Willingness to Adopt Improved Shrimp Aquaculture Practices in Vietnam

Quach Thi Khanh Ngoc[a], Bui Bich Xuan[a,d], Erlend Dancke Sandorf[b]
Truong Ngoc Phong[a], Luong Cong Trung[c] , Tang Thi Hien[a]
[a]Faculty of Economics, Nha Trang University, Nha Trang, Vietnam
[b]Economics Division, Stirling Management School, University of Stirling, United Kingdom
[c]Institute of Aquaculture, Nha Trang University, Vietnam
[d]Norwegian College of Fishery Science, University of Tromsø The Arctic University of Norway, 9037, Tromsø, Norway
Corresponding author's e-mail address: ngocqtk@ntu.edu.vn

Abstracts

The shrimp industry plays a leading role in aquaculture development in Vietnam. Currently, the government is running a credit subsidy program to support farmers investing in improved production methods. This paper aimed to investigate white-legged shrimp farmers' willingness to invest in improved production methods and to examine whether the current government policy for the sector is in line with farmers' preferences using a discrete choice experiment. The results show that farmers do not care about the environmental impacts but emphasize increased yields and more successful crops as the main drivers of their willingness to invest. There is a mismatch between the current subsidized interest rate and farmers' required interest rate. These findings suggest that to promote better investment in improved production methods, the government should focus on the regulatory framework, monitoring and control of environmental impacts, and reevaluate the size of the credit subsidy.

Keywords: sustainability, shrimp aquaculture, improved aquaculture method, discrete choice experiment, Vietnam.

Introduction

Shrimp aquaculture is one of the fastest growing seafood industries in Vietnam and the industry has contributed significantly to the economic development of coastal areas (Jo et al., 2019) and made Vietnam the third largest shrimp aquaculture producer in the world by volume (Food and Agriculture Organization of the United Nations [FAO], 2018). However, despite the significant contribution of aquaculture to the economy, the rapid development of the industry has led to severe environmental impacts with the loss of 80% of mangrove forests over the last 50 years as the most prominent example (Thornton et al., 2009). Furthermore, the waste water from production is often discarded directly into the same water body serving as source water, which leads to severe and persistent disease outbreaks and economic losses to the farmers (Ministry of Agriculture and Rural Development [MARD], 2017). To combat this, farmers are using more than 30 different types of antimicrobials (antibiotics) in production, which raises significant concerns regarding food hygiene and safety (Thuy et al., 2011). This, combined with a rapid increase in the number of eco-certification schemes for aquaculture, which tighten the regulations and requirements for environmentally sustainable production process (Bush et al., 2013; Jonell & Henriksson, 2014), has led farmers to plan for more sustainable production methods and ultimately to reduce their negative environmental impacts.

Recently, the Vietnamese government passed the National Action Plan for Sustainable Aquaculture to encourage shrimp farmers to change from conventional aquaculture production practices to improved production practices and to promote implementation of certification systems for the industry (Republic of Viet Nam Government Portal [VGP], 2018). This is in line with the government's sustainable development goals focusing on productivity improvement and meeting market demand while at the same time protecting the environment. Furthermore, it indicates that the shrimp industry will be under a strategy for large scale development that considers the ecological characteristics of each region to increase productivity and quality of products, and to reduce the environmental impacts. The governmental policy also aims to establish a link between production and trade to enhance the efficiency and competitive strength of the sector, which enhances food security and helps alleviate poverty. Perhaps most notably, the government, through the State Bank of Vietnam, has appointed eight banks to provide 100,000 billion VND (4.31 billion USD) in support of a credit scheme to encourage investment in improved agriculture, but the scheme is open to shrimp aquaculture farmers as well. The credit scheme provides farmers with subsidized interest rates, where the subsidized interest is 0.5-1.5 percentage points below the market interest rate (8.2% for a year loan).[1] Conventional shrimp aquaculture is characterized by semi-intensive or intensive production, which depends mostly on regularly exchanged water and high antibiotic use to reduce the risk of harvest failure. Improved production methods, such as multi-stage farming, biofloc technology, and recirculating aquaculture system (RAS), on the other hand, advocate controlled antibiotic use or no-use of antibiotics during the production and treated water for reuse (Ministry of Agriculture and Rural Development [MARD], 2017).

Food and Agriculture Organization of the United Nations, (FAO, 2017) has created guidelines on how the aquaculture sector can achieve its sustainable development goals with comprehensive indicators for technical, institutional and policy changes. To help with the transition to becoming a sustainable economic sector, we need to understand better farmers' willingness and motivation to invest in and adopt sustainable production practices. Existing research shows that the challenge is multifaceted and that farmers' decision to adopt new sustainable technology depends on technical, social, and economic factors (Kumar et al., 2018). Previous studies investigating farmers' decision to adopt new technologies and practices often focus on farm characteristics and stocking density (Johnson et al., 2014; Engle et al., 2017), prejudices against organic production methods (Lasner & Hamm, 2011), consumers' interest in products that are produced in an environmentally friendly way (Perdikaris et al., 2016) or incentive based regulations for adoption (Nielsen, 2011; 2012). Other factors that may affect adoption, such as investment costs, potential yield, and income, are rarely investigated, with the exception of Whitmarsh et al. (2006); Ngoc et al. (2016); and Mitra et al. (2019).

In Vietnam, there has been quite a few studies focusing on the negative impacts of aquaculture on the environment (Nguyen et al., 2007, Thu et al., 2018, Bui et al., 2013, Tu et al., 2009), however, with a few notable exceptions, see e.g. Bosma et al. (2012) and Ngoc et al. (2016), they rarely explore farmers' decision to adopt new aquaculture practices. Bosma et al. (2012) carried out a study to investigate the factors influencing farmers' decision to adopt integrated rice-fish farming systems in the Mekong delta of Vietnam. They found that farmers who are neighboring irrigated fields and ponds, have more knowledge about rice-fish cultures and better access to loans are more willing to adopt rice-fish farming systems. Farmers' education and training level positively affects the probability of adopting rice-fish farming systems. Ngoc et al. (2016) investigated the determinants affecting the adoption of RAS by catfish farmers in Vietnam using a discrete choice experiment. The results from this study showed that the probability of adopting RAS is positively influenced by yield and the price premium associated with the Aquaculture Stewardship Council (ASC) certification while negatively affected by the initial investment cost. Furthermore, catfish farmers located in saltwater intrusion areas are more likely to adopt RAS relative to their freshwater counterparts. Both studies mainly explored the determinants influencing the farmers' decision to adopt improved production practices and indicated that the main barrier to adoption is the high investment cost.

