard. Therefore, small-scale aquaculture development is important in meeting the growing fish demand and improving the livelihoods of poor and vulnerable households in rural Myanmar.

Despite the potential of small-scale aquaculture for development in Myanmar, a relevant question for agricultural policy makers is whether and how the small-scale aquaculture sector can be made more technically efficient by achieving either the current output level with fewer inputs or more output with the current input level. Answering this question is imperative and requires a better understanding of farmers' current level of technical efficiency and the factors that influence efficiency. Most of the existing literature in aquaculture sector analyzed technical efficiency level of all inputs consecutively, assuming that all inputs used in fish production can be reduced proportionally. However, some inputs are more controllable than others. Therefore, inefficient farmers have better opportunities to improve their farm operations by optimizing specific input amounts (Anh Ngoc et al., 2018). To our knowledge, the current study is the first to assess technical efficiency of fish farming in Myanmar.

Regarding the social aspect of the aquaculture sector, women play a significant role as laborers, managers, and/or decision-makers in aquaculture production process and value chains (FAO, 2018). Women's participation in aquaculture and the important contribution to households' well-being is increasingly recognized (Weeratunge et al., 2009). However, women themselves get few benefits due to gender inequality, especially in gender beliefs, norms and laws in social, cultural, and economic spheres (Weeratunge-Starkloff and Pant, 2011). Gender inequality and inequities constrain effective and efficient performance of value chains in aquaculture sector (Kruijssen et al., 2018). The studies have shown that women's empowerment can lead to improvements in their status both inside and outside of the households – including participation in decision-making process, access to and control over household resources and freedom of movement , all of which may, in turn positively impact agricultural productivity, food and nutrition security of the households(Zereyesus, 2017; Diiro et al., 2018).Regarding the women's empowerment measurement, researchers have used different indicators and dimensions. Among them, decision-making power is a commonly applied proxy women's bargaining power at the household level in several literature (see Malhotra and Mather, 1997; Becker et al., 2006).

Conceptually speaking, technical efficiency of small-scale aquaculture is influenced by a combination of social, economic, and environmental characteristics of fish farming households. Although many previous studies have shown that socioeconomic and production characteristics of fish producers influence technical efficiency, the effect of the social aspect with a focus on gender perspective on technical efficiency has not been studied yet. From the gender perspective, intra-household decision-making power is applied as a measurement of women's empowerment in this study. In this case, gender specific preferences are obtained considerably and better quantification than simply husband and wife's decisions because decisions within the household are made through bargaining between all eligible household members. This approach can also capture the share of women voice and preferences advocated in the different domestic decision-making (Sariyev et al., 2020). This study followed the latest methodology proposed by Sariyev et al. (2020) that takes into account all household members involving in the decision-making activities and aims to develop an index capturing the women's level of participation in decision-making within the household (WPDM). This chapter tries to analyze the overall technical efficiency and input-specific efficiency through different Data Envelopment Analysis (DEA) models and then investigate the implication of WPDM on technical efficiency of small-scale aquaculture.

This introduction section is followed by a literature review based on empirical evidences of studies related to decision-making power as a measurement of women empowerment, the empirical methods and the main variables of interest. After presenting the main variables included in the analysis, the empirical results and discussion are reported. Finally, conclusions and recommendations based on the main results of the study are reported.

3.2 Literature review on decision-making power as a measurement of women's empowerment

Women's empowerment is an important component of the social dimension but it is a complex and difficult process to measure. Using the direct measurement to estimate the real change can be more relevant than using proxy dimensions (Malhotr and Schuler, 2005). However, the existing studies employ proxy indicators and fail to capture the individual's bargaining power directly (Bernard et al., 2020). Measurement of empowerment have been analyzed in the studies from different dimensions with the different operationalization at the community and household levels. Among them, access to and control over the household resources, freedom of movement and household level decision-making power are applied as the common proxy indicators of women empowerment measurement (Malhotra et al., 2002). Using "*the Women's Empowerment in Agriculture Index (WEAI)*" approach, decision-making indicator is considered as a key dimension of women empowerment because it involved in the indicators of three out of the five dimensions. Production, resources and income dimensions include decision made within the households(Alkire et al., 2013). In addition, project-level WEAI, newest version of WEAI also primarily consisted of decision-making activities indicator (Malapit et al., 2019). Another measurement based on the WEAI method approach is "*Women's Empowerment in Livestock Index(WELI)*", in which decision-making involves in the indicators of five out of six different dimensions of this index (Galiè et al., 2018). This study specifically focuses the household level operationalization in one of the dimensions, which is a decision-making process at the household level.

Considering the effect of this aspect of empowerment on technical efficiency in aquaculture sector, the evidence is scant in this sector, but literature in agriculture provides important insights about this relationship. Even in the agriculture sector, most studies analyze the linkage between women's empowerment and agricultural productivity (i.e.Diiro et al., 2018; Wouterse, 2019) and the linkage between gender role and agricultural productivity (i.e Croppenstedt et al., 2013; Gebre et al., 2019). Seymour (2017) reports that women's empowerment in agriculture increased farm's technical efficiency level in rural Bangladesh. Bozoğlu and Ceyhan (2007) report that women's participation in decision-making have a positive correlation with technical efficiency level of vegetable farmers in Turkey. Some authors have examined the effect of the individual dimension of the WEAI on technical efficiency and found a positive relationship for production decision, group membership, and asset ownership, but a negative relationship for time allocation to domestic workload (Adeyeye et al., 2019; Sell et al., 2018). In addition, Allendorf (2007) focuses on the women's level of participation in decision-making within the household as a measure of empowerment to estimate the land rights impact women's empowerment. Sariyev et al. (2020a, 2020b) use decision-making indicator as a proxy of women empowerment to estimate the implications of women's level of participation in decision-making on household's dietary quality and human capital investment.

By and large, studies using decision-making domain as a measurement of women's empowerment consider only one out of many women household members, typically, the spouse of household head or one adult women member (Allendorf, 2007 ; Mishra and Sam, 2016; Allendorf, 2007; Bhagowalia et al., 2012). Such approaches ignore other women members within a household and their own responsibilities and preferences. Peterman et al. (2015) highlight that involvement in the intra-household decision-making process can be considered an intrinsically meaningful empowerment dimension because all household members within a household have that right. In this non-unitary model, a household consists of members who have their utility function, but the final decision of the households results from an interaction between members (Bourguignon and Chiappori, 1994). Furthermore, the allocation of resources among household members has a direct impact on the decision-making power and wellbeing of the household members, especially women and children(Sell and Minot, 2018). Such bargaining power reduces gender inequality by empowering women with more control over decisions, which, in turn, affects their lives by enabling them to allocate more resources to their preferences (Doss, 2013). Although this decision-making approach represents only one dimension of women's empowerment measurement, it is more time efficient and less costly and can be applied to other agricultural studies (Sariyev et al., 2020)

3. 3 Data and methods

3.3.1 Data collection

Our analysis relies on data from 440 small-scale aquaculture households collected during an aquaculture performance assessment baseline survey in 2019 for the project "Scaling systems and partnerships for accelerating the adoption of improved tilapia strains by small-scale fish farmers (SPAITS)". The main institutions involved in the study are WorldFish, the Department of Fisheries (DOF) in Myanmar, and the University of Hohenheim in Germany. In this survey a combination of stratified purposive and random sampling techniques was used. First, the Ayeyarwady Delta Region was selected as the study area because it is the main fish producing region in Myanmar. Second, three townships in the region namely Daydaye, Kyaiklatt, and Phyapon were purposely selected for the study. In these townships, another WorldFish's project "Promoting the sustainable growth of aquaculture in Myanmar (MYFC)" has carried out activities to support the households to engage in small-scale aquaculture. During the SPAITS project baseline survey period, the MYFC project had five batches of farmers. However, the farmers in batch 5 were new to aquaculture and did not have a complete a fish farming cycle at that time. Therefore, farmers in batch 5 were excluded and the total number of 1,776 fish farming households who were in batches 1 through 4 of the MYFC project was used as the sampling frame to select a random sample of 440 households for the study. Among the total sampled households, 17 households have no harvest in the previous fish farming cycle and are dropped from the analyses, leaving a total of 423 households for the analysis.

The survey was conducted from May to July 2019. The questionnaire was pre-designed and pre-tested during an enumerator training held in May 2019. The questionnaire was developed in English and translated into Burmese and programmed in Open Data Kit (ODK) for mobile data collection. The questionnaire consists of different modules for an integrated aquaculture performance assessment, including household characteristics, biological, social, economic, and environmental aspects of fish farming, and the livelihoods and well-being of the fish farming households.

3.3.2 Empirical models

An input-oriented approach DEA model is applied with the aim of using minimum feasible amount of inputs without reducing the given output level in this study. To estimate the overall and input-specific technical efficiency scores, this study moves towards applying radial and non-radial or slack-based measurement (SBM) DEA models. In addition, due to the biased and serially correlated technical efficiency scores generated from the conventional DEA model criticized by Simar and Wilson (2007), a two-stage double bootstrapping DEA technique is also applied to estimate bias-adjusted technical efficiency scores as well as the determinants of these efficiency scores consistently.

3.3.2.1 Analytical framework of data envelopment analysis (DEA) models

Two popular techniques are commonly used to estimate the technical efficiency level of agriculture and aquaculture production: the stochastic frontier analysis (SFA), which is parametric, and data envelopment analysis (DEA), which is non-parametric. The two methods have their own limitations and strengths. Comprehensive reviews of the two methods can be found in Coelli (1995), Forsund et al. (1980), and Murillo-Zamorano (2004).Whereas the superiority of SFA over DEA is that it includes statistical noise into the frontier and allows for statistical tests on the efficiency estimates, DEA is preferred at times because it does not explicitly require any functional form for production function or distribution form for inefficiency terms. It is not possible for the SFA method to estimate the technical inefficiency of each observation, as it provides an average inefficiency estimates over the whole sample. The main advantage of DEA is that the technical inefficiency measure can be estimated for each observation (Forsund et al., 1980). In addition, the DEA method can identify sources and amounts of inefficiency in each input and output for each farm and the efficient set used as a reference for these evaluations (Cooper and Joe, 2010). In the DEA approach, the efficiency or performance of decision-making units are measured in two ways: input-oriented and output-oriented approach methods.

Due to the scarcity and price increase of inputs as well as the restrictions on land use for small-scale aquaculture in Myanmar, efficient use of each input is the main objective of the fish farming households in the study area. Therefore, input-oriented technical efficiency measurement using the DEA method is used in this study to measure the minimum input level of the theoretically efficient farm at the given actual output level with variable return to scale as proposed by Banker et al. (1984). Factors such as constraints on land use, inputs use and other socio-economic constraints of fish farmers may cause the farm not to operate at an optimal scale practically. Therefore, in aquaculture studies, particularly in developing countries, the variable return to scale (VRS) of DEA method for production technology is often assumed (Anh Ngoc et al., 2018; Zongli et al., 2017).

Two common types of conventional (DEA) techniques from the input-oriented approach are applied in this study: radial (reduction in inputs proportionally) and non-radial (reduction in inputs non-proportionally). The radial DEA model, called the CRR (Charnes-Cooper-Rhodes), gives the same specified proportion changes by which all outputs (inputs) are increased (reduced) simultaneously to become efficient and does not take into account slacks in resource usage directly (Tone, 2001). On the other hand, a non-radial DEA model known as the slack-based measurement (SBM) of technical efficiency model as developed by Tone (2001), gives a different proportion and can deal directly with slacks (output shortages and excess of specific inputs) in the efficiency estimation.

Although the conventional DEA method has been applied in different sectors, it still has several inherent restrictions due to its deterministic nature. Related to this point is the observation by Pascoe and Mardle (2003) and Simar and Wilson (2007) that technical efficiency scores estimated by conventional DEA are biased and serially correlated, which leads to the production of invalid statistical inferences for the determinants of the technical efficiency analysis in the second stage. The technical efficiency scores estimated by finite samples are thus subject to sampling variations of the estimated production frontier (Simar and Wilson, 2007). To overcome the above mentioned issues of the conventional DEA technique, we follow a two-stage double bootstrap DEA procedure developed by Simar and Wilson (2007), the details of which are further explained in section 3.3.2.1.2.

3.3.2.1.1 Conventional DEA methods (radial and non-radial or slack-based measure (SBM))

Given the output Y (fish harvested) and inputs set (seed, labor, feed, fertilizer and other miscellaneous cost), the input-based technical efficiency of the DEA framework for the j[th] farms, TE_j is defined as

$$TE_j = \min_{\theta_j,\lambda} \theta_j \text{..............................Eq. (1)}$$

subject to

$$Y_j \leq Y\lambda,$$

$$\theta_j X_j \geq X\lambda,$$

$$\lambda \geq 0$$

$$\sum_{j=1}^{N} \lambda_j = 1$$

where θ_j is the technical efficiency score with $0 \leq \theta_j \leq 1$. If $\theta_j = 1$, the fish farm is technically efficient. The vector λ is an N x 1 vector of weights that clarifies the linear combination of the peers of the j[th] farm. The first constraint in Eq (1) is respective output level of small-scale fish farming. Y_j , kilograms of fish produced, is the actual level of output of the j^{th} farm compared with the theoretically efficient farm ($Y\lambda$) output vector. The second constraint concerns the input levels of small-scale fish farming. Five major inputs, namely fish seed (pieces), feed (kg), fertilizer (kg), total labor (person-days) and other miscellaneous costs (MMK) are included into the VRS DEA model in Eq (1). $\theta_j X_j$ represents the actual input level used by the j^{th} farm multiplied by its efficiency level (θ_j). $X\lambda$ is the minimum input use of the theoretically efficient fish farms, given the actual output level produced by the j^{th} farm. If the solution in Eq (1) is less than one, the quantity of input applied by that particular fish farm can be decreased to as low as $X\lambda$ to produce the same output level. If the solution in Eq (1) turns out to be θ_j=1, that particular small-scale fish farm's inputs level is as low as the level of input applied by the theoretically efficient farms at a given the same level of output. The third constraint in Eq(1) is the convexity constraint, $\sum_{j=1}^{N} \lambda_j = 1$, for assuming the variable returns to scale (see for further details in Coelli et al. (2005). The model, as mentioned above, intends to reduce all inputs proportionally with a given output level. The efficiency score derived from this model is called the radial measure of technical efficiency score, but it cannot estimate a comprehensive efficiency measurement and lacks discriminatory power for individual input (Tone, 2001).

In order to capture the percentage of reduction in the use of any individual input, a non-radial or SBM of technical efficiency model is applied, the mathematical properties of which can be found in Tone (2001). The SBM method is expressed as follows:

$$min_{\rho} = \frac{1 - \left(1/m\right) \sum_{i=1}^{m} S_i^{-}/x_{ik}}{1 + \left(1/s\right) \sum_{r=1}^{s} S_r^{+}/y_{rk}}$$

$$st: x_{rk} = \sum_{j=1}^{n} x_{ij}\lambda_j + S_i^{-}, i = 1, \dots, m$$

$$y_{rk} = \sum_{j=1}^{n} y_{rj}\lambda_j + S_r^{+}, r = 1, \dots, s$$

$$\lambda_j \geq 0, j = 1, \dots, n$$

$$S_i^{-} \geq 0, i = 1, \dots, m$$

$$S_r^{+} \geq 0, r = 1, \dots, s$$

Where, ρ denotes the SBM of technical efficiency of decision making unit (DMU) associated with *s* output set y_{rk} (*s*= different types of fish species) and *m* input set x_{ik} (*m*=seed, feed, fertilizer, labor, other inputs cost); λ_j is a non-negative vector that allows the production possibility set construction for DMU *j*; *n* is the number of DMUs (*j*=1,…*n*); S_i^{-} and S_r^{+} are denoted as slacks associated with inputs *x* (input access) and output vector *y (output shortfalls)*, respectively. S_i^{-} =0 implies no input excess and S_r^{+}=0 implies no output shortage for all *i* and *r*. We have the following formula to calculate any particular input efficiency derived from input-oriented measurement based on the SBM model:

$$\text{Input} - \text{specific technical efficiency} = \frac{\text{OIU}}{\text{AIU}} = \frac{\text{AIU} - \text{IS}}{\text{AIU}}$$

(Haider et al., 2019)

where *OIU* is the optimal input use or input target, *AIU* is the actual input use, and *IS* is the input's slacks value. In the SBM model, the percentage of reduction in each input to close the production frontier is estimated by their related slacks.

3.3.2.1.2 Bootstrap DEA procedure

The simple idea of the bootstrap procedure is to resample the data by mimicking the distribution of the original estimator to develop a data generating process that can be used through the resampled dataset. The reason for using the bootstrap method is to generate bias-corrected technical efficiency scores (BCTE) and obtain consistent statistical inference DEA efficiency scores (Simar and Wilson, 2000, 2007). The details of the implementation, concepts, and analysis of the bootstrap procedure are shown in Badunenko and Mozharovskyi (2016) and Simar and Wilson (2000). The two-stage double bootstrap DEA method involves the following steps: (1) conventional DEA technical efficiency scores in Equation 1 are computed ; (2) these estimated efficiency are combined in a bootstrap technique that is similar to the smoothed bootstrap method, (3) bias-adjusted efficiency scores are generated by the bootstrap procedure (4) the bias-adjusted technical efficiency scores are applied in a parametric bootstrap procedure on the truncated maximum likelihoods to create a set of bootstrap estimates; (5-6) then the standard errors are created for the parameters of the regression analysis. Then, confidence intervals are also created for the efficiency scores and parameters of the regression analysis. To know the bias correction level and consistency of statistical inference for factors explaining inefficiency scores, bias-variance (BV) is calculated following Badunenko and Mozharovskyi (2016).

3.3.2.2 Construction and description of explanatory variables

Variables involved in the bootstrap truncated regression analysis are selected based on most studies related to aquaculture in developing countries. Regarding the characteristics of the households, age, gender, and farming experience of household head, household's total expenditure, education level of household members, and access to extension services are included in technical efficiency analysis. Previous empirical studies have generated mixed findings regarding the linkage between households' characteristics particularly age, experience and education and technical efficiency (see in Alam et al., 2012; Cinemre et al., 2006 ; Iliyasu and Mohamed, 2016; Singh et al., 2009; Tan et al., 2011; Onumah et al., 2010). Household head's gender is expected that men-headed households exhibit higher technical efficiency because they have better access to formal institutions and extension services due to societal and cultural norms. Total household expenditure used as a proxy to capture the wealth effect appears ambiguous as it depends on fish producers' preferences for investment of capital into the aquaculture sector against the non-aquaculture sector (Alam et al., 2012) . The impact of access to extension services on technical efficiency has been found to be positive by Cinemre et al. (2006), Iliyasu and Mohamed (2016), and Singh et al. (2009) .

Regarding the production practices in the study areas, integrated aquaculture-agriculture systems (IAA), polyculture, and pond size are used to capture the impact of aquaculture practices and management on the technical efficiency of fish farming. Empirical studies by Cinemre et al. (2006) and Onumah et al. (2010) find the link between pond size and technical efficiency in aquaculture sector to be negative, while Tan et al. (2011) reports a positive relationship. Dey et al. (2010) has reported that IAA farming system is an effective production strategy for improving technical efficiency and productivity. Moreover, polyculture would have a positive relationship with technical efficiency, as it encourages efficient input use and takes advantage of the beneficial interactions between compatible species cultured in the same pond (Halwart and Gupta, 2004).

Regarding the environmental aspect, adopting the climate change adaptation strategies against the climate shocks is expected to have a positive impact on the technical efficiency. As the agriculture including aquaculture is the most sensitive sectors to climate variability, any change in the climate system has a significant impact on the process of farming activities and productivity (Gornall et al., 2010). Mase et al. (2017) highlight that farmers' perception of climate change are essential for implementing the useful and successful adaptation strategies. Roco et al. (2017) find adopting the climate change adaptation practices positively and significantly influence productivity. In regard to the social aspect of aquaculture sector, WPDM is expected to influence the technical efficiency positively. The women's empowerment indicators such as access to and control over household's productive resources and input into decision-making give financial independence and security to women, which increases the bargaining power of women within their households. These aspects may also directly influence agricultural productivity through household members' ability to organize and allocate resources (Mcpeak and Doss, 2017; Sell and Minot, 2018).

3.3.2.3 Principal component analysis (PCA) to generate the women's participation in decision-making index (WPDMI)

Although there are different dimensions of women's empowerment, this study focuses on the decision-making dimension only as a measurement of women's empowerment. In order to represent the decision-making power in different decision activities, the survey data includes the information about the decision related to many activities at the household level. Among the activities, priority is given to the decisions that are appropriate for most of the selected households because all households are not involved in the same livelihood activities. The index in this study is generated from seven decision variables related to input use in fish production, harvested fish use, quantity and type of food consumed, land allocation, fish income, crop income, and livestock income allocation. In this regard, selected decisions are made by more than 90 % of the selected households except decision in livestock income allocation (60 % of the households) and it reflects the most relevant decision-making variables for the selected households. In order to capture the accurate and required information, the respondents are asked who made the decision in the selected variables. Then, the responses are cross-checked with the household roster. To generate an index using PCA technique, households are first assigned weights related to their respective decision domains based on women's involvement in the decision-making activities. Following Sariyev et al. (2020), weights for each decision-making variable are computed by the ratio of the number of women decision makers within the household to the total number of decision-makers within the household in each decision activity. These assigned weights range between 0 and 1, with 0 showing no women participation and 1 showing only women participation. Table 3.1 summarizes the different weights of each decision domain.

3.4. Empirical results and discussion

3.4.1 Descriptive statistics of the variables

Descriptive statistics of the variables included in the technical efficiency and regression analysis are shown in Table 3.1. The average household head is 52 years old and have three years of small-scale fish farming experience. Both male and female household members have an average education level of seven years. The total annual expenditure of households is 1,253,322 MMK (USD 924[18]). About 93% of the sampled households are headed by male.

Regarding the quantity of inputs used during the previous fish production cycle, the average quantity of total stocked fingerling, feed, fertilizer, labor and other miscellaneous costs are 482 pieces, 77 kg, 61 kg, 276 person-days and 18,097 MMK (USD 13.24), respectively. The average harvested quantity of all fish species in the previous cycle is 132 kg. Regarding fish farming practices, 56% of fish farming households apply integrated fish farming but only 2% of those households adopt the polyculture system. While 75% of sampled households perceive

[18] USD 1 in July 2020 at the market exchange rate was worth MMK 1,366 (https://www.exchange-rates.org).

about climate change and then adopt mitigation strategies, 57% of households' farm are affected by the climate shocks in previous fish production cycle. Among the decision-making variables, women are most involved in those related to the type and quantity of food consumed by the household, followed by income allocation from the livestock, fish, and crop sectors.

Table 3.1: Descriptive statistics for variables included in the DEA model and regression analysis

Variables	Mean	Std. Dev.
Demographic characteristics of households		
Gender of household head (1=male, 0=female)	0.93	0.27
Age of household head (years)	52	12.18
Education level of male household members (years)	7	2.57
Education level of female household members (years)	7	2.47
Fish farming experience (years)	3	2.24
Total household expenditure per year (MMK)[19]	1,253,322	1,438,529
Aquaculture production characteristics		
Pond size (ha)	0.04	0.06
Total fish output harvested (kg) per household	131.78	171.72
Number of fish stocked (pieces) per household	481.97	315.20
Total feed use (kg) per household	76.49	186.69
Total fertilizer use (kg) per household	61.29	135.44
Total labor use (person-day) per household per crop cycle	276	103.19
Other miscellaneous costs (MMK) per household	18097	23434
Integrated fish farming (1=yes, 0=no)	0.56	0.50
Pond culture system (1=polyculture, 0=monoculture)	0.02	0.15
Household adopted mitigation strategies against climatic shocks (1=yes, 0=no)	0.75	0.44
Climatic shocks affected fish farming in previous cycle (1=yes, 0=no)	0.57	0.50
Women involvement in decision-making activities		
Input use in fish production (%)	0.13	0.30

[19] USD 1 in July 2020 at the market exchange rate was worth MMK 1,366 (https://www.exchange-rates.org).

Harvested fish use (%)	0.28	0.38
Land allocation (%)	0.17	0.30
Type and quantity of food consumed by household (%)	0.72	0.39
Fish income allocation (%)	0.37	0.36
Crop income allocation (%)	0.38	0.35
Livestock income allocation (%)	0.43	0.28

Source: Author's calculation

3.4.2 Estimates of technical efficiency (TE) of small-scale aquaculture farms through radial DEA, non-radial DEA or SBM, and bootstrap DEA in study areas

Results of technical efficiency analysis (radial DEA, non-radial DEA and bootstrap DEA techniques) are presented in Figure 3.1. The average technical efficiency score under the radial DEA analysis is 0.55, which implies that the fish farming households in this study could reduce approximately 45% of their input use without changing their output level. However, the magnitude of the non-radial efficiency score is at an average level of 0.40, so the feasible input reduction is 60%. Theoretically, the average TE derived from the radial model is 15% higher than that derived through non-radial method, which indicates radial TE overestimates the efficiency level because it does not take into account the slacks in efficiency estimation and it lacks discriminatory power.

The results of the bootstrap DEA in Figure 3.1 reveal that the overall BCTE score is 0.44, which highlights that there is substantial potential for input reduction at 56%. These findings reveal that the radial DEA model efficiency scores are overestimated if the sample bias is not adjusted. Looking at the confidence interval of BCTE scores, it is distinct that the gap between the lower (0.41) and upper (0.54) boundary is comparatively small. Moreover, while the BCTE scores are within the confidence interval, the radial DEA efficiency scores are not within this interval due to the sample bias(Simar and Wilson, 2007). Furthermore, the statistic of bias-variance test is far above one for all BCTE scores, that confirms the accuracy and reliability of efficiency scores generated from bootstrap procedure. These particular results show that BCTE scores are statistically reliable and characterize well the data generating process. Therefore, the bootstrap procedure can minimize the sample sensitivity.

As presented in Figure 3.1, most of the fish farming households fall within the radial technical efficiency scores range of 0.3-0.6 (59%), while 15.37% of the sampled households register technical efficiency scores between 0.8 and 1. Additionally, 47% of sampled households record non-radial technical efficiency score range of 0.3-0.6 and only 9.33% of sampled households operate with the efficiency score between 0.8 to 1. Moreover, looking at the BCTE scores, 69% of fish farming households' efficiency score range from 0.3 to 0.6, but only 2.6% of sampled households' technical efficiency scores record within the range of 0.8 to 1. The results highlight that many fish farms in this analysis are relatively inefficient, indicating that there is still room to improve fish farm technical efficiency even if current input levels and technology are maintained.

Table 3.2 presents the results of Kolmogorov-Smirnov tests for the equality of technical efficiency distributions by major farmed fish species and production systems. Among the most common fish species groups, there are statistically significant differences at the 5% and 10% levels in the radial and bias-corrected efficiency level scores of fish species groups, except the Rohu and Pangasius group, respectively. Regarding household groups based on location, there are significant differences at the 10% and 5% level in the radial and non-radial TE scores among sampled households within the Daydaye and Phyapon group, respectively. In addition, all TE scores among households within polyculture and sediment removal groups are statistically significantly at the 5% and 10% level, respectively. The radial and BCTE efficiency scores in the integrated farming system group are statistically significant at the 10% level.

Table 3.2: Kolmogorov-Smirnov test for the equality of distribution between any pair of radial TE, non-radial TE, and BCTE based on production technology

	Radial TE		Non-radial TE		BCTE	
	Test value	P-value	Test value	P-value	Test value	P-value
Fish species[a]						
F1 & F2	0.07	0.78	0.08	0.54	0.08	0.58
F1 & F3	0.20	0.06	0.16	0.19	0.22	0.03
F2 & F3	0.21	0.04	0.12	0.56	0.21	0.04
Study areas[b]						
A1 & A2	0.14	0.08	0.16	0.03	0.09	0.49
A1 & A3	0.13	0.60	0.16	0.29	0.14	0.52
A2 & A3	0.16	0.25	0.12	0.53	0.17	0.18
Facility type[c] (P&C)	0.13	0.56	0.12	0.63	0.14	0.53

Integrated farming system (Yes & No)	0.13	0.05	0.09	0.26	0.12	0.06
Polyculture (Yes & No)	0.50	0.02	0.47	0.04	0.48	0.03
Sediment removal (Yes & No)	0.16	0.01	0.13	0.07	0.13	0.06

Notes: The null hypothesis is the equality of distribution. P-values less than 0.01, 0.05, and 0.1 correspond to ***, **, and *, respectively.

[a]The most common species among the fish farmers in the study area are Rohu (F1), Pangasius (F2), and silver barb (F3).

[b]A1= Daydaye, A2=Phyapon, A3=Kyaiklattt, [c] P= Pond, C= Chan Myaung

Source: Author's calculation

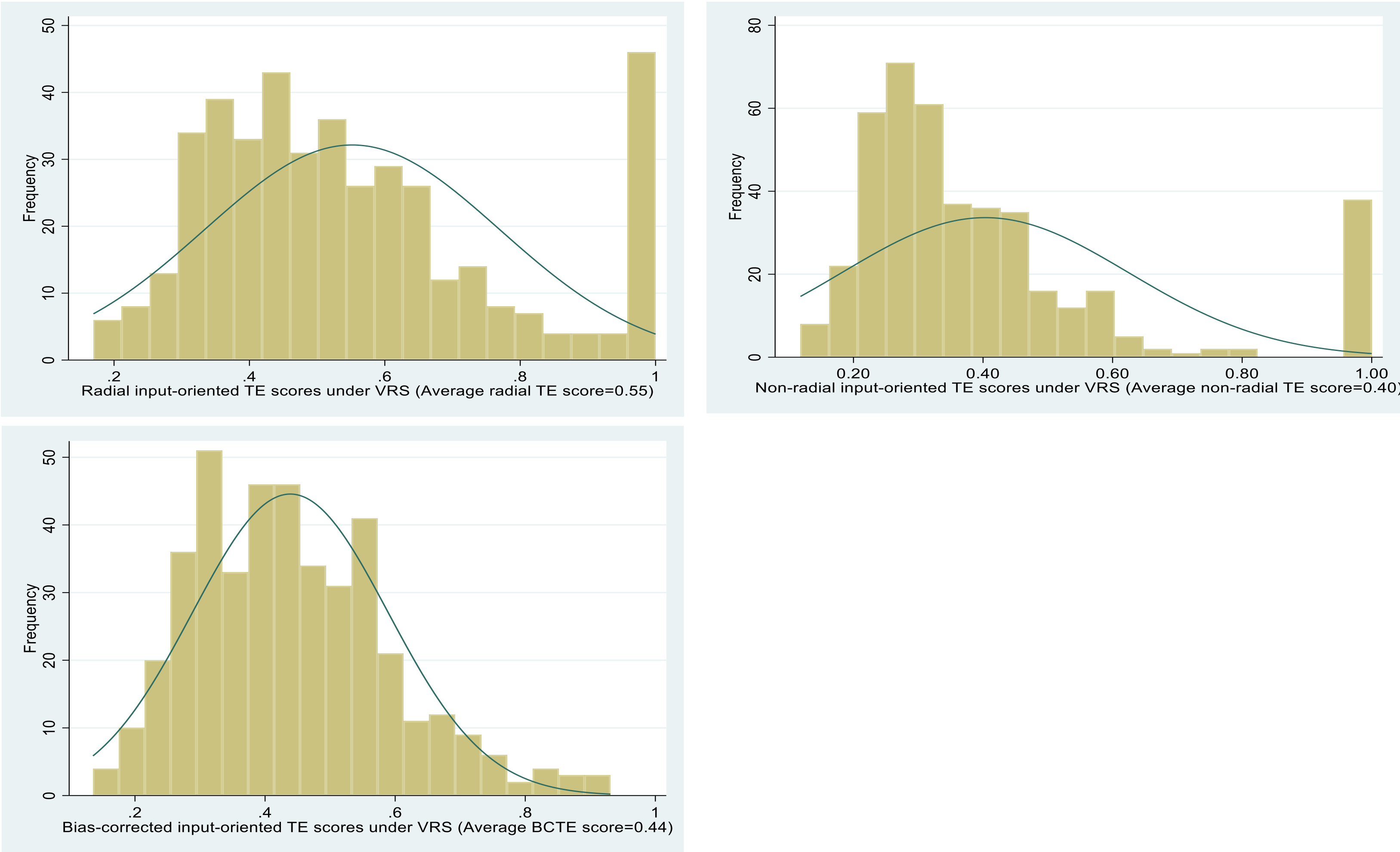

Figure 3.1: Frequency distribution of technical efficiency scores through radial, non-radial (SBM), and bootstrap DEA models

Source: Author's calculation

3.4.3. Slack variable analysis results

A slack variable refers to the deficit output or excess input used in fish production. Assuming fish farms are operating in a similar environment, setting appropriate input targets for lower efficiency farms helps the farms to reach or be close to the production frontier in comparison with the farms on the frontier. Input targets (projected point) refer to "the total amount of inputs adjustment required for inefficient DMU to operate on the production frontier" (Tone, 2001). The actual input use is higher than an input target for an inefficient firm. Input slacks refer to "the differences between the input target and actual input amount" (Ramanathan, 2003).