It is unclear what the impact of the current government policy is, how advantages provided by improved aquaculture methods affect farmers' adoption decision and whether the government's credit subsidy scheme is in line with farmers' preferences. The impact of the improved shrimp aquaculture policy depends very much on whether farmers invest in improved production methods. This study, therefore, will add to the growing literature on sustainable aquaculture in Vietnam by investigating shrimp farmers' responses toward the government policy associated with sustainable shrimp aquaculture development by looking at their willingness to adopt improved production practices and level of the preferred credit subsidy. A discrete choice experiment is used to elicit farmers' preferences for different investment options using varying levels of the credit subsidy as the

[1] Market interest rate was issued by Agribank at the time of the survey design, July 2018.
x

compensation vehicle. This allows for comparison between the estimated subsidized interest rate and the current government subsidized interest rate to invest in improved production practices.

In standard economic theory, two common market-based instruments can be used to target and change behavior: taxes and subsidies. In Vietnam, an environmental fee levied at wastewater already exists, however, it is too small to induce farmers to change from conventional to improved farming methods. A clear policy is to increase the size of the environmental fee to strengthen the incentives to invest. However, given the social context, this is an infeasible alternative. Most aquaculture farms in Vietnam are small-scale household businesses without real access to investment capital to change their production methods. Increasing the fees is likely to leave shrimp farmers worse off with even less capital to put towards investment. A more feasible policy alternative is to expand upon the existing credit subsidy policy, where the government guarantees for the loan and subsidizes the interest rate for shrimp farmers who are willing to invest. A credit subsidy can be viewed as both good and bad. It is good when it helps achieve the desired goals and bad when it makes some sectors favored over others (Schrank & Keithly, 1999). Initially, credit subsidies help especially small-scale farmers adopt new technologies and reduce their disadvantage relative to large-scale farmers, who often have the financial capacity to be early adopters and can use the increased efficiency from new technology to undercut the competition by pressuring prices (Fan et al., 2008; Guillen et al., 2019). This is highly relevant in the Vietnamese context where 91.4% of farms are less than 1 ha (Anh et al., 2019).

Methodology

Discrete choice experiment

To evaluate the effects of different factors on farmers' decision to adopt improved aquaculture practices, a discrete choice experiment (DCE) was designed. A DCE is a stated preference technique where people are asked to make a sequence of choices among a finite set of policy alternatives described by a number of attributes. By varying the combination of attribute levels across alternatives and choice tasks, we can estimate shrimp farmers' preferences for each experimentally designed investment alternative by looking at how they make trade-offs when choosing among the available alternatives (Ortega et al., 2014; Ngoc et al., 2016).

There were two experimentally designed policy alternatives and an opt-out option (i.e., status quo). Each alternative was described by four attributes: change in yield, additional crop, reduced water exchange during production, and subsidized interest rate. The attributes were identified based on a review of the relevant literature and two focus group discussions with experts on white-legged shrimp farming and shrimp farmers.

Applying environmentally friendly improved production methods, such as water quality control methods and reduced use of antibiotics and biocides, may increase yields per crop. However, some improved methods require certain areas to be put aside for supply and water treatment ponds, which may reduce the area available for shrimp ponds and consequently reduce the yield per crop. The change in crop yield attribute captures this effect. With conventional shrimp farming, a successful farmer will have 1 to 2 crops per year, whereas with improved shrimp farming, the successful farmer may have 2 to 3 crops per year. The additional crop attribute captures this effect. The environmental impact from production is captured through the water exchange attribute. Conventional shrimp farming methods require farmers to change the pond water daily, whereas improved farming methods, which rely heavily on water treatment, allows for reuse of water and consequently much lower water exchange. This reduces the runoffs into common source waters and improves water quality. Investing in improved production methods is expensive and access to capital remain a barrier to many farmers. Currently, there is a credit subsidy scheme in place for agricultural investment that is also open to aquaculture investment. To capture the extent and scale of subsidy that induce farmers to switch from existing aquaculture methods, each investment alternative contains a subsidized (preferred) interest rate. An overview of the attributes and their levels is provided in Table 1.

Table 1. Attributes and levels of choice experiment

Attribute	Description	Levels

Yield	The crop yield change	-20%; -10%; 0; +10%; +20%
Crop	Added new crop per annum	0; 1
Water exchange	Average percentage of water exchanged per crop	10%; 15%; 20%; 25%; 30%
Interest rate	Preferential interest rate for a year loan	4.2%; 5.2%; 6.2%; 7.2%; 8.2%

Attributes and levels were combined into 15 choice tasks blocked into three blocks of 5 choice tasks each. An initial efficient design using zero priors was created. To increase the efficiency of the design, a pilot survey with 30 respondents was conducted to obtain more informative priors used to update the design. The design was optimized for the multinomial logit model and efficiency determined based on minimizing the d-error (Scarpa & Rose, 2008). Each respondent was randomly allocated into one of the three blocks. Prior to the discrete choice experiment, respondents were introduced to the attributes and their levels. They were asked to choose between the two experimentally designed alternatives and the status quo, i.e. the "I will not invest" option, and told that there are no right or wrong answers and that only their preferences matter. An example choice task is provided in Table 2.

Table 2. Example choice card.