Our results show that the estimates for efficiency in fingerling and feed inputs are 0.68 and 0.36, respectively, which implies that average fingerling and feed use could be reduced by 32% and 64%, respectively, and still produce the current level of output. Generally, fish farming households assume that the higher the stocking density, the higher the output. In reality, overstocking reduces space availability, creating stress for fish and eventually leading to a high mortality rate (Iliyasu and Mohamed, 2016). Therefore, information on the suitable stocking density is of paramount importance for the success in fish farming because overstocking the fingerlings has adverse effects on fish growth. There are two major implications of the overuse of feed input: increased production costs, which in turn lower profits, and contamination of the fish environment that leads to reduced oxygen levels and higher mortality rates (Iliyasu and Mohamed, 2016). As the sampled fish farming households are smallholders with an average of only three years of aquaculture experience, they did not employ recommended stocking densities and feed amounts, which leads to the inefficient use of inputs.

The potential input reduction for the fertilizer is around 70%. All fish farming households apply fertilizer, mostly at the pond preparation stage. Lime, phosphate, and urea are the most commonly used fertilizers for households. The estimated average labor efficiency score is 0.44, which implies that fish farming households can reduce their use of labor by approximately 56%. Most of the sampled households depend heavily on the use of family labor in fish production activities, particularly feeding activities, while a few casual workers are occasionally hired for pond preparation and harvesting. The slack-based efficiency score in the other input costs is found to be reduced around 70%. Among these miscellaneous costs, fuel cost and rent for machinery account for the largest share of these costs.

3.4.4 Women's level of participation in decision-making activities of small-scale fish farming households

Our results in Table A2 reveal that most of the decision-making variables have shown strongly significant and positive correlation, supporting the use of PCA. The null-hypothesis of Bartlett's test is rejected (see Table A1). For the validation of results of PCA, factors with an eigenvalue greater than one remain in the analysis. The absolute factor loadings of all decision variables are higher than 0.4 (see Table A4), indicating that all decision variables are essential for the factor, that is the level of participation in decision-making. Moreover, as the final validity test, all decision-making variables have a KMO value greater than 0.6, and the overall KMO value is 0.77, which indicates adequate sampling. All validity tests of the model produce positive estimates, indicating that the WPDMI that is generated based the predicted outcome values effectively represents information included in the decision-making variables. The WPDMI is a continuous index between -1.45 and 2.83. Figure 3.2 presents the histogram of the WPDMI.

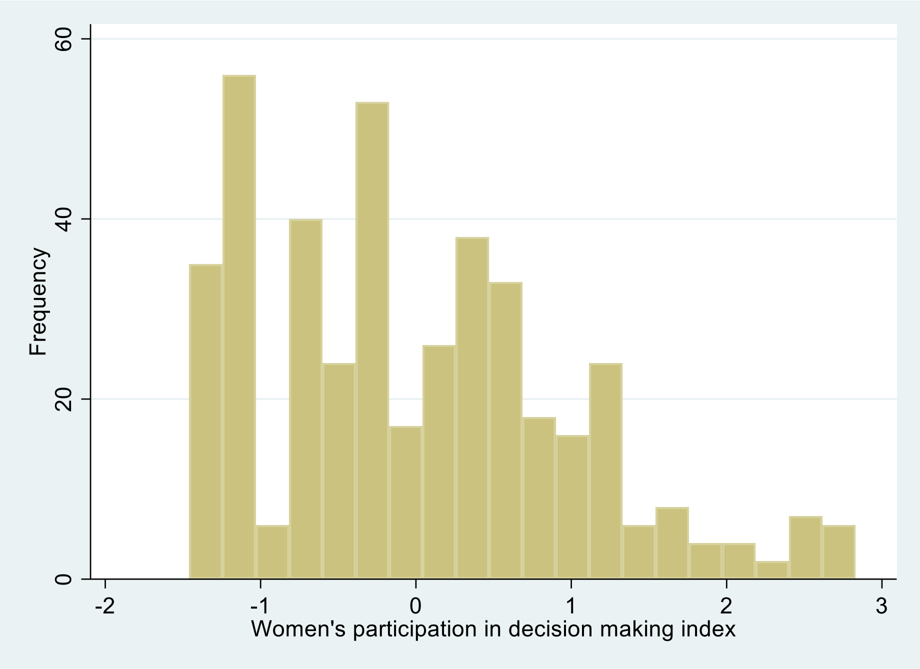

Figure 3.2: Histogram of the WPDMI (N=423)

Source: Author's calculation

3.4.5 Determinants of technical efficiency

The estimations of the bootstrapped truncated regression analysis on the determinants of technical efficiency are presented in Table 3.3. As the dependent variable represents inefficiency, hence, a positive (negative) coefficient sign indicates a negative (positive) source of technical efficiency.

Regarding demographic variables of the households, although age, age squared, experience of the household head, household's total expenditure, average education level of household members and access to extension services are expected to impact the technical efficiency of their farms, we do not find any linkages between these variables and technical. Long et al. (2020a, 2020b) and Nguyen and Fisher (2014) also report an insignificant relationship between education, experience and access to training variables and technical efficiency in Vietnam.

The coefficient of household head's gender is negative and statistically significant at the 5% level. It shows that male-headed household is associated with higher technical efficiency compared female-headed household. This could be because following the social and cultural norms in the study area, male-headed households are often more engaged in social networks that improve access to agricultural extension services, training, improved agricultural technology, and productive resources that lead to higher yield and technical efficiency for the farm. Similar empirical results are reported by Alene et al. (2008), Aguilar et al. (2015), Oluwatayo and Adedeji (2019), and Quisumbing et al. (2013).

As expected, the WPDM is positively associated with technical efficiency of small-scale fish farms and statistically significant at the 5% level. Women's level of participation in decision-making process within the household raise their voice within the household and increase their access to production resources, which in turn positively affects the agricultural productivity (Adeyeye et al., 2019). It also indicates that the relative bargaining power of male and female within the households depends on their relative utilization and access to and control over the resources. The strong bargaining power that results in intensive participation in decision-making activities processes may directly influence the technical efficiency of fish farming through its effect on the household members' ability to allocate and organize productive resources optimally. In addition, women's level of participation in decision-making tends to have "spillover" to the farms operated by others within the households by sharing the information or pooling resources. The past studies focused on the comprehensive measurement of women empowerment report that while all dimensions' indicators of women empowerment are essential, the women's participation in decision making on production activities has a more significant effect on improving the agricultural productivity (Diiro et al., 2018). Engaging in the aquaculture and fisheries sector improves women's decision-making power within households and financial independence (Morrison et al., 2007). The finding is consistent with those of studies in the agricultural sector by Seymour (2017) and Bozoğlu and Ceyhan (2007). Analysis by Seymour (2017) suggests that a woman's relative empowerment level within her household is more significantly associated with technical efficiency improvement compared to her individual level of empowerment.

Among the fish farming systems, polyculture has a positive relationship with technical efficiency and is statistically significant at the 5% level. Regarding the environmental aspect, adoption of mitigation strategies against climatic shocks has a positive and significance effect on technical efficiency at the 5% significance level. Farmers who are aware of climate variability are able to make more efficient use of their productive resources by applying the adaptation practices based on their knowledge and understanding of climate change (Ehiakpor et al., 2016).Efficient and moderately efficient farmers are more perceptive of climate change, compared to less efficient farmers(Torres et al., 2019). As documented by Torres et al. (2019) and Roco et al. (2017) the use of climate change adaptation strategies is imperative to sustain and promote agricultural productivity and technical efficiency. Additionally, the sign of the pond size coefficient is in line with our expectations. The results indicate that pond size has a positive effect on the level of technical efficiency that is statistically significant at the 1% level, showing that fish farming in larger ponds is more efficient than farming in smaller ponds. Due to the economies of scale, expanding the level of output as the pond size increases leads to an increase in input use efficiency with lower production costs.

Table 3.3: Bootstrapped truncated regression analysis

Variables	Coefficient	S.E.
Farmers' socio-economic characteristics		
Age of household head (years)	0.003	0.004
Age squared of household head (years^2)	-0.000	0.000
Fish farming experience (years)	0.001	0.003
Extension services (1=yes, 0=no)	-0.020	0.021
Education level of male household members (years)	-0.003	0.003
Education level of female household members (years)	-0.001	0.003

Log of total household expenditure (MMK)	-0.005	0.009
Household head gender (1=male, 0=female)	-0.090	0.040**
Women's participation in decision-making index (WPDMI)	-0.017	0.008**
Production characteristics		
Integrated farming system (1=yes, 0=no)	-0.012	0.016
Polyculture (1=yes, 0=no)	-0.106	0.052**
Pond size groups[a]		
Group 2	-0.045	0.017***
Group 3	-0.063	0.018***
Household adopted mitigation strategies against climatic shocks (1=yes, 0=no)	-0.041	0.020**
Climatic shocks affected fish farming in the previous production cycle (1=yes, 0=no)	0.012	0.020
_cons	0.629	0.154***
Sigma	0.145	0.006***
Observations	423	

Notes: P-values less than 0.01, 0.05, and 0.1 correspond to ***, **, and *, respectively. S.E. is the bootstrapped standard error. [a]Pond size is split into three groups: group 1 (<0.02 ha), group 2 (0.02 ha-0.04 ha), and group 3 (>0.04 ha).
Source: Author's calculation

3.5. Conclusions and policy recommendations

In this study, we estimate both the overall input technical efficiency and input-specific technical efficiency through different DEA approaches and then how the WPDM relate to bias-corrected technical efficiency through bootstrapped truncated regression model.

Efficiency estimates reveal that sampled small-scale aquaculture households are operating their production below the production frontier, indicating that there is room for improvement if current input levels and technology are maintained. Theoretically, the average TE derived from the radial DEA method is 15% higher than that derived from the non-radial method, which presents radial TE overestimates the efficiency level because it does not take into account the slacks in efficiency estimation and it lacks discriminatory power. In addition, results of the slack analysis have shown that all the inputs used in fish production contain slacks and they could be reduced accordingly. Therefore, small-scale aquaculture households need to better manage fish feeding practices and stocking density to increase their profit by decreasing their production costs. In addition, the estimated efficiency scores of the bootstrap DEA model have also revealed that the radial DEA model efficiency scores are overestimated if the sample bias is not adjusted.

We observe that a higher level of women's participation in decision-making process is associated with the improvement of technical efficiency. To draw lessons from this research finding, we conclude that the WPDM is one of the crucial strategies for more efficient resource utilization that maximizes output. Therefore, small-scale aquaculture in Myanmar is a suitable entry for empowering the women through their strong bargaining power because most of the small ponds are located in backyard plots, allowing access to and control over the household resources and integration with home gardening, child care, and household chores.

Additionally, our results highlight that male-headed farming households are more technically efficient than female-headed farming households. This could be due to social and cultural norms that favour the networking and opportunity available to male-household heads. Therefore, involving female farmers or female-headed households in development projects or intervention programs that aim to raise fish production would help to reduce the gender imbalances in access to support services that increase productivity. From the evidence presented in this study, scale of economies exists in Myanmar's small-scale aquaculture sector. This implies that small-scale fish farming households could gain higher productivity with more efficient input utilization by increasing their pond size. In addition, another considerable scope of improvement in this sector is in the different fish farming systems, such as polyculture, which also significantly influences the technical efficiency.

Looking at households' adoption of adaptation strategies against climatic shocks, our results indicate that households who perceived climate change and adopted the adaptation practices have a higher technical efficiency level. This finding suggests a need to make better use of available resources for implementing region-specific climate change adaptation strategies to overcome the adverse effects of climate change. As the effect of the adverse climatic variation depends on the implemented production system, it is necessary to observe and adapt these systems according to climatic variation to increase the production capacity through optimal use of available productive resources (Torres et al., 2019).

There are important policy implications based on the findings from this study. Firstly, to achieve the purpose of increased technical efficiency of small-scale aquaculture in Myanmar, the government and other development organizations must disseminate the information on the best management practices through quality and effective extension services and provide incentives to the small-scale fish farmers for improving the productivity and the efficiency of their fish farming. Given the inefficient and inappropriate ratio use of inputs, particularly feed and seed, cooperation with local or international organizations and research institutes should be encouraged to develop a proper fish feeding formula with good feeding practices that corresponds to the stage of fish growth, culture system, and species types to reduce the current inefficient use of feed and provide information on the suitable fish stocking density. Additionally, the policies or intervention programs directed to increase productivity and technical efficiency of small-scale aquaculture should be implemented together with policies designed to encourage women's empowerment. Then, government or non-government organizations should set up dissemination programs and training schemes in relation to climate variability to enhance households' understanding and knowledge about this issue in implementing adaptation practices effectively.

Nevertheless, this study has some limitations because this study is unable to measure the women's empowerment score and Gender Parity Index (GPI) by using the "*Women's Empowerment in Agriculture Index (WEAI)*" and its version constructed by Feed the Future due to the lack of information on the indicators of this technique. To calculate the WEAI, a constructed questionnaire would have to be used for the domains of empowerment and to ask the respondents of both genders particularly main male and female decision makers separately. However, not all of these related questions could be included in the survey questionnaire of this study due to time availability and the objective of the survey is to focus on the integrated performance analysis of small-scale aquaculture, including social, economic, and technical aspects, but not specifically women's empowerment. Therefore, future women empowerment studies could consider using both the WEAI and WPDMI methods to analyze the differences and complementarities between these two indicators of empowerment in aquaculture. However, overall, this study suggests a useful approach for estimating the women's decision-making power as a measure of women empowerment by capturing the intra-household decision making.

3.6 References

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Chapter 4: The Impact of Sustainable Aquaculture Technologies on the Welfare of Small-scale Fish Farming Households: Evidence from Myanmar

Abstract

This study analyzes the determinants and potential impacts of the adoption of sustainable aquaculture (SA) technologies on the welfare of small-scale aquaculture (SSA) households in Myanmar. Welfare is measured by fish yield per hectare, Household Dietary Diversity Score (HDDS), and Total Food Consumption Score (TFCS). This study relies on household-level data collected from 423 SSA households in 2019. We employ an endogenous switching regression (ESR) model framework to estimate the actual welfare effects of the adoption of SA technologies by controlling for both selection bias and endogeneity. Our analysis reveals that distance to the sale point, membership in farmers' organizations, knowledge about aquaculture production, and location are the main drivers behind adopting SA technologies. Results also reveal that the adoption of SA technologies increases fish yield per ha, HDDS, and TFCS of SSA households. However, the adopters would benefit more from the adoption of SA technologies in terms of fish yield and TFCS because the average treatment effect on the treated (ATT) is greater than the average treatment effect on the untreated (ATU) for those outcome variables. The non-adopters stand to benefit the most in terms of an increase in dietary diversity if they were to adopt the technologies, as the ATU is greater than ATT for the outcome variable of HDDS. Our research findings suggest that policies targeted at raising the incomes and food security of SSA households should emphasize promoting farmer's awareness and technical skills about SA technologies by providing improved support, such as in extension services and inputs.

Keywords: Sustainable aquaculture technologies, welfare outcomes, small-scale fish farming, endogenous switching regression, Myanmar.

4.1 Introduction

The development of small-scale aquaculture (SSA) is a significant contributor to food and nutrition security and poverty alleviation of households through direct and indirect pathways (Pant et al., 2014; Otsuka et al., 2016). However, several constraints, such as land-use restrictions, lack of access to credit, escalating input prices, and lack of improved technologies, have often prevented SSA farmers from utilizing their ponds efficiently in most developing countries (Belton, 2017; Duijn et al., 2018). Moreover, although stand-alone aquaculture farms are successful for large-scale aquaculture both in developing and developed countries, stand-alone aquaculture farms or production technologies that rely on traditional practices are risky ventures and no longer an option for small-scale fish farming households (Prein, 2002). Asfaw et al. (2012) report that achieving productivity growth in the agriculture sector would not be possible without implementing yield-improvement practices because the expansion of production areas is not possible to fulfill the demand from the increasing population. Therefore, renewing or modifying resources and assets used to produce goods and services, as well as implementing innovative technologies is critical for increasing productivity (FAO, 2018). Adopting systematic modifications for existing production practices and new technologies play a critical role in increasing aquaculture productivity more efficiently, economically, and sustainably (Asche, 2008).

Recent studies report that investment in new management, production systems, and products of aquaculture sector provides substantial benefits to producers and consumers (Kumar et al., 2018; Kumar and Engle, 2016). However, insights into what types of aquaculture technology is suitable for SSA farmers are still limited. Due to limited institutional support for and extension service access of SSA farmers, improvements in pond management activities based on local resources and expertise would likely bring about quick, attainable, and positive impacts on the fish production of small-scale aquaculture households (Steinbronn, 2009). Despite the dominance of large-scale fish farming in Myanmar due to land-use restrictions, the number of illegally operated small and medium ponds is significantly higher than official recorded data. These outcomes highlight that profitability and employment opportunities have enticed farmers to enter the sector informally, without legal permission. While government support in Myanmar has focused on large-scale fish farming with a favorable policy environment, potential and existing SSA farmers face several constraints, such as land-use restrictions and lack of government support. Despite abundant natural resources and untapped benefits that favor SSA development, the potential and challenges of SSA farmers are often overlooked and not documented in development strategies by the Government (Belton et al., 2015). Studies on the performance of SSA technologies on productivity are very limited (Karim et al., 2020).

Drawing from the previous literature related to SSA farmers, Integrated Aquaculture and Agriculture (IAA) is considered a sustainable food production practice and model for developing a SSA farming system (Pretty, 2008; Edwards, 2008). In addition, Pucher et al. (2013) propose modified pond management practices (MPMPs) as the sustainable aquaculture system for SSA farmers, which includes a pond water management system, liming, chemical fertilization, regular pellet feeding, common carp rearing, and record bookkeeping. The above-mentioned MPMPs have been tested as a field research trial in six ponds belonging to Black Thai farmers in Northern Vietnam. Higher fish yield and net economic return for SSA farmers can be reached after modifying pond management practices.

To the best of our knowledge, the previous studies on IAA has focused on the overview and performance of the IAA system (Ahmed et al., 2014; Huong et al., 2018) and failed to move beyond analyzing its impacts on farm productivity and farm income (Dey et al., 2010). Very few studies explore the IAA system's potential role based on a rice-fish culture field trial in Myanmar (Dubois et al., 2019). There is no empirical evidence about MPMPs elsewhere, including Myanmar, except for the field research trial mentioned above. Based on the limitations of the previously mentioned studies, IAA and MPMPs are considered sustainable aquaculture (SA) technologies for SSA households in this study. While there are a vast number of studies about the determinants and impacts of the adoption of sustainable or improved agricultural technologies (e.g., Asfaw et al., 2012; Abdulai, 2016; Khonje et al., 2018), none of these studies examined determinants of the adoption of sustainable aquaculture practices and its impact on the welfare outcomes of SSA households. Therefore, this study examines the determinants and potential impacts of SA technologies on welfare outcomes of the households, which are measured by fish yield per hectare (ha), Household Dietary Diversity Score (HDDS), and Total Food Consumption Score (TFCS). The empirical evidence of this study will contribute to the limited studies on sustainable aquaculture practices, specifically about the role of IAA and MPMPs for SSA farmers, by providing micro-level information on adoption and its impacts on welfare. Clear evidence of the benefits of the adoption of SA technologies on farms households is imperative if these practices are adopted and/or promoted by government and other organizations.

4.2 Overview of sustainable aquaculture technologies for SSA households

Although technologies related to aquaculture have been defined more broadly in the studies (Little and Bunting, 2016a; Kumar and Engle, 2016; Joffre et al., 2017), this study focuses on the IAA and MPMPs as SA production practices. There are two main types of IAA farming system depending on the biophysical conditions: (i) pond-based IAA and (ii) rice-fish farming system. Fish is the main production with the integration of crops and/or livestock farming in the pond-based IAA, while rice is the main crop in the rice-fish farming system (Ahmed et al., 2014). In this study, the integration of fish farming with rice, vegetables, fruits and livestock farming is considered as the IAA system. Integrated farming system involving aquaculture can be defined as concurrent linkages between two or more aquaculture sectors and agricultural activities, including livestock, where these sequential linkages may have a direct impact on-site or an indirect impact off-site, providing opportunities and satisfying needs for the practitioners (Prein, 2002). In addition to being able to increase the fish productivity per unit of land, agro-industrial input use and risks are reduced as a result of diversification, reusing water, and recycling nutrients, and therefore the supply of a more balanced diet for farming households can be sustained (Edwards et al., 1998; Prein, 2002; Ahmed et al., 2014). Therefore, farm product diversification through aquaculture has been suggested as a tool that can contribute significantly to the livelihood development of poor farm households in developing countries (Ahmed et al., 2014; Huong et al., 2018; Dey et al., 2010).

Regarding MPMPs, traditionally managed pond water system[20] results in ponds with a high loss of nutrients, increased turbidity, and reduced production of natural food resources in the ponds, such as plankton, due to the removal of water from the upper pond layer, which results in lower yields(Steinbronn, 2009; Pucher et al., 2013). Moreover, as farmers utilize pesticides mostly in their rice fields, it harms fish and natural foods in ponds and makes fish consumption risky for human health (Lamers et al., 2011). Therefore, a modified pond water management system[21] can enhance the production of small-scale ponds by helping to decrease the turbidity of pond water and loss of nutrients caused by flashing out (Pucher et al., 2013; Little and Bunting, 2016; Phuong and Oanh, 2010). Pond fertilization is a relatively low cost technique that significantly improves production efficiency because it can stimulate plankton blooms to

[20] In a traditional pond water management system, water from all surrounding water sources (paddy fields, channels, and gardens) flows into fish ponds without any control system, so water either flows in constantly through holes in dikes or through openings created for that purposes (Reinhardt et al., 2012).

[21] In order to reduce the impacts of pesticides or eroded particles derived from neighboring fields (particularly paddy fields), proper pipes or proper channels are installed around ponds to control inflows and outflows.

provide an essential source of natural food for fish (Belton et al., 2017). In addition, it is also recommended to use lime in the pond preparation and repairing stage to allow for optimal organic matter decomposition, disinfection of the bottom of the pond from harmful bacteria, and reduction in turbidity, all of which help ensure sustainable fish production (Pucher et al., 2013). Compared with low-quality feed ingredients, pellet feeds enable the most effective feed uptake by fish due to the flow of required nutrients and fewer nutrients leaching into the pond, minimizing adverse environmental impacts (Little and Bunting, 2016; Pucher et al., 2013). Pucher et al. (2013) and Steinbronn (2009) state that compared to common carp species, grass carp are very sensitive and susceptible to diseases that lead to high fish mortality. Therefore, modified pond management systems lead to higher productivity levels, reductions in both turbidity and nutrient loss, and higher levels of oxygen production during the day.

The link between the SA technologies and welfare outcomes of SSA households is presented as follows. As already mentioned above, SA technologies may directly affect fish productivity and improve the conservation and use of natural resources (such as soil, water and biodiversity) through integrated resource management. These technologies also provide remarkable benefits to small-scale rural farmers, resulting in increased home consumption of fish and higher incomes through increased farm productivity for producers and improved accessibility of fish for non-producer households. The increased income from households who adopted SA technologies will flow to the purchase of other food items, leading to improved household dietary diversity and food consumption score (Prein and Ahmed, 2000; Dey et al., 2010). Therefore, a farm household's decision to adopt a SA technology for increased farm productivity enhances the availability and utilization of fish and other foods at the household level.

4.3 Data and methods

4.3.1 Data collection

The data used in this study are from 440 SSA households collected during an aquaculture performance assessment baseline survey in 2019 for the project "Scaling systems and partnerships for accelerating the adoption of improved tilapia strains by small-scale fish farmers (SPAITS)."[22] In this survey, a combination of stratified purposive and random sampling techniques was used. First, the Ayeyarwady Delta Region was selected as the study area because it is the main fish producing region in Myanmar. Second, three townships in the

[22] For more information on the SPAITS project, see the following website: worldfishcenter.org

region, namely Daydaye, Kyaiklatt, and Phyapon, were purposely selected for the study. In these townships, another WorldFish's project, "Promoting the sustainable growth of aquaculture in Myanmar (MYFC)," carried out activities to support households to engage in small-scale aquaculture. During the SPAITS project baseline survey period, the MYFC project had five batches of farmers. However, the farmers in the fifth batch were new to aquaculture and did not have a complete fish farming cycle at that time. Therefore, farmers in the fifth batch were excluded. A total of 1,776 fish farming households who were in batches one through four of the MYFC project was applied as the sampling frame to select a random sample of 440 households for this study. Among the total sampled households, 17 households had no harvest in the previous fish farming cycle and were dropped from the analyses, leaving 423 households. The survey questionnaire includes several factors: household characteristics; social variables, economic variables, and environmental aspects of fish farming; pond management practices; and farmers' livelihoods.

Among the aforementioned set of MPMPs, we focus on pond water management activity and chemical fertilization in this study because almost all selected households applied lime at pond preparation (100%), used pellet feed (80%), and reared the common carp and catfish species (90%). Only 54% of total households practiced pond water management and 73% practiced chemical fertilization. We define a dummy variable as a measure of MPMPs. It takes the value of one if a household undertakes both practices (pond water management and chemical fertilization) and takes the value of zero otherwise. Although most farmers applied organic or chemical fertilizer in the pond, in general the amount of natural food production in the pond is low. This can be attributed to improper pond water management, such as high water flow rates, as there is evidence of an inverse relationship between the abundance of natural food in ponds and water flow rates (Pucher et al., 2013). After generating a variable for the MPMPs, a farm household who practiced one or both SA technologies (IAA and/or MPMPs) is defined as an adopter, while a non-adopter is one who did not adopt any of these technologies.

4.3.2 Empirical models

4.3.2.1 Analytical framework

This section provides a brief overview followed by a detailed explanation of the econometric estimation techniques used in this study. Self-selection bias and endogeneity are the main challenges in analyzing technology adoption impacts based on non-randomized experimental studies (Khonje et al., 2018). In examining the implications of SA technologies on welfare outcomes, randomly assigning households to treatment group could ensure that the treatment status is not correlated with any other factors, both observed and unobserved. However, as the technology adoption in this study is not randomly assigned to households, the decision to adopt is likely influenced by self-selection bias. Households who adopt SA technologies may be systematically different to the non-adopters. Due to the fact that farmers adopting technologies are self-selected, these individual factors could potentially affect the decision to adopt and also the outcomes of this decision (Di Falco and Veronesi, 2013). For example, the adoption decision may be influenced by unobservable factors, such as technical abilities and management skills, which aid in understanding and using the technology. If we fail to control for these factors, it will yield inconsistent estimates of the technologies' actual impact on the outcome variables (Abdulai and Huffman, 2014).

Most impact evaluation studies have used alternative statistical approaches for dealing with selection bias, including difference-in-difference (DID) and propensity score matching (PSM). The DID approach requires data collected from both the control and treatment groups before and after technology adoption (Vigani and Kathage, 2019). As our data are cross-sectional and collected after farmers have adopted the technologies, the PSM technique is the more suitable option. However, PSM can only address selection bias caused by observable factors (Abdulai, 2016; Jaleta et al., 2016). Therefore, we use the full information maximum likelihood endogenous switching regression (FIML ESR) for the main analysis to control for both selection bias and endogeneity (Asfaw et al., 2012; Abdulai, 2016; Di Falco et al., 2011). We then use PSM to check the robustness of the results.

4.3.2.2 Modeling impact of SA technologies on welfare outcomes: Endogenous switching regression

The first stage of ESR model is the selection equation for the adoption of SA technologies that is based on a dichotomous choice measurement function. The observed welfare outcomes of the adoption of SA technologies can be modeled following a random utility framework. Considering a utility maximizing i^{th} farming households that faces a decision on whether to adopt SA technologies, the probability that a small-scale fish farming household will adopt SA technologies is determined by a comparison of the expected benefit of adoption U_1 against the expected benefit of non-adoption U_0. It will adopt SA technologies only if ${Y_1}^* = U_1 - U_0 > 0$. The net benefit ${Y_1}^*$ is an unobserved or latent response variable for the adoption of SA technologies, which is determined by observed variables Z_i and the error term ε_i:

$$Y_i^* = Z_i\alpha_j + \varepsilon_i \text{ with } Y_i = \begin{bmatrix} 1 \; if \; Y_1^* > 0 \\ 0 \; if \; Y_1^* < 0 \end{bmatrix}, \tag{1}$$

where Y_i^* is a binary indicator that equals one for adopter households and zero for non-adopter households, Z_i, represents household-level variables that influence the household's technology adoption decision, α_j is a vector of parameters to be estimated, and ε_i is the random error term.

Applying the ESR model of the welfare outcome variables, where farm households face two possible regimes: (1) to adopt and (2) not to adopt,

$$\begin{cases} Regime\ 1: Q_{1i} = X_{1i}\beta_1 + \mu_{1i} \; if \; Y_i = 1 \quad (for\ adopters) & (2a) \\ Regime\ 2: Q_{2i} = X_{2i}\beta_2 + \mu_{2i} \; if \; Y_i = 0 \quad (for\ non-adopters) & (2b) \end{cases}$$

where Q_i is the observed outcome variable (log of fish yield per ha, HDDS, and TFCS), X_i represents vectors of exogenous variables influencing the outcome equations, β_i is list of the parameters to be estimated, and μ_i are the error terms.

Following Fuglie and Bosch (1995), the error terms in the above three equations are assumed to have a trivariate normal distribution with zero mean vector and the following variance-covariance matrix structures as:

$$\Sigma = cov\ (\varepsilon_i, \mu_{1i}, \mu_{2i}) = \begin{bmatrix} \sigma_\varepsilon^2 & \sigma_{\mu 1\varepsilon} & \sigma_{\mu 2\varepsilon} \\ \sigma_{\mu 1\varepsilon} & \sigma_{\mu 1}^2 & \sigma_{\mu 1\mu 2} \\ \sigma_{\mu 2\varepsilon} & \sigma_{\mu 1\mu 2} & \sigma_{\mu 2}^2 \end{bmatrix}, \tag{3}$$

where: Σ is the variance-covariance matrix that controls for selection bias; σ_ε^2 is the variance of the error term in Eq (1); $\sigma_{\mu 1}^2\ and\ \sigma_{\mu 1}^2$ are the variance of error terms in Eq (2a) and (2b), respectively; and $\sigma_{\mu 1\varepsilon}\ and\ \sigma_{\mu 2\varepsilon}$ are the covariance of the error terms, ε_i, μ_{1i}, and μ_{2i}. The variance of the error term σ_ε^2 in Eq (1) can be assumed to be equal to one since the coefficients are only estimable up to a scale factor. Maddala (1983) states that the covariance between $\mu_{1i} and\ \mu_{2i}$ (denoted as $\sigma_{\mu 1\mu 2}$) is unobservable since a small-holder household cannot simultaneously be an adopter and non-adopter and therefore $\sigma_{\mu 1\mu 2}$ cannot be estimated. According to Di Falco et al. (2011), as the error term ε_i from Eq (1) is correlated with the error terms of the outcome functions μ_{1i} in Eq (2a) and μ_{2i} in Eq (2b), the conditional expected values of the error terms $\{\mu_{1i}|Y_i = 1\}$ and $\{\mu_{2i}|Y_i = 0\}$ on the sample selection are non-zero and given by:

$$E\{\mu_{1i}|Y_i = 1\} = \sigma_{\mu 1\varepsilon}\left(\frac{\phi(Z_i\alpha_j)}{\Phi(Z_i\alpha_j)}\right) = \sigma_{\mu 1\varepsilon}\lambda_{1i} \quad (4a)$$

$$E\{\mu_{2i}|Y_i = 0\} = -\sigma_{\mu 2\varepsilon}\left(\frac{\phi(Z_i\alpha_j)}{1-\Phi(Z_i\alpha_j)}\right) = \sigma_{\mu 2\varepsilon}\lambda_{2i} \quad (4b)$$

where ϕ(.) is the standard normal probability density function, Φ(.)is the standard normal cumulative density function, $\lambda_{1i} = \left(\frac{\phi(Z_i\alpha_j)}{\Phi(Z_i\alpha_j)}\right)$, and λ_{2i}=$\left(\frac{-\phi(Z_i\alpha_j)}{1-\Phi(Z_i\alpha_j)}\right)$. Following Maddala (1991), a probit model in Eq (1) is applied to generate λ_{1i} and λ_{2i} . In the second stage of Eq (2a) and Eq (2b), the impacts of SA technologies are estimated using OLS by including terms λ_{1i} and λ_{2i} as additional regressors to correct for selection bias.