Scenario 1	Plan A	Plan B	Plan C
Change in crop yield	20%	20%	*I would like to keep my current practice*
Added new crop per annum	1	0	
Water exchange level for each crop	15%	10%	
Per annum interest rate	4.2%	4.2%	
I choose			

Econometric model

The utility farmer *n* receives from choosing alternative *i* in choice task *t* can be expressed by the random utility function in Equation 1.

$$V_{nit} = \beta_n X_{nit} + \varepsilon_{nit}. \quad (1)$$

where β_n is a vector of utility weights to be estimated, X_{nit} is a vector of attribute levels, and ε_{nit} is an alternative-specific error term assumed to be independent and identically distributed following a type I extreme value distribution. Under standard assumptions this leads to the well-known multinomial logit model (McFadden, 1974). Assuming that respondent n choses their utility-maximising option out of a choice set $j = 1, \dots, J$ in any choice situation $t = 1, \dots, T_n$, the probability of recording a choice sequence $y_n = [y_{nt}, \dots, y_{nT}]$ is:

$$P(y_n|X_{nit}) = \prod_{t=1}^{T_n} \frac{exp(\beta X_{nit})}{\sum_{j=1}^{J} exp(\beta X_{njt})} \quad (2)$$

However, the multinomial logit model assumes that all farmers have the same preferences for investing in improved aquaculture. This is a very restrictive assumption. To take into account that farmers' preferences vary, mixed logit (MIXL) and latent class (LC) models are also estimated. In the mixed logit model, the coefficient β is a function of a set of parameters as follows (Train, 2002; Hensher & Greene, 2003) :

$$\beta_n = \beta + \Gamma\eta_n \quad (3)$$

where β is a vector of the population estimated mean, Γ is the estimated standard deviation/spread and η_n is a vector of draws from a specified distribution (Train, 2002). The mixed logit probability of the sequence of choices made by a farmer can be specified as the integral of the product of logit formula over all possible values of β:

$$P(y_n|X_{nit}) = \int \prod_{t=1}^{T_n} \frac{exp(\beta_n X_{nit})}{\sum_{j=1}^{J} exp(\beta_n X_{njt})} f(\beta|\theta) d\beta \quad (4)$$

Notice that the mixed logit model takes the panel structure of the data into account. The integral in Equation 3 does not have a closed form solution, but is approximated through simulation.

The LC model on the other hand does not require the analyst to make any assumptions about how preferences are distributed in the sample. The analyst has to decide on how many support points to estimate in each distribution, i.e. the number of classes. The model is based on the assumption that there is a finite number of different farmers in the world that have the same preferences. Effectively, the model assumes preference homogeneity within classes and heterogeneity between them (Greene & Hensher, 2013). The probability of the sequence of choices made by a given farmer is the expression in Equation 5:

$$P(y_n|X_{nit}) = \sum_{c=1}^{C} \pi(c|z_n) \prod_{t=1}^{T} \frac{exp(\beta_c X_{nit})}{\sum_{j=1}^{J} exp(\beta_c X_{njt})}. \qquad (5)$$

where β_c is the specific coefficient vector for class c and π_{nc} is the probability that farmers *n* belongs to class *c*.

All models are estimated in NLOGIT 6.0. In the present study, farmers' willingness-to-accept a subsidy (their preferred interest rate) to invest in improved production methods is calculated. Using a linear-in-the-parameters utility function, the marginal willingness-to-pay (MWTP) is simply the marginal rate of substitution between the non-monetary and monetary attribute, which here reduces to the negative ratio of the parameters. The formula is shown in Equation 6.

$$MWTP = -\left(\frac{\beta_k}{\beta_{interest\ rate}}\right) \qquad (6)$$

where β_k and $\beta_{interest\ rate}$ are the coefficients of k-th attribute and of the interest rate attribute. In the MIXL model, the willingness-to-pay is a ratio of distributions and needs to be simulated, whereas in the LC model, it is the weighted sum across classes, where the weights are the class probabilities. Farmers' marginal WTP, measured as a preferred interest rate, for a year loan can be used to assess their willingness to adopt improved production practices.

Data collection

The data was gathered by face-to-face interviews in April of 2019 from four provinces; Khanh Hoa, Ninh Thuan, Soc Trang, and Bac Lieu, where most of the white-legged shrimp production takes place. Each interview lasted approximately 20 minutes. The first part of questionnaire elicited general information on farming activities such as existing farming methods, size of the farm, production level, water exchange. The second part of the questionnaire was dedicated to perceptions and attitudes toward shrimp farming. The choice sets were presented in the third part followed by a set of standard socio-economic variables. A sample of 205 completed surveys was obtained.

Results

Characteristics of samples

Table 3 shows summary statistics for the sample. Most of the farmers in the sample are male with an average age of 49 and 17 years of shrimp farming experience. The majority have not finished secondary school, i.e. less than nine years of education. The average farm is 1.48 ha and the average household size is 4.58, and the mean monthly household income is 19.58 VND million (844 USD)[2].

Table 3. Summary statistics of farmer households in the sample.

Variable	Mean	Std. Dev./ share
Gender (%)		
Male	98.5	
Female	1.5	
Age of respondents (years)	49.11	9.69
Farming experience (years)	6.63	5.89
Education		
Not finished secondary school	126	61.75%
Secondary school and high school	45	22.07%
Professional qualification of degree	6	2.94%
Undergraduate degree	27	13.24%

[2] 1 USD = 23,195 VND

Farming Area (ha)	1.48	1.05
Labour (in persons)	4.51	3.56
Household size (members)	4.58	1.43
Monthly household income (million VND)	19.58	10.41
The number of respondents:		
Khanh Hoa	55	
Ninh Thuan	50	
Soc Trang	50	
Bac Lieu	50	

Reasons for the adoption of improved shrimp aquaculture

To better understand what underlies farmers' decision to invest and adopt improved aquaculture practices, information about their perceptions on the methods' advantages as well as their financial means and their knowledge and capacity to adopt the techniques were collected. Figure 1 reports farmers' perceptions of improved shrimp farming methods. A large share of farmers believed that improved production methods can help increase the price of shrimp (66.2%), control the spread of disease (81.5%), and allow them to use fewer antibiotics and pesticides (81%). Almost all of the farmers state that they are concerned about the water quality in the shrimp ponds. Furthermore, many farmers believe that they have the necessary knowledge to invest in, and adopt, improved production methods (69.3%), and that they can successfully apply improved practices on their own farm (57.1%). However, farmers' financial capacity to adopt improved aquaculture methods was remarkably low. Only 20.5% of the farmers indicated they have sufficient financial capacity to invest in improved farming practices.