If the covariance terms $\sigma_{\mu 1\varepsilon}\ and\ \sigma_{\mu 2\varepsilon}$ are non-zero ($\alpha_{\mu 1\varepsilon} \neq \alpha_{\mu 2\varepsilon} \neq 0$), the adoption decision and outcome equations are correlated. This indicates that the decision to adopt is an endogenous variable. The FIML ESR[23] model, which analyzes the selection and outcome equations simultaneously to produce consistent standard errors. The logarithmic likelihood function for the ESR model given the trivariate normal distribution of the error terms is specified as follows:

$$lnL_i = \sum_{i=1}^{N} Y_i\left[ln\phi\left(\frac{\mu_{1i}}{\sigma_{\mu_1}}\right) - ln\sigma_{\mu_1} + ln\Phi(\theta_{1i})\right] + (1-Y_i)\left[ln\phi\left(\frac{\mu_{2i}}{\sigma_{\mu_2}}\right) - ln\sigma_{\mu_2} + \ln(1 - \Phi(\theta_{2i})\right], \quad (5)$$

where Y_i, ϕ, and Φ are defined earlier and $\theta_{ji} = \frac{(Z_i\alpha_j + {}^{\rho_i\mu_{ji}}/_{\sigma_{j)}}}{\sqrt{1-\rho_j^2}}$, j = 1, 2 with ρ_j representing the correlation coefficient between ε_i and μ_{ji}.

Following Di Falco et al. (2011) and Maddala (1983), it is important to impose an exclusion restriction on the outcome equations. Therefore, instrumental variables that identify the selection into the treatment group are needed. It means that Z_i variables in the Eq (1) should consist of at least one variable that is not part of X_i in the outcome equations. Following Di Falco et al. (2011), we check for the validity of instrumental variables using the falsification test. If an instrument is valid, it will influence the decision to adopt SA technologies, but it will not have a direct effect on the welfare outcome among the farm households that did not adopt SA technologies. In this study, knowledge about aquaculture is hypothesized to have an impact

[23] The full information maximum likelihood method was estimated using the 'movestay' command in Stata.

on the adoption decision, and it only affects the welfare outcomes through the decision to adopt SA technologies. For constructing this variable, we asked the farmers ten knowledge questions about aquaculture production activities. The farm households who answered many questions correctly are more likely to adopt SA technologies compared with those who could answer fewer questions.

Estimation of counterfactuals and average treatment effects

The ESR model's coefficient can be applied to make the comparison of expected welfare outcomes of households who adopted SA technologies (6a) with respect to those who did not adopt (6b) observed in the actual condition. Additionally, it allows us to investigate SA technologies' expected effect on the outcome variables in the counterfactual situation in which the actual adopters did not adopt (6c) and that the actual non-adopters adopted (6d). The conditional expected treatments effects for the welfare outcomes in the four conditions are calculated as follows:

Adopters (observed in the sample)

$$E(Q_{1i}|Y_i = 1) = X_{1i}\beta_1 + \sigma_{\mu 1\varepsilon}\lambda_{1i} \tag{6a}$$

Non-adopters (observed in the sample)

$$E(Q_{2i}|Y_i = 0) = X_{2i}\beta_2 + \sigma_{\mu 2\varepsilon}\lambda_{2i} \tag{6b}$$

Adopters, had they decided not to adopt (counterfactual)

$$E(Q_{2i}|Y_i = 1) = X_{1i}\beta_2 + \sigma_{\mu 2\varepsilon}\lambda_{1i} \tag{6c}$$

Non-adopters, had they decided to adopt (counterfactual)

$$E(Q_{1i}|Y_i = 0) = X_{2i}\beta_1 + \sigma_{\mu 1\varepsilon}\lambda_{2i} \tag{6d}$$

The average effect of the treatment on the treated (i.e., the adopters) (ATT) are the difference between Eqs (6a) and (6c), controlling for both observable and unobservable characteristics. The ATT is given by:

$$\begin{aligned} ATT &= E(Q_{1i}|Y_i = 1) - E(Q_{2i}|Y_i = 1) \\ &= X_{1i}(\beta_1 - \beta_2) + (\sigma_{\mu 1\varepsilon} - \sigma_{\mu 2\varepsilon})\lambda_{1i} \end{aligned} \tag{7}$$

Eq (7) measures the expected difference in adopter households' welfare outcomes with their counterfactual, if they had similar characteristics as the non-adopters or if their characteristics had the same effects on the outcome variables. The selection term (λ) adjusts the ATT to account for the potential effects of unobservable factors(Shiferaw et al., 2014).

Similarly, this model also allows the calculation of the average effect of the treatment on the untreated (i.e, non-adopters) (ATU) as the difference between Eqs (6d) and (6b). The ATU is given by:

$$\begin{aligned} \mathrm{ATU} &= \mathrm{E}(\mathrm{Q}_{1\mathrm{i}}|\mathrm{Y}_{\mathrm{i}}=0) - \mathrm{E}(\mathrm{Q}_{2\mathrm{i}}|\mathrm{Y}_{\mathrm{i}}=0) \\ &= X_{2i}(\beta_1-\beta_2)+(\sigma_{\mu 1\varepsilon}-\sigma_{\mu 2\varepsilon})\lambda_{2i} \end{aligned} \quad (8)$$

Eq (8) measures the expected difference in the welfare outcomes of the non-adopters with their counterfactual, if they had similar characteristics as the adopters or if their characteristics had the same effects on the outcome variables. The term (λ) captures all potential effects of unobservable factors for ATU(Shiferaw et al., 2014).

The ESR model only works if there is a valid instrumental variable. Therefore, in addition to testing the validity of the instrument, we also repeat the analysis using propensity score matching (PSM) to check for the robustness of the results. A detailed explanation of PSM is not provided here, as we use it only for robustness check, but more information about the technique can be found in Caliendo and Kopeinig (2008).

4.3.2.3 Measurement of food security

To measure the food security of households, HDDS and TFCS developed by the World Food Program (FAO and WFP, 2012; WFP, 2008) are used. Following Ruel (2003), we used a seven-day recall period for the HDDS measurement from twelve food groups as it has the longest recall period with the least recall error. HDDS reflects a household's food accessibility and counts the variety of food groups consumed by a household. Although dietary diversity indicators do not comprehensively capture the food security of the households (Cafiero et al., 2014), it has been used to measure food accessibility at the household level in multi-country analysis (Hoddinott and Yohannes, 2002). However, dietary diversity scores do not capture food consumption frequency or the nutritional adequacy of the different food groups. Therefore, TFCS is also used to reflect the micronutrient levels in a household's diet (Steyn et al., 2006). The score captures the frequency of nine food groups consumed in the last seven days. We generate TFCS for a household following the World Food Program's technical guidance sheet. First, we categorize the food consumed by a household into nine food groups. Second, we add the frequency of consumption within the same food group and that gives us the frequency value for each consumed food group. If a food group's frequency value is above seven, we recode this as seven (WFP, 2008). Third, these values are multiplied by the respective weights assigned to each food group to obtain the weighted scores of food group.

Finally, the weighted food group scores are summed up to produce the TFCS of the individual household.[24]

4.4 Empirical results and discussion

The first subsection of the results section starts by showing the mean differences between the adopters and non-adopters for outcomes and explanatory variables included in the econometric analysis. Then, it examines the determinants of the adopting the SA technologies, followed by welfare outcomes of adoption of the technology. For the asset index variable as a proxy for wealth, Principal Component Analysis (PCA) was used to generate an index. This index includes information on ownership of durable household assets.

4.4.1 Mean differences between adopters and non-adopter's characteristics

Table 4.1 presents mean differences between the adopter and non-adopter households for several variables included in the analysis. All outcome variables, except for HDDS, are not significantly different between adopters and non-adopters. Among the explanatory variables, the household head's age, distance to the point-of-sale where harvested products are sold, living in Phyapon Township, membership in farmers' organizations, access to off-farm activities, and knowledge about aquaculture activities are significantly different between the two household groups, but the remaining variables are not significantly different between the two groups. In this study, although adopters earn a higher average gross margin per ha, their variable cost of fish production per ha is higher than that of non-adopters – the difference, however, are statistically insignificant. Since SA technologies incur additional costs, these technologies will be adopted if the total expected revenue outweighs the total expected cost. Although labor allocation, which includes family and hired labor, to fish production activities by the adopters is higher than that for non-adopters, SA technology adoption generates higher returns to family labor for the adopters 3.09 USD[25] per day compared with 1.09 USD per day for the non-adopters. This study emphasizes the fish production activities of SSA farming households. Therefore, the survey contains only data pertaining to labor involved in fish production. These findings confirm that SA technologies may enhance product yield, but capital and labor

[24] The maximum consumption score (TFCS = 112) is obtained when all food groups are consumed by a household in the recall period and the minimum consumption score (TFCS = 0) when a household did not consume any food groups in the recall period (for detail, see WFP and FAO, 2008)

[25] 1 USD in October 2020 at the market exchange rate was worth MMK 1,300. Retrieved from https://www.exchange-rates.org. The purchasing power parity rate in 2019 was 434.71 MMK per US dollar (Work Bank, 2019) Retrieved from https://www.worldbank.org.

requirement constraints may prohibit the adoption of SA technologies by small-scale farming households.

4.4.2 Endogenous switching regression results

This section reports estimates of the factors that influence a household's decision to adopt SA technologies, as well as its impacts on the outcome variables, namely log of fish yield per ha, HDDS, and TFCS using the FIML ESR model. Columns 1, 5, and 9 in Table 4.2 report the estimated results by Ordinary Least Square (OLS) pertaining to outcome functions without switching by including a dummy variable specifying the SA technologies adoption. The remaining columns in Table 4.2 show the estimated results of the selection Eq (1) and of the outcome functions Eq (2a) and Eq (2b) for SSA farming households. Following the Di Falco et al. (2011) procedure on the simple rejection test, knowledge about aquaculture is considered a valid instrumental variable because it is a statistically significant driver in the decision to adopt the SA technologies but does not significantly influence welfare outcomes of the households that did not adopt the technologies (see Table A5).

4.4.3 Determinants of the adoption of SA technologies

The estimates in the SA technologies selection equation can be evaluated as normal probit coefficients. Columns 2, 6, and 10 of Table 4.2 present the results from the selection equations for all specifications. There are differences in some coefficient estimates of the selection equations, but the estimates' sign and significance are similar, indicating robustness of the overall research findings.

Regarding the determinants of the adoption of SA technologies, age of household head has a negative effect on the adoption of SA technologies across all specifications. Younger household heads may be more willing to adopt new technologies because they tend to be less risk averse and, thus, are more willing to bear the risk of adopting a new technology. Having off-farm income negatively affects the decision to adopt SA technologies. When households have other sources of income and are less reliant on the income from farm activities, there could be less focus and financial investments on the new technologies in this sector. They may also not have time to learn about these technologies.

Table 4.1: Descriptive statistics of outcomes and explanatory variables

	Full sample (N = 423)		Adopters (N = 314)		Non-adopters (N = 109)		Difference
	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	
Welfare outcome variables							
Fish yield (kg/ha)	5136.80	9996.90	5395.71	10638.84	4390.95	7855.96	
Log of fish yield (kg/ha)	7.83	1.21	7.87	1.22	7.69	1.20	
Household dietary diversity score (HDDS)	10.45	0.97	10.52	0.96	10.24	1.01	**
Total Food Consumption Score (TFCS)	62.08	10.17	62.44	10.36	61.06	9.56	
Household demographic and socio-economics variables							
Age of household head (years)	52	12	54	13	51	11	**
Gender of household head (1 = male, 0=female)	0.93	0.25	0.94	0.24	0.91	0.29	
Household head education (years)	6	2.41	6	2.38	6	2.50	
Household size (No.)	5	1.75	5	1.72	5	1.83	
Dependency ratio (%)	28.12	22.21	27.15	21.52	30.92	23.97	
Asset index	0.00	1.00	0.01	1.00	-0.03	0.99	
Access to off-farm activities (1=yes, 0=no)	0.20	0.39	0.17	0.37	0.29	0.45	***
Log of total owned agricultural land (ha)	0.61	1.49	0.68	1.28	0.41	1.98	
Phyapon region (1=yes, 0=no)	0.70	0.45	0.75	0.44	0.58	0.49	***
Pond distance from homestead (walking minutes)	3.22	5.29	3.05	5.14	3.71	5.72	
Distance to point-of-sale (miles)	1.36	4.51	1.53	5.15	0.87	1.55	**

Climate shock(s) in last production cycle (1=yes, 0=no)	0.57	0.49	0.55	0.49	0.62	0.48	
Membership in farmers' organizations (1=yes, 0=no)	0.85	0.35	0.90	0.30	0.74	0.44	***
Access to information through NGOs (1=yes, 0=no)	0.86	0.35	0.85	0.36	0.88	0.31	
Access to climate-information (1=yes, 0=no)	0.56	0.50	0.57	0.49	0.51	0.50	
Knowledge questions about the aquaculture (out of 10)	7	0.95	7	0.87	6	1.07	***
Costs and returns of production							
Total variable cost for fish production (USD/ha)	4289.17	5729.67	4455.55	6155.84	3809.89	4259.21	
Gross revenue (USD/ha)	7216.26	13940.41	7552.75	14449.66	6246.92	12367.56	
Gross margin (USD/ha)	2927.08	10821.98	3097.19	11363.56	2437.03	9113.23	
Average daily wage for family labor (USD)	2.58	25.72	3.09	29.70	1.09	5.08	

Notes: P-values less than 0.01, 0.05, and 0.1 correspond to ***, **, and *, respectively.

Source: Author's calculation

The regional differences, as indicated by the statistically significant region dummy, are partly due to distance and accessibility of transportation to extension offices. It may also be because Phyapon Township is closer to the Worldfish regional office and other local, international organizations, and cooperatives offices that provide support to SSA farmers. The positive and significant coefficient of distance to the point of sale indicates that households who have easier access to the market when selling their products have a higher probability of adopting the SA technologies. Participation in the local farmers' organizations is positive and statistically significant, probably because these organizations facilitate the flow of information about aquaculture production and new technologies. As shown in previous studies, information provision sources play a vital role in determining the decision to adopt technology (Abdulai, 2016; Di Falco et al., 2011).

4.4.4 Impact of SA technologies on the welfare outcomes of SSA households

We now turn to the outcome implications of the adoption of SA technologies. Estimates through the OLS model in columns 1, 5, and 9 of Table 4.2 suggest that there is no difference in log of fish yield per ha, HDDS, or TFCS between adopter and non-adopter households because the dummy variable adoption is positive and insignificant across all outcome equations. In this model, the adoption of the technology is assumed to be exogenous. However, as the decision to adopt could be influenced by both observable and unobservable factors that are not controlled for in the regression, the estimates from this model could be biased. Moreover, the results from this model do not explain the potential structural differences explicitly between the outcome functions of adopter and non-adopter households.