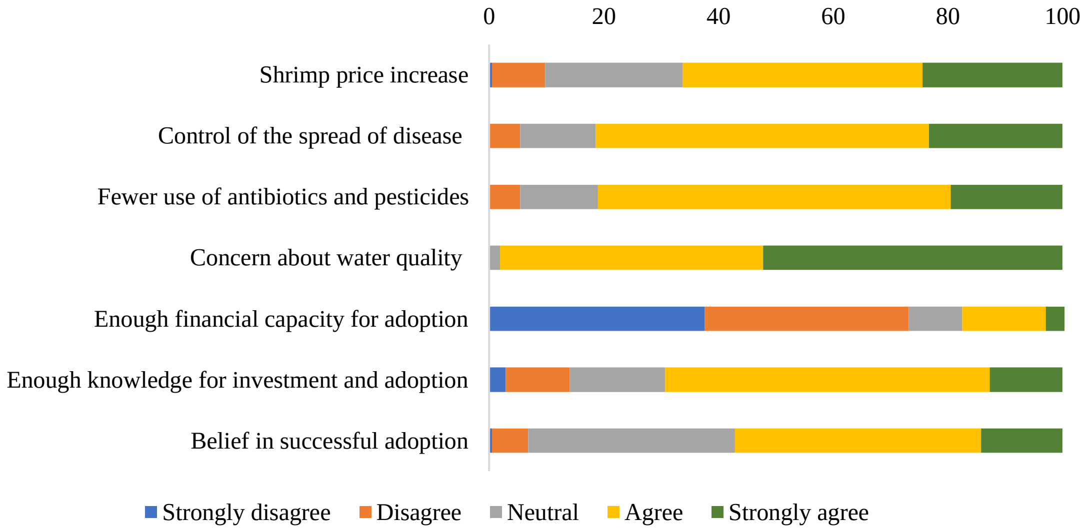

Figure 1. Perceived benefits and capacities for adoption of improved shrimp production practices (measured in %).

Farmers' preferences towards the adoption of improved shrimp aquaculture methods

Table 4 provides an overview of the variables entering the utility functions and their description. Because the crop yield attribute contained both increases and decreases in yield, and it would be expected that the signs are different, separate parameters are estimated. The average water exchange per crop is recoded based on farmer self-reported current water exchange such that it enters the model as a reduction in water exchange per crop. It is hypothesized that some farmers may be willing to accept a lower yield per crop if the reduction is offset by an increase in the number of crops. To capture this, an interaction term between yield and an additional crop is included. To address any potential opt-out or status quo effects, an alternative specific constant for the "I don't want to invest alternative" is included (Campbell & Erdem, 2018). In the MIXL model, 5000 Modified Latin Hypercube Sampling (MLHS) draws per respondent and random parameter were used to approximate the integrals.

Table 4. Descriptions of variables used in regression models.

Variables	Description
ASC	Alternative specific constant (1 = no-change option, 0 = management plan A or B)
YDDEC	Decrease in crop yield by 10% or 20%
YDINC	Increase in crop yield by 10% or 20%
CROP	Added new crop in year equal to 1
YIELDCROP	Interaction YIELD and CROP
WATER	Wastewater reduction in crop
INTEREST RATE	Per annum interest rate for the loan

Table 5 and 6 show the estimation of the MNL and MIXL model, and LC model, respectively. First, for the MNL model, all parameters have the expected sign. Farmers dislike an increase in the interest rate (a smaller subsidy in this case), and they prefer an additional crop and higher yields. They dislike a reduction in yield, but the positive and significant interaction term suggests that an additional crop may offset some of the disutility from reduced yield. They do care about the reduction in wastewater however the estimate is weakly significant ($P < 0.1$). Lastly, the estimate for the alternative specific constant is negative, large and significant, which indicates that farmers tend to choose one of the investment options.

The MNL model assumes independence from irrelevant alternatives (IIA) and ignores any heterogeneity between farmers. In the MIXL model, the parameters follow pre-specified distributions to capture unobserved preference heterogeneity among farmers. It is assumed that all farmers have positive utility associated with an increase in yield and negative utility associated with a decrease in yield and an increase in the interest rate (reduction in the subsidy). To accommodate this, these three parameters are assumed to follow constrained triangular distributions where the spread is constrained to be less than or equal to the mean. Alternatively, a log-normal distribution with and without sign change could have been assumed. However, the log-normal distribution tends to have a large mass close to zero and a long tail, which can result in quite implausible WTP estimates (Hensher et al., 2015)[3]. The parameters of the remaining attributes and the alternatives specific constant are assumed to follow normal distributions. Allowing for preference heterogeneity leads to a substantial and significant improvement in model fit, however, it cannot be ruled out that part of this improvement is because the MIXL model takes the panel structure of the data into account. While direct comparison of parameters is not feasible because the models are subject to different scaling, some general remarks should be made. The means of the preference distributions have the same sign, except for water exchange, and are of roughly the same magnitude as the estimates in the MNL model, except for perhaps decrease in crop yield and wastewater reduction.

Looking at the distributions for the additional crop and increase in crop yield, the means are positive and highly significant and the spread is equal to the mean. This indicates that there is significant heterogeneity with respect to this attribute with half the farmers having stronger preferences and half the farmers having weaker preferences relative to the mean. Interestingly, when considering preference heterogeneity, both the mean and spread of decrease in crop yield are insignificant. This indicates that farmers who are willing to invest in high tech production practices do not care about the possible reduction in yield, on average.

The interaction between yield and an additional crop is large and significant, but the standard deviation is insignificant indicating little heterogeneity. It is not particularly surprising and is possibly the result of an additional crop always being desired regardless of whether it comes with an increase or decrease in yield. Indeed, failure rates of crops under conventional farming is so high, that even one additional successful crop is very important to farmers.

Table 5. Estimation results for the MNL and MIXL models

[3] A MIXL model was also estimated, in which the random parameters followed normal distributions and were correlated, but the model fit did not improve from the current MIXL model and the random parameters were weakly correlated. A MIXL model in WTP space did not converge.

	MNL Model		MIXL Model			
	Mean	S.E.	Mean	S.E.	SD	S.E.
Parameters						
INTEREST RATE	-65.314***	5.108	-71.104***	6.692	71.104***	6.692
CROP	0.889***	0.1414	1.060***	0.137	1.060***	0.137
YDDEC	-0.413**	0.171	-0.175	0.205	0.175	0.205
YDINC	1.869***	0.172	2.394***	0.248	2.394***	0.248
YIELD.CROP	2.451***	0.689	2.756***	0.786	1.209	2.970
WATER	0.733*	0.394	-0.424	0.729	1.762	2.206
ASC_SQ	-3.654***	0.321	-4.686***	0.495	0.683	0.426
Model statistics						
Observation	1025		1025			
Parameters	7		14			
Log L	-841.497		-816.295			
Likelihood ratio test			50***			
AIC/N	1.656		1.612			
BIC/N	1.689		1.660			
McFadden R-squared	0.197		0.275			

Notes: ***, **, * ==> Significance at 1%, 5%, 10% level of confidence; S.E.=standard error; SD=standard deviation

The mean of the distribution for wastewater reduction is negative, but insignificant, which indicates that, on average, farmers do not care particularly about reducing wastewater, and while the standard deviation is large, it is also insignificant. The mean of the distribution for the ASC is negative and large, which indicates that farmers prefer either of the experimentally designed alternatives over the opt-out option implying that they are likely to invest in improved production methods. Furthermore, there is very little heterogeneity with respect to this behavior as evident by the insignificant standard deviation. The conventional shrimp aquaculture industry in Vietnam has faced major challenges with disease and water pollution, which is a strong contributor to why farmers have looked to alternative production methods and species.

Results of the LC model with two latent classes are reported in Table 6. The LC model fits the data better compared to the MIXL model. Choosing the correct number of classes to estimate implies trading off economic feasibility with statistical fit. In this case, moving beyond two classes led to numerical instability and implausible signs for the interest rate coefficient in one of the classes. Farmers in Class 1 are likely to be indifferent to alternative investments as evident by the very large, negative and insignificant ASC, but they are very sensitive to changes in the interest rate. Except for wastewater reduction, none of the other parameters in Class 1 are significant. Those in Class 2, on the other hand, are likely to invest in improved production methods. This is also the largest class comprising roughly 67% of respondents. The fact that most parameters are significant and of the expected signs, indicate that farmers in this class have made trade-offs. While models cannot be compared directly, it can be noted that the parameter estimates are of the same sign, significance and rough magnitude as the MNL results and means in the MIXL model, which suggests a certain convergence of estimates between different model specifications.

Table 6: Estimation results from the Latent Class Model

Variables	**Class 1**		**Class 2**	
	Coef.	**s.e.**	**Coef.**	**s.e.**
CROP	45.551	195.048	0.506***	0.133
YDDEC	35.204	194.755	-0.343*	0.198
YDINC	72.738	292.806	1.028***	0.204
YIELD.CROP	199.079	974.198	1.590**	0.764
WATER	-32.685*	19.429	0.769	0.476
INTEREST RATE	-718.755*	377.886	-55.3950***	5.604
ASC_SQ	-11.055	194.983	-3.318***	0.346

Class probability	0.33	0.67
LL function	-783.629	
Choice sets	1025	
Respondents	205	
MF R-sq	0.304	
AIC/N	1.558	

Notes: ***, **, * ==> Significance at 1%, 5%, 10% level of confidence.

MWTP results

Table 7 presents the derived marginal willingness-to-pay estimates from the MNL, MIXL and LC models. The marginal willingness-to-pay from the MNL and LC models were estimated using the formula in Equation 5 and standard errors were obtained using the Delta method. We report the simulated mean, median and 2.5 and 97.5 percentiles of the simulated willingness-to-pay distributions from the MIXL model.

The mean MWTPs[4] associated with the three parameters (YDINC - increase in crop yield by 10 or 20 %, CROP - additional crop, and YIELDCROP - interaction YIELD and CROP) in the MIXL model were significant, i.e., the 2.5 and 97.5 quantiles do not overlap zero, which implies that farmers are willing to pay for the increase in productivity as a result of investing in improved aquaculture methods. Specifically, the farmers are willing to pay for the increase in crop yield at an interest rate of 5.2% for a year loan. However, they are only willing to pay 2.3% of the interest rate for the added new crop. The estimates of decrease in crop yield and wastewater reduction parameters were insignificant, hence the MWTPs of related attributes were insignificant. All significance tests were conducted using the Wald test statistic.

Table 7. Marginal willingness-to-pay

	MNL Model		**MIXL Model**				**LC Model**			
							Class 1		**Class 2**	
	Mean	95% C.I.	Mean	Median	2.5% quantile	97.5% quantile	Mean	95% C.I	Mean	95% C.I
CROP	0.014	[0.010; 0.017]	0.023	0.015	0.002	0.080	0.063	[-0.467; 0.594]	0.009	[0.005; 0.014]
YDDEC	-0.006	[-0.011; -0.001]	-0.002	-0.002	-0.002	-0.002	0.049	[-0.482; 0.580]	-0.006	[-0.013; 0.001]
YDINC	0.029	[0.024; 0.034]	0.052	0.034	0.005	0.182	0.101	[-0.695; 0.897]	0.019	[0.012; 0.025]
YIELD.CROP	0.037	[0.017; 0.058]	0.048	0.037	0.004	0.155	0.277	[-2.377; 2.931]	0.029	[0.001; 0.055]
WATER	0.011	[-0.001; 0.023]	-0.009	-0.008	-0.077	0.057	-0.045	[-0.055; -0.036]	0.014	[-0.003; 0.031]

The mean MWTP from the LC model are overall lower compared to those from the MIXL model. The class specific MWTP is reported, however, the sample level (weighted sum) is straight forward to calculate. Farmers in Class 1 would request a compensation equal to 4.5% of the investment in improved aquaculture methods to reduce wastewater compared to insignificant MWTP in Class 2. Farmers were willing to pay for an additional crop an interest rate of 0.9% and for an increase in crop yield an interest rate of 1.9%. They may also adopt the improved methods, accepting the loss in production in exchange for a compensation of 0.6% of the investment.