Regarding the estimates from the second stage of ESR model, the differences in the outcome equations coefficient between the adopters and non-adopters illustrates the presence of heterogeneity in the sampled households. Notable differences between the two household groups confirm that the switching regression model is more appropriate compared to data pooling in one regression for all outcome variables. The value of $\boldsymbol{\sigma_j}$ in the lower part of Table 4.2 is the square root of the variance of the error terms from the welfare outcome equations in all specifications. The significance of $\boldsymbol{\sigma_j}$ indicates the welfare outcomes of adopters and non-adopters are heterogeneous. The variables that explained this heterogeneity are presented in columns 3, 4, 7,8, 11, and 12 of Table 4.2.

In the log of fish yield per ha equation, while the variable representing access to off-farm activities has a positive and significant effect on fish yield of adopters, climate shocks negatively and significantly affect adopter's fish yield, but these effects are insignificant among non-adopters. A possible explanation for access to off-farm income variable is that as there are costs involved in adopting the new technology, having access to income from other sources can offer the necessary financial resources required for fish production activities, which, in turn, enhances fish yield. Then, about 60% of households' farm are affected by the climate shocks in previous fish production cycle that led to the production losses. The variable representing distance between the fish pond and homestead influences the fish yield for non-adopters negatively and significantly, but it has no significant impact on adopters. The reason distance is less of a problem for adopters could be because new technology, such as IAA, allows the pond to be more self-sufficient. For the non-adopters, nearer fish ponds have the advantage of enabling more frequent visits, which could facilitate input application and better management. This research finding is in line with the study by Assefa et al. (2020), which indicates that a short distance from the homestead to plot corresponds to lower yield gaps by prioritizing operation management, more inputs, and frequent visits. In addition, household head's age has significant and positive effect on the fish yield of non-adopters, but it no impact significant on the adopters. A possible explanation for the household head's age variable could be that older household head have more experience managing the fish pond to enhance the fish yield.

Regarding the estimates of the HDDS equation, the asset index is significant and positive for both adopters and non-adopters, indicating that the assets index as a proxy of wealth plays a crucial role in improving household dietary diversity. The age of the household head positively and significantly affects adopter's HDDS, but we do not find any impact for non-adopters. This indicates that HDDS is significantly higher among the adopters with an older household head. Likewise, the coefficient estimates in the TFCS equation appear to have impacts on adopters and non-adopters differently. While variables such as household size, location dummy, and access to information through non-government organizations (NGOs) affect the TFCS of adopters, the household head's age, asset index, and membership in an organization affect the TFCS of non-adopters. Regarding the results for the adopters, the estimates of the influence of household size on TFCS are in line with other studies, such as Parvathi (2018) and Asfaw et al. (2012) which observe that a larger family size increases household's dietary diversity, food consumption scores, and food consumption expenditure.

Chowdhury (2016) suggests that a larger family size implies the family labor availability, which is presumably more diligent and productive than hired labor. In addition, adequate knowledge and understanding of technology through access to information may increase the benefits from a technology. The region dummy variable is also significant and negative for the adopters. This indicates that adopter households in Phyapon consume a less diversified diet than households in the other selected townships.

For non-adopter households, we find a positive and significant link between the asset index and TFCS. Moreover, the TFCS is significantly higher among non-adopter households with an older household head. Interestingly, although participation in the farmers' organizations can lead to a better assessment of the information about enhancing fish productivity, it negatively affects the TFCS of non-adopters. This result implies that about 60% of households' farm are affected by the climate shocks in previous fish production cycle that led to the production losses, which in turn negatively affect the TFCS of the households.

The significance of likelihood ratio test for joint independence of the selection and outcome equations presented in the last row of Table 4.2 indicates that there is joint dependence between selection Eq (1) and outcome Eqs (2a) and (2b) for adopters and non-adopters, respectively. The value of ρ_j in the lower part of Table 4.2 shows the correlation coefficients between the error terms of the selection Eq (1) and the outcome functions (2a) and (2b). The significant outcome of ρ_j in all specifications indicates that the error terms between Eq (1) and Eqs (2a) and (2b) are correlated, indicating that selection bias occurred in the adoption decision. These results also highlight that both observable and unobservable factors influence the household's decision to adopt and welfare outcomes. Therefore, results from the ESR model support our assumption that adopting technology is endogenous and that using the ESR model is justified. The negative and significant sign of the covariance terms for ρ_j indicates positive selection bias, indicating that SSA farming households with an above mean fish yield per ha, HDDS, and TFCS are more likely to adopt SA technologies. This research finding is in line with empirical studies in agriculture sector by Abdulai (2016) and Abdulai and Huffman (2014).

Table 4.2: Parameter estimates of SA technologies adoption and welfare outcomes

	Log of fish yield per ha				Household Dietary Diversity Score (HDDS)				Total Food Consumption Score (TFCS)			
Explanatory variables	OLS	Adoption 1/0	Adopters	Non-adopters	OLS	Adoption 1/0	Adopters	Non-adopters	OLS	Adoption 1/0	Adopters	Non-adopters
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
SA technologies dummy (1=yes, 0=no)	0.051				0.180				1.194			
	(0.140)				(0.111)				(1.610)			
Age of household head (yrs)	0.005	-0.015**	0.006	0.020*	0.004	-0.010*	0.013**	0.003	0.082*	-0.015**	0.079	0.179*
	(0.005)	(0.006)	(0.007)	(0.012)	(0.004)	(0.006)	(0.006)	(0.009)	(0.042)	(0.006)	(0.055)	(0.093)
Household head education (yrs)	-0.009	0.007	-0.007	-0.032	0.025	0.016	0.021	0.052	0.105	0.006	0.143	0.071
	(0.026)	(0.031)	(0.030)	(0.059)	(0.020)	(0.030)	(0.027)	(0.046)	(0.192)	(0.031)	(0.255)	(0.470)
Gender of household head (1 = male, 0=female)	-0.049	0.194	-0.205	-0.093	0.438*	0.008	0.266	0.407	0.350	0.169	-0.547	-3.177
	(0.233)	(0.266)	(0.288)	(0.455)	(0.242)	(0.254)	(0.246)	(0.327)	(1.997)	(0.268)	(2.412)	(3.610)
Asset index	0.005	-0.033	-0.037	0.182	0.109**	-0.076	0.121*	0.239*	1.145*	-0.044	0.947	2.329**
	(0.067)	(0.082)	(0.080)	(0.152)	(0.049)	(0.078)	(0.069)	0.114	0.583	0.082	0.670	1.175
Access to off-farm activities (1=yes, 0=no)	0.174	-0.372**	0.340*	0.347	-0.008	-0.401**	0.165	-0.020	1.484	-0.374**	-1.205	0.459
	(0.152)	(0.171)	(0.201)	(0.314)	(0.118)	(0.168)	(0.161)	(0.245)	(1.283)	(0.171)	(1.601)	(2.516)

Household size (No.)	0.033	-0.001	0.030	0.045	0.035	-0.016	0.055	-0.002	0.557*	-0.010	0.650*	0.369
	(0.034)	(0.040)	(0.040)	(0.070)	(0.028)	(0.039)	(0.035)	(0.053)	(0.311)	(0.040)	(0.337)	(0.560)
Dependency ratio (%)	0.001	-0.004	0.002	0.002	-0.002	-0.003	-0.001	0.001	0.005	-0.004	-0.010	0.061
	(0.003)	(0.003)	(0.003)	(0.005)	(0.002)	(0.003)	(0.003)	(0.004)	(0.022)	(0.003)	(0.027)	(0.043)
Location dummy (1= Phyapon)	0.198	0.469***	0.185	-0.161	0.131	0.356**	-0.111	0.248	0.499	0.424***	-2.372*	0.067
	(0.133)	(0.156)	(0.184)	(0.308)	(0.110)	(0.153)	(0.140)	(0.240)	(1.229)	(0.156)	(1.374)	(2.716)
Climate shock(s) (1=yes, 0=no)	-0.327***	-0.257*	-0.254*	-0.264	0.050	-0.222	0.137	0.159	0.457	-0.220	0.441	-0.927
	(0.120)	(0.147)	(0.150)	(0.266)	(0.098)	(0.144)	(0.122)	(0.205)	(0.980)	(0.145)	(1.184)	(2.132)
Log of total owned agricultural land (ha)	0.042	0.063	0.097	-0.087	0.036	0.060	-0.038	0.015	0.241	0.045	-0.138	-1.049
	(0.045)	(0.052)	(0.067)	(0.083)	(0.033)	(0.051)	(0.053)	(0.060)	(0.422)	(0.052)	(0.536)	(0.663)
Pond distance from the homestead (walking minutes)	-0.026**	-0.013	-0.016	-0.044*	0.001	-0.004	0.007	-0.001	0.071	-0.008	0.180	0.046
	(0.011)	(0.013)	(0.014)	(0.024)	(0.009)	(0.014)	(0.012)	(0.018)	(0.107)	(0.013)	(0.114)	(0.194)
Distance to the point of sale (miles)	0.026**	0.072*	0.020	0.114	0.009	0.058*	0.004	0.019	0.019	0.066*	0.007	-0.128
	(0.013)	(0.039)	(0.014)	(0.081)	(0.006)	(0.034)	(0.012)	(0.064)	(0.101)	(0.038)	(0.114)	(0.657)
Access to information from NGOs (1=yes, 0=no)	-0.059	-0.167	-0.064	0.152	-0.202	-0.138	-0.074	-0.466	3.245**	-0.163	3.973**	1.961
	(0.180)	(0.229)	(0.204)	(0.441)	(0.152)	(0.215)	(0.179)	(0.336)	(1.377)	(0.226)	(1.707)	(3.543)

Access to climate information (1=yes, 0=no)	0.115	0.024	0.013	0.434	-0.114	0.064	-0.070	-0.262	3.230***	-0.002	3.053**	3.347
	(0.129)	(0.158)	(0.147)	(0.278)	(0.104)	(0.149)	(0.130)	(0.206)	(1.133)	(0.154)	(1.251)	(2.163)
Membership in farmers' organizations (1=yes, 0=no)	0.438**	0.547***	0.409	-0.068	0.277	0.370*	-0.191	0.291	2.320	0.476**	-2.280	-6.603**
	(0.181)	(0.200)	(0.299)	(0.352)	(0.172)	(0.208)	(0.211)	(0.258)	(1.425)	(0.203)	(2.104)	(3.145)
Knowledge about the aquaculture		0.230***				0.214**				0.227***		
		(0.070)				(0.071)				(0.075)		
Constant	7.089***	-0.722	7.307***	5.146***	9.289***	-0.576	9.864***	9.129***	51.666***	-0.535	54.135***	42.570
	(0.525)	(0.740)	(0.633)	(1.245)	(0.471)	(0.693)	(0.521)	(0.987)	(4.193)	(0.774)	(5.035)	(9.596)
σ_1 & σ_2			1.181***	1.526***			1.110*	0.956			9.993***	11.636
			(0.067)	(0.248)			(0.064)	(0.114)			(0.418)	(2.087)
ρ_1 & ρ_2			-0.223	-0.839***			-0.875***	-0.337			-0.143	-0.785***
			(0.438)	(0.113)			(0.06)	(0.375)			(0.199)	(0.163)
LR test of independent equations $\chi2$			5.09**				11.12***				1.32	

Notes: Numbers in the parentheses are standard errors. P-values less than 0.01, 0.05, and 0.1 correspond to ***, **, and *, respectively. Columns 1, 5, and 9 are estimated using OLS, while the remaining columns are estimated using endogenous switching regression (ESR).

Source: Author's calculation

Table 4.3 presents the expected household welfare outcomes (log of fish yield per ha, HDDS, and TFCS) from the adoption of SA technologies under actual and counterfactual conditions for SSA farming households. Cells (a) and (b) in Table 4.3 report expected outcomes in the actual condition, while (c) and (d) are in the counterfactuals. The expected log of fish yield per ha, HDDS, and TFCS are 7.87, 10.51, and 62.43, respectively, for adopters, and 7.69, 10.25, and 61.07, respectively, for non-adopters in the actual observed conditions. The average treatment effects of SA technologies on the adopters indicate that adopters (a) in the actual case would have produced 2.12 (that is 36.86 %) and consumed 0.62 (that is 6.28%) and 17.02 (that is 37.48%) less if they had not adopted this technology in the counterfactual case (c). Concerning the ATU, non-adopters (b) would have produced 0.49 (that is 6.39 %) and consumed 1.75 (that is 17.07%) and 4.45 (that is 7.29%) more if they had instead adopted SA technologies in the counterfactual case (d). These findings confirm that the adoption of SA technologies significantly and positively influence welfare outcomes of SSA households. However, although both adopters and non-adopters would benefit from adopting SA technologies, the adopters would benefit the most in terms of log of fish yield per ha and TFCS because ATT is larger than the ATU for these outcomes. Regarding the HDDS, the impact of SA technologies is more critical for non-adopters because ATU is larger than the ATT. All these differences are statistically significant at the 1% level.

Table 4.3: Average welfare outcomes for households in the actual and counterfactual condition

	Decision stage			Increase
	Adopters (N = 314)	Non-Adopters (N = 109)	Treatment effects	%
Log of average fish yield (kg/ha)[26]				
Adopters	(a) 7.87 (0.02)	(c) 5.75 (0.04)	ATT = 2.12 (0.05) ***	36.86
Non-adopters	(d) 8.18 (0.04)	(b) 7.69 (0.06)	ATU = 0.49 (0.07) ***	6.39
Household Dietary Diversity (HDDS)				
Adopters	(a) 10.51 (0.01)	(c) 9.88 (0.03)	ATT = 0.62 (0.03) ***	6.28
Non-adopters	(d) 12.00 (0.03)	(b) 10.25 (0.04)	ATU = 1.75 (0.05) ***	17.07
Total Food Consumption Score (TFCS)				
Adopters	(a) 62.43 (0.16)	(c) 45.41 (0.18)	ATT = 17.02 (0.24) ***	37.48
Non-adopters	(d) 65.52 (0.28)	(b) 61.07 (0.35)	ATU = 4.45 (0.46) ***	7.29

Notes: Numbers in the parentheses are standard errors. P-values less than 0.01, 0.05, and 0.1 correspond to ***, **, and *, respectively.
Source: Author’s calculation

4.4.5 Propensity score matching (PSM)

As estimates of the ESR model are sensitive to the choice of instrumental variables, we use PSM for the robustness check of results from the ESR model. We follow the guidelines and steps proposed by Caliendo and Kopeinig (2008) for implementing PSM. First, we estimate the propensity score by a probit model. Second, we use the radius caliper matching method, which is a commonly applied method and utilizes all neighbors within a given caliper to construct the counterfactual (Dehejia and Wahba, 2002). Cochran and Rubin (1973) suggest that the caliper size (c) should be the standard deviation(s)[27] of the propensity score. Next, we follow the standard approach for testing common support by comparing the groups' minimum

[26] The average fish yield per ha is the expected mean yield of adopters and non-adopters based on the ESR model's estimated coefficients. As the dependent variable in the fish yield equation is the logarithm of fish yield in kg per ha, the expected mean values are also displayed in logarithmic form. Converting the logarithmic form of mean values back to fish yield would not be accurate due to the inequality of geometric and arithmetic averages.

[27] Rosenbaum and Rubins' (1985) suggest one-fourth of the standard deviation (caliper=0.25 * sd).

and maximum propensity scores. Finally, we calculate the treatment effects and their standard errors through the bootstrapping method with 500 replications.

For brevity, we do not present detailed estimates of the probit model. Estimates of the common support region and propensity score distribution is displayed in Figure 4.1. The red bars show the distribution of propensity scores for adopters, blue bars show the distribution for non-adopters, and green bars shows off-support households. "Treated: on-support" shows the observations in the adoption group that have a matching pair of non-adopters. "Treated: off-support" shows the observations in the adoption group that do not have a matching pair of non-adopters (Shiferaw et al., 2014).