The difference between the mean MWTP value for each attribute and the market interest rate for a year loan (8.2%) is the subsidized interest rate required for shrimp farmers to invest in improved aquaculture practices in Vietnam. As such, for the MIXL model, if the crop yield would be increased from adoption, the government needs to provide the subsidized interest rate of 3.0% (3.0% = 8.2% - 5.2%) on loans investing in the improved methods for farmers. As for the additional crop, the interest rate subsidy level is higher, with 5.9% (5.9% = 8.2% - 2.3%) on loans indicating that farmers have more motivation to adopt improved shrimp aquaculture regarding the crop yield compared to the additional crop. For the LC model, the subsidized interest rate for adoption will equal 7.3% if adoption can help to increase number of crop and equal 6.3% if the adoption can bring higher production for farmers in Class 2.

[4] The mean MWTP is the interest rate for a year loan that farmers are willing to pay for particular attribute regarding improved aquaculture methods.

Discussion and conclusions

Environmental and productivity challenges with aquaculture production in Vietnam is likely to continue for the foreseeable future. Farmers' decision to invest in improved aquaculture methods are driven by their willingness-to-pay for the investment. For example, farmers lack access to affordable capital and, if the barrier to invest is too high, then what is their willingness-to-accept a subsidy to make the investment? For this reason, it is important to understand farmers' preferences for different aspects of an investment option to better understand what drives any given farmer's decision to invest. In the present study, a discrete choice experiment is applied to explore the use of a credit subsidy, which is in line with current governmental policies. The majority of farmers are interested in improved aquaculture methods, which indicates that there is a potential to promote adoption of improved technologies for shrimp aquaculture in Vietnam. It is clear from the results that the important drivers of this willingness-to-invest are the potential improvements in yield and the possibility of an additional crop. It is a bit surprising that farmers do not appear to place any emphasis on the reduced wastewater, which would improve the quality of the water source. It is possible that this reflects a tragedy of the commons situation where no individual farmer has the incentive to reduce his exchange of water if no-one else does. It is also possible that this lack of weight on wastewater stems from a lack of knowledge about the potential benefits this yields and how improved production methods work. It is the belief of authors that this result reflects the need for better management for wastewater, and perhaps a policy or information campaign targeting the reduction of wastewater discharge from the aquaculture industry.

Perhaps most importantly, this study highlights the need to design a more appropriate credit subsidy scheme and policies that aim to support farmers who are willing to adopt improved shrimp farming methods. The current interest rate for year loans to invest in improved agricultural practices is equal to 6.5% per year. This is much higher, i.e. a smaller subsidy, compared to what the results of the present study suggest. Furthermore, applying for a loan with a preferential interest rate is a complex and rigid process, which is another barrier faced by many farmers, who on average have less than 9 years of education. As an additional complication, farmers often use agricultural land as the collateral, however the assets attached to agricultural land have not been certified for ownership to carry out procedures for registration of secured loans. Additionally, many farmers are unable to meet the loan conditions due to inadequate business and production plans (Belton et al., 2011; Marschke & Wilkings, 2014). All of these factors have led to difficulties in accessing the preferential interest rate/credit subsidy program.

The results presented here provide immediate implications for the development of shrimp aquaculture in Vietnam and point towards some apparent routes to design policy schemes that will increase investment in improved aquaculture production methods. Going forward it is important to take into consideration, economic, social and technical challenges. Furthermore, the results suggest that the government may need to revise the level of the credit subsidy as well as provide better information on how to apply for loans. A credit subsidy scheme could provide a good incentive and encourage shrimp farmers to invest in improved aquaculture methods. However, provision of subsidies has been debated as it is not likely to increase economic welfare (Binswanger, 1980) and it may kill innovation (Duflo et al., 2011; Kumar et al., 2018). Therefore, the provision of a credit subsidy should only be used in the early stages of technological development to help offset the risk of investment and potential compensate for losses (Omotilewa et al., 2019). Furthermore, additional benefits may be had with an expansive policy that help farmers target domestic and export markets where consumers are willing to pay a price premium for eco- and environmentally friendly labeled products. This policy would do well to recognize the inter-linkage between stakeholders along the supply chain to encourage farmers to switch production methods. Since the aquaculture development plans have been, and continue to be, put in place in different regions in Vietnam, it is essential to consider the natural conditions and scale of shrimp aquaculture of each region. With different improved aquaculture methods, the farming technology applied for each area should offer the shrimp industry a sustainable measure to simultaneously address environmental and socioeconomic issues associated with its growth.

Farmers are generally more concerned about the pressing issues of subsistence and income. Therefore the government faces the challenge of balancing growth in demand with environmental and social sustainability (Bush et al., 2009; Anh et al., 2019). The shrimp aquaculture industry requires a framework of regulation, control and monitoring of environmental impacts for further sustainable development. The regulations for shrimp farming should not only control effluent flows from aquaculture but also incorporate standards and certification in environmental governance. While the Vietnamese government still struggles to ensure compliance, a participatory approach that brings together farmers, processors and retailers to make the interrelations within the governance system could be a promising strategy for shrimp aquaculture industry (Anh et al., 2011).

Previous studies have valued new culture systems using economic feasibility analysis (Campo & Zuniga-jara, 2018) or bioeconomic modelling to analyze the improved efficiency of new methods on aquaculture management and economic viability (Llorente & Luna, 2015). This paper applies a stated preference experiment to elicit farmers' willingness-to-adopt improved aquaculture methods and discuss the implications for the design of a subsidy program aiming to promote adoption. Due to the heterogeneity with respect to the interest rate attribute, any subsidy program needs to take into account that farmers value different aspects of the subsidy program differently. This information is very helpful to improve the cost-effectiveness of the current subsidy program in Vietnam. That said, there are challenges associated with the application of choice experiments in developing countries, especially in rural poor areas with the use of monetary WTP and payment vehicles (Rigby & Russell, 2016). However, the present study indicates that CE can be a useful tool for policy planning in developing countries. The choice experiment survey evaluated different aspects of improved aquaculture methods. It thereby can integrate farmers' preferences into decision making, helping managers identify appropriate management scenarios for management of aquaculture and opportunities for income generation for farmers.

References

Anh, P. T., Bush, S. R., Mol, A. P. J., & Kroeze, C. (2011). The Multi-Level Environmental Governance of Vietnamese Aquaculture : Global Certification , National Standards , Local Cooperatives. *Journal of Environmental Policy & Planning*, *13*(4), 373–397. https://doi.org/10.1080/1523908X.2011.633701

Anh, T., Nguyen, T., Anh, K., Nguyen, T., & Jolly, C. (2019). Is Super-Intensification the Solution to Shrimp Production and Export Sustainability ? *Sustainablility*, *11*(5277), 1–22.

Belton, B., Haque, M. M., Little, D. C., & Sinh, L. X. (2011). Certifying catfish in Vietnam and Bangladesh: Who will make the grade and will it matter? *Food Policy*, *36*(2), 289–299. https://doi.org/10.1016/j.foodpol.2010.11.027

Binswanger, H. P. (1980). Attitudes toward risk: Experimental measurement in rural India. *American Journal of Agricultural Economics*, *62*(3), 395–407.

Bosma, R. H., Nhan, D. K., Udo, H. M. J., & Kaymak, U. (2012). Factors affecting farmers' adoption of integrated rice – fish farming systems in the Mekong delta , Vietnam. *Reviews in Aquaculture*, *4*(3), 178–190. https://doi.org/10.1111/j.1753-5131.2012.01069.x

Bui, T. D., Luong-van, J., Maier, S. W., & Austin, C. M. (2013). Assessment and monitoring of nutrient loading in the sediments of tidal creeks receiving shrimp farm effluent in Quang Ninh , Vietnam. *Environmental monitoring and assessment*, *185*(10), 8715–8731. https://doi.org/10.1007/s10661-013-3207-2

Bush, S. R., Little, D. C., Bush, S. R., Belton, B., Hall, D., Vandergeest, P., Murray, F. J., Ponte, S., Oosterveer, P., Islam, M. S., Mol, A. P. J., Hatanaka, M., Kruijssen, F., Ha, T. T. T., Little, D. C., & Kusumawati, R. (2013). Certify Sustainable Aquaculture? *Science*, *341*(6150), 1067–1068. https://doi.org/10.1126/science.1237314

Bush, Simon R, Khiem, N. T., & Sinh, L. X. (2009). Governing the Environmental and Social Dimensions of Pangasius Production in Vietnam : A Review. *Aquacutlture Economics & Management*, *13*, 271–293. https://doi.org/10.1080/13657300903351594

Campbell, D., & Erdem, S. (2018). Including Opt - Out Options in Discrete Choice Experiments : Issues to Consider. *The Patient - Patient-Centered Outcomes Research*, *12*(1), 1-14.

https://doi.org/10.1007/s40271-018-0324-6
Campo, S. R., & Zuniga-jara, S. (2018). Reviewing capital cost estimations in aquaculture. *Aquaculture Economics & Management*, *22*(1), 72–93. https://doi.org/10.1080/13657305.2017.1300839
Duflo, E., Kremer, M., & Robinson, J. (2011). Nudging farmers to use fertilizer: Theory and experimental evidence from Kenya. *American economic review*, 101(6), 2350-90.
Engle, C. R., Minh, H. N., Tinh, H. Q., Racine, P., Viriyatum, R., McNevin, A., Boyd, C. E., & Paungkaew, D. (2017). Economics of Sustainable Intensification of Aquaculture: Evidence from Shrimp Farms in Vietnam and Thailand. *Journal of the World Aquaculture Society*, *48*(2), 227–239. https://doi.org/10.1111/jwas.12423
Fan, S., Gulati, A., & Thorat, S. (2008). Investment, subsidies, and pro-poor growth in rural India. *Agricultural Economics*, *39*(2), 163–170. https://doi.org/10.1111/j.1574-0862.2008.00328.x
Food and Agriculture Organization of the United Nations. (2017). *Aquaculture, The Sustainable Development Goals (SDGs)/Agenda 2030 and FAO'S Common Vision for Ssustainable Food and Agriculture* (Issue August).
Food and Agriculture Organization of the United Nations. (2018). *The State of World Fisheries and Aquaculture*. UN FAO Fisheries and Aquaculture Department, Rome.
Greene, W. H., & Hensher, D. A. (2013). Revealing additional dimensions of preference heterogeneity in a latent class mixed multinomial logit model. *Applied Economics*, *45*(14), 1897–1902. https://doi.org/10.1080/00036846.2011.650325
Guillen, J., Asche, F., Carvalho, N., Fernández Polanco, J. M., Llorente, I., Nielsen, R., Nielsen, M., & Villasante, S. (2019). Aquaculture subsidies in the European Union: Evolution, impact and future potential for growth. *Marine Policy*, *104*(March), 19–28. https://doi.org/10.1016/j.marpol.2019.02.045
Hang, P. T. T., Rossi, P., Dang, H., Dinh, K., Tu, N., & Pham, A. (2018). Analysis of antibiotic multi-resistant bacteria and resistance genes in the ef fl uent of an intensive shrimp farm (Long An , Vietnam). *Journal of Environmental Management*, *214*, 149–156. https://doi.org/10.1016/j.jenvman.2018.02.089
Hensher, D. A., & Greene, W. H. (2003). The Mixed Logit model : The state of practice. *Transportation*, *30*, 133–176.
Hensher, D. A., Rose, J. M., & Greene, W. H. (2015). *Applied Choice Analysis*. Cambridge University Press.
Jo, O. M., Poortvliet, P. M., & Klerkx, L. (2019). To cluster or not to cluster farmers ? In fl uences on network interactions , risk perceptions , and adoption of aquaculture practices. *Agricultural Systems*, *173*, 151–160. https://doi.org/10.1016/j.agsy.2019.02.011
Johnson, K., Engle, C., & Wagner, B. (2014). Comparative economics of US catfish production strategies: Evidence from a cross-sectional survey. *Journal of the World Aquaculture Society*, *45*(3), 279–289. https://doi.org/10.1111/jwas.12117
Jonell, M., & Henriksson, P. J. G. (2014). Mangrove-shrimp farms in Vietnam-Comparing organic and conventional systems using life cycle assessment. *Aquaculture*, *447*, 66–75. https://doi.org/10.1016/j.aquaculture.2014.11.001
Kumar, G., Engle, C., & Tucker, C. (2018). Factors Driving Aquaculture Technology Adoption. *Journal of the World Aquaculture Society*. https://doi.org/10.1111/jwas.12514
Lasner, T., & Hamm, U. (2011). Ecopreneurship in Aquaculture – The adoption of organic fishfarming methods. *Organic Is Life Knowledge for Tomorrow*, *2*, 72–75.
Llorente, I., & Luna, L. (2015). Bioeconomic modelling in aquaculture: an overview of the literature. *Aquaculture International*, *24*(4), 931–948. https://doi.org/10.1007/s10499-015-9962-z
Marschke, M., & Wilkings, A. (2014). Is certification a viable option for small producer fish farmers in the global south? Insights from Vietnam. *Marine Policy*, *50*, 197–206. https://doi.org/10.1016/j.marpol.2014.06.010
McFadden. (1974). *Frontiers in econometrics, economic theory and mathematical economics* In P.