The estimated propensity scores range from 0.34 to 1.00, with a mean of 0.77 for adopters and range from 0.16 to 0.94, with a mean value of 0.66 for non-adopters. The common support region is between 0.34 to 0.94, which is the minimum and maximum value of the adopters and non-adopters. The farm households whose estimated propensity scores are less than 0.34 and larger than 0.94 are not considered in the matching. Therefore, where there is no overlap between adopters and non-adopters, matches cannot be made to calculate the ATT parameter. Figure 4.1 reveals substantial overlap in the propensity score distribution for adopters and non-adopters. Table 4.4 indicates the average treatment effects of SA technologies on SSA households' welfare outcomes. The results from PSM indicate that while adopting SA technologies has a significant impact on TFCS, it has no significant impact on the log of fish yield per ha and HDDS. Moreover, the ESR model estimates reveal a higher impact on all outcome variables compared with the estimates from PSM. This could be because the ESR model controls for both unobservable and observable factors, while PSM only controls for observable factors that are included in the probit regression when generating the propensity score.

Table 4.4: Average treatment effects through propensity score matching

Matching algorithms	Outcome variables	Means outcome variables		ATT difference
		Adopters (N = 314)	Non-adopters (N = 109)	
	Log of yield per ha [a]	7.84	7.82	0.02 (0.15)
	HDDS	10.52	10.39	0.13 (0.11)
	TFCS	62.58	60.16	2.42 (1.18) **

Notes: Numbers in the parentheses are the bootstrapped standard errors.

[a] The dependent variable for the fish yield equation is the log of yield in kg per ha.

P-values less than 0.01, 0.05, and 0.1 correspond to ***, **, and *, respectively.

Source: Author's calculation

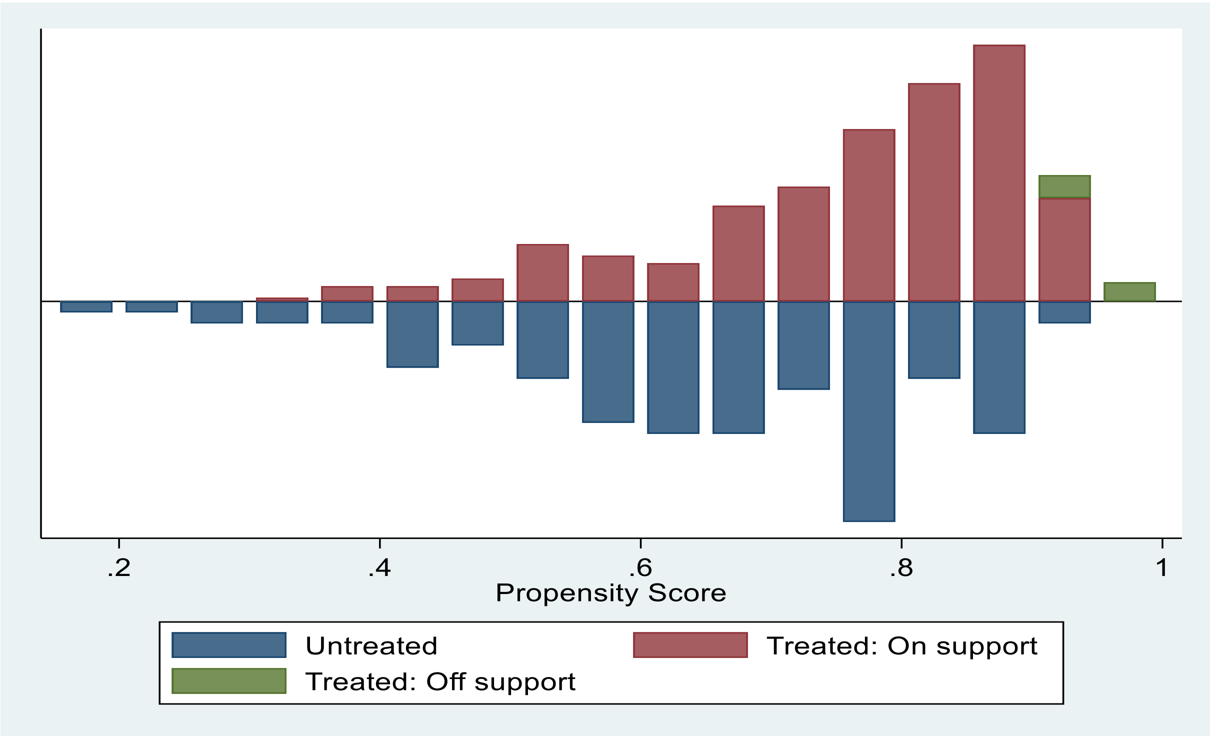

Figure 4.1: Distribution of propensity scores and common support area

Source: Author's calculation

4.5 Conclusions and policy recommendations

This study uses cross-sectional survey data of 423 SSA farming households to evaluate the driving factors behind SSA households' decision to adopt SA technologies and the impacts of this technological adoption on log of fish yield per ha, HDDS, and TFCS. The difference between adopters and non-adopters in the outcome variables and the estimates obtained from the OLS model could reflect the impact of technology adoption. However, when adoption relies on individual decision and is not randomly assigned, these assessments will lead to self-selection bias, as they do not consider the effects of unobservable factors. Therefore, the ESR model is applied to estimate the impact of SA technologies on welfare outcomes.

There are two main conclusions based on the analysis. First, "the adopters" of SA technologies in the study areas have systematically different characteristics from "the non-adopters." These structural differences indicate sources of variation between the adopters and non-adopters, but the estimation results of the OLS models cannot take these sources of variation into account. Therefore, using the OLS estimates for impact assessment in this case will lead to misleading conclusion. Second, results from the ESR model suggest that after taking into account for all confounding factors, the adoption of SA technologies positively and significantly influences the welfare outcomes of SSA households. However, among the adopters, SA technologies seem to be particularly important in improving their fish yield and food security with higher ATT in both fish yield and TFCS. The non-adopters would benefit the most in term of an increase in dietary diversity if they were to adopt the SA technologies, as the ATU for HDDS is higher than ATT.

As shown in the results, distance to the point-of-sale, membership in farmers' organizations, knowledge about aquaculture production, and location are the main drivers behind adopting SA technologies. Younger farmers are more likely to adopt the SA technologies because they are more willing to take risks. Households who sell their output in the main market have a higher probability of adopting SA technologies because they receive a fair or higher selling price. Therefore, enhancing market access for selling farm products and purchasing pond inputs is crucial to expand the adoption of new technologies. Moreover, membership in local farmer-based organizations may promote small-scale farmers' awareness about new technologies through information dissemination. This implies that the lack of information on new technology and limited knowledge of aquaculture production activities are barriers to adoption. Promoting knowledge through information dissemination programs may be a useful and effective policy to induce small-scale farming households to adopt SA technologies.

Although development organizations make great efforts to provide quality extension services to farmers, disseminated information has seldom flowed to diverse, resource-limited small-scale farming households. Therefore, the government should emphasize the strengthening of extension services and rural organizations to disseminate information and promote farmers' awareness and practical knowledge about SA technologies. Household welfare policy measures, such as improving access to information with other input support, strengthening local farmer organizations, and improving road infrastructure for better access to the main market, are paramount in encouraging the adoption of technologies. Widespread and successful adoption of aquaculture technologies among SSA farmers could not happen without the support of adequate and effective extension services. These research findings are particularly important for designing policies related to effective SA practices for SSA development. Future research based on randomized experimental data and/or action-research pond trials related to various SA technologies in Myanmar should be carried out to find out more about SA technologies that are suitable for small-scale fish farmers. More research efforts can help better understand the role of different aquaculture technologies and identify the most successful ones for SSA farmers.

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Chapter 5: Discussion and Conclusions

The rapidly growing aquaculture sector and simultaneous stagnation of capture fishery production are observed throughout the world. Even though Myanmar is one of the major consumers of fish and producers of aquaculture fish worldwide, to date, a holistic approach that considers the demand and supply side of Myanmar's aquaculture sector is rare. Therefore, this thesis investigated the disaggregated fish demand structure of household groups from a demand perspective, as well as determinants and implications of small-scale aquaculture sector performance and associated livelihood outcomes from the supply side. Estimated fish demand parameters across household groups at the micro-level are critical for understanding future demand and for providing policy advice and interventions to support sustainable fisheries and development of the aquaculture sector. Determinants and implications of performance in the small-scale aquaculture sector, as well as corresponding livelihood outcomes are important in designing programs and policies for small-scale aquaculture sector development and associated livelihood outcomes. In the remainder of the final chapter of this thesis, we provide a summary and general discussion on the thesis' overarching results and contribution to the existing literature before providing policy recommendations, limitations of the study, and an orientation for future research.

5.1 Summary of the main research findings and policy recommendations

5.1.1 Disaggregated fish demand structure by the specified household groups

Chapter 2 analyzes the fish demand system differentiated by fish source and household categories. Most studies have investigated fish demand at the aggregate-level, ignoring potential differences in consumption behavior across household groups. The most common problems related to the demand system estimation procedure are sample selection bias derived from zero observations and endogeneity. Empirical evidence suggests that the quality of the estimated demand parameters may depend on the statistical techniques, types of research dataset, and adopted assumptions (Okrent and Alston, 2011). Bronnmann et al. (2019) highlight that ignoring quality-adjusted price and the self-selection bias issue tends to be less elastic demand estimates. This fish demand study is the first to use available household-level survey data in Myanmar and fills this research gap by categorizing households into explicit wealth and location groups and by controlling for selection bias and endogeneity using multi-stage budgeting approaches combined with a Quadratic Almost Ideal Demand System (QUAIDS) model.

The findings show that disaggregated fish demand by all household groups will increase with income because fish is an essential food item in Myanmar's dietary patterns. A larger share of the demand for all sources of fish is expected to come from poor and rural households in the context of increasing income due to those household groups' higher income elasticity of demand. The income elasticity of aquaculture fish demand is estimated to be higher than that for other fish sources. This result holds true across all household groups. Therefore, aquaculture fish consumption will grow faster than that of capture fishery sources if household income increases in Myanmar. Based on the simulated results, the domestic market for aquaculture fish has considerable potential for long-term growth as urbanization, communication, and incomes improve and the productivity of capture fishery sources decline. The less elastic price elasticities of demand for poor and rural households in most cases explain that those households have less animal protein substitutes for fish available and accessible because fish, except for high-value fish species, is the cheapest type of animal protein source. Therefore, poverty alleviation programs that increase household income are more likely to have a positive impact on household fish consumption, which, in turn, can positively contribute to household food and nutrition security.

We also observe a growing aquaculture market in urban areas because aquaculture fish demand is the least responsive to changes in its own prices in urban households compared to other fish sources. Moreover, aquaculture fish demand for urban households is not as responsive to changes in price compared to that for rural households. Based on the quantity of fish consumption of urban households, they consume a significant amount of aquaculture fish, compared with other capture fishery sources. This implies that as urbanization continues and incomes grow, urban households will gain an increasing share of the aquaculture fish market due to the declining market share of capture fishery sources. Moreover, a higher degree of substitution for aquaculture fish from marine capture and dried fish indicates that households in Myanmar would turn towards purchasing more farmed fish in the face of higher prices for marine capture fish and dried fish. If the fish supply from aquaculture does not increase in response to an increase in fish demand and income, the aquaculture fish price will increase. This will affect household food security to a greater extent. Therefore, lower production costs and further product diversification of the aquaculture sector will be lower the general price level of fish and provide a broader range of consumer choices to meet local household demand.

Furthermore, we find that the price elasticity of fish demand from all sources is elastic, indicating that an increase in the production of all fishery sources is likely to increase fish producer's revenue. However, production efficiency, particularly for aquaculture farmers, needs to improve to generate profitable when they face the reducing prices that will accompany an increase in supply. Therefore, it is critical to retain and even expand the supports and incentives for these farmers to continue aquaculture production. The management policy and governance of capture fishery sources, if effective, is likely to increase revenue for capture fishery. A major contribution to the literature is the analysis of how the consumption patterns of disaggregated fish groups differ across household categories and how and to what extent the growing aquaculture production can compensate for declining capture fishery production to fulfill the increase in the demand for fish from an increasing population.

The findings in this chapter can be applied to provide policy recommendations to increase the fish supply from all sources. To sustainably increase aquaculture production over the long-run, the subsector needs to be competitive and inclusive to smallholders with accompanying land-use regulatory reforms, higher diversification of fish species, and new production technologies. The current "Farmland Law 2012" fails to consider aquaculture to be a form of agriculture. Hence, farmers who utilize agricultural land for other purposes legally must apply for a permission order ("La Ya 30 certificate"). This application process is bureaucratic, complicated, lengthy, and costly, which is preventing the potential for including aquaculture legally, particularly in smaller farms. The sampled SSA households report that most aquaculture farmers have few incentives to apply for this certificate because they are unlikely to be able to navigate the processes or afford legal assistance without outside help. Despite rapid growth in the sector, there is still little diversity of fish species (70% of all fish farms is dominated by "indigenous carp, Rohu") and production technologies. Therefore, the government needs to support research and development programs in the hatchery sector for a new generation of species and implementing the new or improved aquaculture technologies. Sustainable production from capture fishery sources can be achieved through improved monitoring, control, and surveillance that help to reduce overfishing and reinforce better capture fishery management and governance. Although development of the aquaculture sector has massive potential to positively contribute to household food and nutrition security, sustainable production from all fishery sources will be more beneficial than merely growth in one sub-sector. Moreover, investments and development in fish marketing and distribution systems are essential to bridge the supply-demand gap and ensure household accessibility with affordable prices. The empirical results can be fed into a multi-market partial equilibrium simulation model for further policy analysis. In addition, the results are useful for calibrating demand equations in fish foresight modeling studies to inform policies and decision-making to support sustainable fisheries and aquaculture development, which, in turn, can contribute positively to the Sustainable Development Goals.

5.1.2 The link between women's level of participation in the decision-making (WPDM) processes and the technical efficiency of small-scale aquaculture (SSA) farming

Chapter 3 examines the current technical efficiency level of SSA farming and the effect of gender aspects of the WPDM process on technical efficiency. Conceptually speaking, the technical efficiency of SSA farmers can be influenced by a combination of social, economic, and environmental characteristics of households. Although many previous studies have explored the effects of socioeconomic and production characteristics of households on technical efficiency, the effect of gendered aspects of intra-household decision-making on technical efficiency has not been examined yet. From a methodological perspective, two-stage double bootstrap data envelopment analysis (DEA) provides more accurate technical efficiency scores as well as valid statistical inferences for the determinants of the technical efficiency than the conventional DEA method. The results show that SSA households are operating their fish farms below the production frontier. All of the inputs used in production contained slacks, such that all of them are over-utilized in inappropriate ratios. The average bias-corrected efficiency scores of SSA farms in our study region in Myanmar is relatively low (0.44), compared to the average efficiency scores of fish farming in other countries, such as 0.58 in Taiwan (Chang et al., 2010) and 0.86 in Malaysia (Iliyasu and Mohamed, 2016).

Regarding the determinants of technical efficiency, while some of household characteristics, such as household head gender, pond size, production characteristics, and climate change adaptation strategies, are significant shifters to enhance efficiency, WPDM is also a significant factor for improving technical efficiency through alternative resource utilization. Other studies in the agricultural sector confirm this finding that although all indicators of women's empowerment measurement are essential for improving agricultural productivity, technical efficiency, and household food and nutrition security, WPDM has a more significant effect on these outcome variables (Zereyesus, 2017; Diiro et al., 2018;

Seymour, 2017). Engaging in aquaculture production activities improves the decision-making power of women within the household, as well as financial independence (Morrison et al., 2007). Diiro et al. (2018) report that the adult household members' bargaining power within a household depends on the utilization, access to and control over the resources. Strong bargaining power results in intensive participation in decision-making activities that may directly influence farming's technical efficiency and productivity through its effects on the ability of household members to allocate and organize resources optimally. Based on the empirical evidence, SSA in Myanmar is a suitable entry for empowering women because most small ponds in Myanmar are located in backyard plots, allowing women access to and control over household's productive resources, participation in decision-making process, and integration with home gardening, child care, and household chores. Moreover, implementing gender-responsive technologies, such as backyard dike vegetable gardening, WISH,[28] and Chan Myaung,[29] would motivate women to become more actively involved in production and decision-making processes.

This chapter contributes to the debate about the impact of the SSA sector on women's empowerment. In addition, it provides further evidence of the importance of decision-making power of women on the productive resource allocation of households for improving production efficiency. This study also suggests that even though the sampled households in this study received some support, such as inputs and necessary technologies from the project, they still face several constraints in improving their production efficiency. To overcome the current constraints of SSA farmers, the following recommendations can be provided based on the findings to promote government policies and intervention programs targeted at improving technical efficiency among SSA farming households. The inefficient and inappropriate ratio use of inputs results in higher production costs and contamination of the fish pond environment, which can have negative health and environmental implications. Therefore, cooperation with domestic or international organizations and government research institutes should be encouraged to generate fish feeding formula that corresponds to the stage of fish growth, fish culture, and species in Myanmar and to provide information on the suitable fish stocking density. This would help fish farms succeed economically and environmentally.

[28] The WISH ponds are "small ponds dug into permeable soil and lined with a plastic tarpaulin sheet bought locally" (Karim et al., 2020, P.3).
[29] Chan Myaung is "the local name of irrigation channels (both freshwater and brackish water) that crisscross the Ayeyarwady Delta regions, providing irrigation water for plants grown on the embankments" (Karim et al., 2020, P.3)

Due to the dominance of a single fish species in the aquaculture sector, the government needs to support and prioritize research and development programs in the hatchery sector for a new generation of species that have a relatively faster growth rate and shorter production cycle. Higher quality and diversification play a critical role in increasing options for both farmers and consumers. Through the country's economic and political transition, the government should offer incentives to private companies to make investments in the high-quality inputs sector through international standards and best management practices. Indeed, providing incentives to private input producers to be competitive and offer fair prices in the input market is crucial to foster competition and improve the quality of the supply of inputs, particularly in the fish seed and feed sector, and facilitate sustainable SSA sector development. In addition, strengthening extension services in the realm of best management practices, including climate change adaptation practices and input support initiated by the government, is crucial for improving SSA farming's technical efficiency. Polices and intervention programs targeted at improving aquaculture productivity of SSA households would benefit by including gender-inclusive intervention programs to improve women's empowerment.

5.1.3 Determinants of the adoption of sustainable aquaculture (SA) technologies and its impact on welfare outcomes of SSA farming households

Chapter 4 investigates the determinants and potential impacts of SA technologies, such as Integrated Aquaculture-Agriculture (IAA) and Modified Pond Management Practices (MPMPs), on welfare outcomes of SSA households using an endogenous switching regression (ESR) model to control for the self-selection bias problem due to the non-randomized nature of the experimental studies. The estimated results in the second stage of the ESR model reveal heterogeneity in the outcome variables between adopter and non-adopter households. Therefore, the coefficient estimates in all welfare outcome equations, except for the assets index, appear to impact the adopters and non-adopters differently. The significant value of the ρ_j highlights that the error terms of the selection (adoption) and outcome equations are correlated. These findings highlight that both observable and unobservable factors influence both the SA technologies adoption decision and welfare outcomes of the households. The results confirm that the ESR model is more appropriate than data pooling in a regression model.

The findings show that distance to the sale point, membership in farmers' organizations, knowledge about aquaculture production, and location are the main influencing factors in the household's technology adoption decision. The actual and counterfactual results of the ESR model show that the adoption of SA technologies increases SSA households' welfare outcomes measured by log of fish yield per ha, HDDS and TFCS. However, the adopters would benefit the most in terms of fish yield and TFCS from adopting the SA technologies because the average treatment effects of adoption for these outcome variables are larger for the adopters relative to the non-adopters. The non-adopters stand to benefit the most in terms of an increase in dietary diversity if they were to adopt the technologies, as the ATU is greater than ATT for the outcome variable of HDDS. This study suggests that instead of fish production in the traditional way, diversifying or modifying available assets and resources plays a vital role in improving the SSA sector and households' welfare outcomes. This study's empirical evidence contributes to the literature on the importance of SA technologies for improving welfare outcomes by providing micro-level information. This finding supports the claim that sustainably achieving production growth rate in the agriculture sector would not be possible without implementing yield improvement technologies/practices because traditional production practices or production area expansion alone are not enough to fulfill the demand of a gradually increasing population. The clear evidence of the adoption of SA technologies on farms is imperative if these practices are adopted and/or promoted by the government and other organizations.

Based on the findings of this chapter, we provide recommendations to policymakers. As mentioned in the literature, development in the institutional capacity to disseminate information and extension services is crucial to promote farmers' awareness and technical skills to adopt improved technologies, as well as to achieve the positive welfare impacts from the adoption of technologies (Di Falco et al., 2011; Abdulai and Huffman, 2014). The findings in this study highlight that both knowledge about aquaculture production and information sources are main drivers for technology adoption and improving household welfare outcomes. However, existing SSA farmers in Myanmar lack institutional support and extension services from the government. Although development organizations make great efforts to provide quality extension services to farmers, disseminated information has seldom flowed to diverse and resource limited SSA farmers. Therefore, the government should prioritize and support human resources development programs by allocating more resources to implement effective extension services and training programs. In addition, collaboration between government and non-government organizations may be an effective strategy to facilitate technical training and capacity development programs and provide effective extension services to farmers.

Widespread and successful adoption of SA technologies among SSA farmers could not happen without supporting improved extension services.

5.2 Limitations of this thesis and recommendations for future research

In the empirical studies in this thesis about demand and supply of aquaculture, a range of analytical techniques was employed. Each of these empirical studies has both strengths and limitations. Moreover, the detailed analysis of the institutional and policy environment governing the contextual factors concerning the demand and supply side of the aquaculture are not discussed in this thesis and thus require future research. The demand system presented in Chapter 2 that uses cross-sectional food consumption survey data at the household-level has limitations in terms of accuracy. First, recalls of food consumption captured all food that entered the household, but did not account for food that was not consumed by family members. Some food may have been given to hired laborers or guests and/or may have been wasted. This would thus result in an overestimation of a household's food intake. However, individual-level food consumption data is hardly available for developing countries. Second, the estimated results are based on the food commodities' unit values due to the inability to obtain food prices directly. Therefore, if the survey captures market prices paid by households for individual food items, estimation results could be more accurate. Despite the above limitations, our analysis can provide practical and vital information about the consumer demand structure and preferences for disaggregated fish species. As the analysis focused on primary fishery sources and then considered all low- and high-value fish species in the same source as one group, a potential field of future research is to disaggregate the consumption data covering four groups of fishery sources into smaller subgroups based on main species (e.g., Rohu, Hilsa, and other low-value species) within each group and explore its nutrient contribution (e.g., vitamins, minerals, and essential fatty acids). Moreover, this analysis was based on one-year fish consumption data. Hence, it is impossible to track the change in demand elasticities over time. This calls for future research using panel or longitudinal data.

The two-stage double bootstrap DEA method applied in Chapter 3 generates bias-corrected and more accurate technical efficiency scores than the conventional DEA method, as well as more valid statistical inferences for the determinants of the technical efficiency analysis in the second stage. Regarding women's empowerment, just the WPDM indicator was used due to a lack of information about other comprehensive women's empowerment indicators. Therefore, future research should consider alternative indexes, such as the comprehensive assessment of women's empowerment using the "*Women's empowerment in the Fisheries Index (WEFI)*" developed by World Fish or the "*Women's Empowerment in Agricultural Index (WEAI)*" developed by Feed the Future. The regression model could be improved with a larger sample size.

The ESR model used in Chapter 4 considers controlling for selection bias and endogeneity problems due to the non-randomized experimental studies to estimate better results. In addition, we also conducted propensity score matching (PSM) for checking the robustness of the ESR model's estimated treatment effects due to the sensitivity of the selection of instrumental variables in the ESR model. However, it is recommended that future impact assessment studies use randomized control trials to find out more evidence about the SA technologies suitable for SSA farmers. Regarding the food security measurement, standard food security measurements, such as HDDS and TFCS, were used in this thesis. However, there is still a debate in reporting the food security status using a single dimension due to food security's multidimensionality. Follow-up research should focus on the impact of aquaculture technologies on the four pillars of food security. Another attempt on the impact assessment of aquaculture technologies with panel data would provide useful evidence for policymakers to draw a generalization about changes in the effects of technology adoption on SSA households' welfare outcomes over time.

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Appendices

Table A1: Bartlett test of sphericity

factortest DM_IU, DM_HU, DM_N, DM_LA, DM_FI, DM_CI, DM_LI			
Determinant of the correlation matrix	Det	=	0.064
Bartlett test of sphericity	Chi^2	=	1149.247
	Degrees of freedom	=	21
	p value	=	0.000
	H0: variables are not intercorrelated		
Kaiser-Meyer-Olkin (KMO) sampling adequacy measurement	KMO	=	0.77

Note: DM=Decision-making, IU= Input use, HU=Harvest use, N=Nutrition, LA= Land allocation, FI=Fish income, CI=Crop income and LI=Livestock income

Source: Author's calculation

Table A2: Correlation of decision variables

WPDM regarding	IU	HU	N	LA	FI	CI	LI
IU	1						
HU	0.527***	1					
N	0.129***	0.305***	1				
LA	0.489***	0.381***	0.194***	1			
FI	0.298***	0.576***	0.313***	0.217***	1		
CI	0.288***	0.537***	0.304***	0.389***	0.776***	1	
LI	0.214***	0.395***	0.276***	0.296***	0.526***	0.607***	1

Note: IU= Input use, HU=Harvest use, N=Nutrition, LA= Land allocation, FI=Fish income, CI=Crop income and LI=Livestock income. P-values less than 0.01, 0.05, and 0.1 correspond to ***, **, and *, respectively.

Source: Author's calculation

Table A3: Factor analysis of decision variables

Factor	Eigenvalue	Proportion
Factor1	3.385	0.484
Factor2	1.121	0.160
Factor3	0.820	0.117
Factor4	0.665	0.095
Factor5	0.461	0.066
Factor6	0.362	0.052
Factor7	0.186	0.027

Source: Author's calculation

Table A4: Factor loadings and KMO results of the decision variables

Variable	Factor loading	KMO
IU	0.585	0.704
HU	0.785	0.834
N	0.475	0.899
LA	0.583	0.690
FI	0.808	0.725
CI	0.845	0.729
LI	0.703	0.892

Extraction method: PCA

Overall KMO: 0.77

Note: IU= Input use, HU=Harvest use, N=Nutrition, LA= Land allocation, FI=Fish income, CI=Crop income and LI=Livestock income

Source: Author's calculation

Table A5: Parameter estimates- validity test on the selection of instrumental variable

	Adoption 1/0 (selection equation)			Outcome functions by farm households that did not adopt		
	Log of yield per ha (kg)	Household dietary diversity (HDDS)	Total food consumption score (TFCS)	Log of yield per ha (kg)	Household dietary diversity (HDDS)	Total food consumption score (TFCS)
Knowledge about aquaculture production	0.242*** (0.072)	0.242*** (0.072)	0.242*** (0.072)	0.105 (0.118)	0.075 (0.099)	0.744 (0.955)
Chi^2	11.43***	11.43***	11.43***	F-stat = 0.78	F-stat = 0.58	F-stat = 0.61

Note: P-values less than 0.01, 0.05, and 0.1 correspond to ***, **, and *, respectively.

Source: Author’s calculation

CURRICULUM VITAE

Personal Details

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Present address	-	Department of Rural Development Theory and Policy (490a), Institute of Agricultural Sciences in the Tropics (Hans-Ruthenberg Institute), University of Hohenheim, Wollgrasweg 43, 70599 Stuttgart, Germany
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Academic Education

October 2017-present	-	Ph.D Candidate in Agricultural Economics, Department of Rural Development Theory and Policy (490a), Institute of Agricultural Sciences in the Tropics (Hans-Ruthenberg Institute), University of Hohenheim, Stuttgart, Germany
November 2009-December 2012	-	Master of Agricultural Science (Agricultural Economics), Department of Agricultural Economics, Yezin Agricultural University, Nay Pyi Taw, Myanmar
November 2005-September 2009	-	Bachelor of Agricultural Science (Agricultural Economics), Department of Agricultural Economics, Yezin Agricultural University, Nay Pyi Taw, Myanmar

Work Experience

Employer	-	Department of Agricultural Economics, Yezin Agricultural University, Nay Pyi Taw, Myanmar
Position:	-	Assistant Lecturer
Period	-	2012-till date

Conference, Workshop and Training Contributions

Conference

- Aung, Y.M., M. Zeller., L.Y.Khor., and N.Tran. (2020). Women's Role in Small-scale Aquaculture Sector and its Implications for Technical Efficiency: Empirical Evidence in Myanmar. Oral presentation at the International Conference on International Research on Food Security, Natural Resource Management and Rural Development. Tropentag 2020, virtual conference "Food and nutrition security and its resilience to global crisis".
- Theingi Myint and Yee Mon Aung (2017). Analysis of Pulses Industry Value Chain in Bago and Mon State, Myanmar. Poster presentation at the International Conference research on food security, natural resource management and rural development. Tropentag 2017. "Future agriculture: socio-ecological transitions and bio-cultural shifts". 20-22 September 2017 in Bonn, Germany.

Workshop and Training

- Training Seminar on "Stress and Time Management" held on 22 July 2019 at the Institute of Agricultural Sciences in the Tropics (490c), University of Hohenheim, Germany.
- Workshop on "Presenting your research in English" held on December 14th, 2018 at the Institute of Agricultural Sciences in the Tropics (490c), University of Hohenheim, Germany.
- Workshop on "Scientific writing" held on Oct 30th and December 4th ,2018 at the University of Hohenheim, Germany.
- Training Seminar on "Team Management and Accountability" held during 16-17 November 2017 at the Institute of Agricultural Sciences in the Tropics (490c), University of Hohenheim, Germany.

Project Participation

- Ph.D. Candidate in Worldfish project on the title of "Scaling Systems and Partnerships for Accelerated Adoption of Improved Tilapia Strains (SPAITS)," since Feb 2019

- Research assistant in international/local research projects in collaboration with Yezin Agricultural University
    - "Study on Per Capita Rice Consumption and Ratio of Household Expenditure in Myanmar" research project in 2016, funded by Myanmar Rice Federation
    - "Assessment of Supply Chain Management of Sesame in Selected Areas of Myanmar" research project in 2016, funded by Japan International Cooperation Agency (JICA)
    - "The Potential of Expanding Myanmar's Rice Exports to China" research project in 2015, funded by Economic Research Institute for ASEAN and East Asia
    - "Providing Insights in Myanmar Agricultural Farming to British American Tobacco project from 2013 to 2015", funded by British American Tobacco Company
    - "Determinants of Food Security of Vulnerable Rural Households at the Central Region, Myanmar" research project in 2015, granted by SEARCA Seed Fund for Strategic Research and Training (SFRT) Program
    - "Non-fishery Value Chain Study in Myanmar" research project in 2015, funded by HELVETAS, Swiss Inter-cooperation
    - "Socio-economic Survey Metrics and Indicators for Tracking in GRiSP (MISTIG) project from 2014 to 2015", funded by International Rice Research Institute (IRRI)

Scholarship Award

- German Academic Exchange Service (DAAD) June 2017- March 2021

Computer Skills

- MS Office, SPSS, STATA

Stuttgart/January 2021

(Place/date) Yee Mon Aung

Affidavit

pursuant to Sec. 8(2) of the University of Hohenheim's doctoral degree regulations for Dr.sc.agr.

1. I hereby declare that I independently completed the doctoral thesis submitted on the topic

An Economic Analysis of Fish Demand and Livelihood Outcomes of Small-scale Aquaculture in Myanmar

……………………………………………………………………………………………

2. I only used the sources and aids documented and only made use of permissible assistance by third parties. In particular, I properly documented any contents which I used - either by directly quoting or paraphasing - from other works.
3. I did not accept any assistance from a commercial doctoral agency or consulting firm.
4. I am aware of the meaning of this affidavit and the criminal penalties of an incorrect or incomplete affidavit.

I hereby confirm the correctness of the above declaration. I hereby affirm in lieu of oath that I have, to the best of my knowledge, declared nothing but the truth and have not omitted any information.

Stuttgart/January 2021

(Place/date) Yee Mon Aung