Zarembka (Ed.), *Frontiers in econometrics* (pp. 105–142). https://doi.org/10.1080/07373937.2014.997882

Ministry of Agriculture and Rural Development. (2017). *Overall Project: Developing Vietnam Shrimp Industry by 2030*.

Mitra, S., Khan, M. A., & Nielsen, R. (2019). Credit constraints and aquaculture productivity. *Aquaculture Economics and Management*, *23*(4), 410–427. https://doi.org/10.1080/13657305.2019.1641571

Ngoc, P. T. A., Meuwissen, M. P. M., Cong, T., Bosma, R. H., Verreth, J., & Oude, A. (2016). Adoption of Recirculating Aquaculture Systems in Large Pangasius Farms : A Choice Experiment. *Aquaculture*, *460*, 90–97. https://doi.org/10.1016/j.aquaculture.2016.03.055

Nguyen, V. T., Momtaz, S., & Zimmerman, K. (2007). Water pollution concerns in shrimp farming in Vietnam: A case study of Can Gio, Ho Chi Minh City. *The International Journal of Environmental, Cultural, Economic and Social Sustainability*, *3*(2), 129-136.

Nielsen, R. (2011). Green and technical efficient growth in Danish fresh water aquaculture. *Aquaculture Economics and Management*, *15*(4), 262–277. https://doi.org/10.1080/13657305.2011.624574

Nielsen, R. (2012). Introducing individual transferable quotas on nitrogen in Danish fresh water aquaculture: Production and profitability gains. *Ecological Economics*, *75*, 83–90. https://doi.org/10.1016/j.ecolecon.2012.01.002

Omotilewa, O. J., Ricker-Gilbert, J., & Ainembabazi, J. H. (2019). Subsidies for Agricultural Technology Adoption: Evidence from a Randomized Experiment with Improved Grain Storage Bags in Uganda. *American Journal of Agricultural Economics*, *101*(3), 753–772. https://doi.org/10.1093/ajae/aay108

Ortega, D. L., Wang, H. H., Olynk, N. J., & Wu, L. (2014). China Economic Review Chinese producer behavior : Aquaculture farmers in southern China. *China Economic Review*, *28*, 17–24. https://doi.org/10.1016/j.chieco.2013.11.001

Perdikaris, C., Chrysafi, A., & Ganias, K. (2016). Environmentally Friendly Practices and Perceptions in Aquaculture: A Sectoral Case-study from a Mediterranean-based Industry. *Reviews in Fisheries Science and Aquaculture*, *24*(2), 113–125. https://doi.org/10.1080/23308249.2015.1112358

Rigby, J. M. G. D., & Russell, D. A. P. N. (2016). Discrete Choice Experiments in Developing Countries : Willingness to Pay Versus Willingness to Work. *Environmental and Resource Economics*, *65*(4), 697–721. https://doi.org/10.1007/s10640-015-9919-8

Scarpa, R., & Rose, J. M. (2008). Design efficiency for non-market valuation with choice modelling: How to measure it, what to report and why. *Australian Journal of Agricultural and Resource Economics*, *52*(3), 253–282. https://doi.org/10.1111/j.1467-8489.2007.00436.x

Schrank, W. E., & Keithly, W. R. (1999). The Concept of Subsidies. *Marine Resource Economics*, *14*, 151–164. https://doi.org/10.1017/CBO9781107415324.004

Socialist Republic of Viet Nam Government Portal. (2018). Decree No 79/QĐ-TTg: National Action Plan on Development of Vietnam's Shrimp Industry by 2025 (pp. 27). Retrieved March 1, 2018, from http://vanban.chinhphu.vn/portal/page/portal/chinhphu/hethongvanban?class_id=2&_page=1&mode=detail&document_id=192650http://vanban.chinhphu.vn/portal/page/portal/chinhphu/hethongvanban?class_id=2&_page=1&mode=detail&document_id=192650

Thornton, C., Shanahan, M., Williams, J., Foundation, E. J., Peter, S., & London, N. (2009). From Wetlands to Wastelands : Impacts of Shrimp Farming. *The Society of Wetland Scientists Bulletin*, *20*(1), 48–53. https://doi.org/10.1672/0732-9393(2003)020

Thuy, H. T. T., Nga, L. P., & Loan, T. T. cam. (2011). Antibiotic contaminants in coastal wetlands from Vietnamese shrimp farming. *Environmental Science and Pollution Research*, *18*, 835–841. https://doi.org/10.1007/s11356-011-0475-7

Train, K. (2002). *Discrete Choice Methods with Simulation*. Cambridge University Press.

Tu, H. T., Silvestre, F., Scippo, M., Thome, J., Thanh, N., & Kestemont, P. (2009). Ecotoxicology and Environmental Safety Acetylcholinesterase activity as a biomarker of exposure to antibiotics and pesticides in the black tiger shrimp (Penaeus monodon). *Ecotoxicology and Environmental Safety*, *72*, 1463–1470. https://doi.org/10.1016/j.ecoenv.2009.04.008

Whitmarsh, D. J., Cook, E. J., & Black, K. D. (2006). Searching for sustainability in aquaculture: An investigation into the economic prospects for an integrated salmon-mussel production system. *Marine Policy*, *30*(3), 293–298. https://doi.org/10.1016/j.marpol.2005.01.004