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Adoption of Recirculating Aquaculture Systems in Pangasius Farms: A Choice Experiment

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A growing number of European customers' demands certified pangasius such as ASC in order to ensure sustainable production. Implementing Recirculating Aquaculture Systems (RAS) contributes to an improved water quality, a key issue in achieving ASC certification. This study uses a choice experiment to measure farmers' preferences for RAS in pangasius production in Vietnam. The farmers' choice for RAS is positively affected by enhanced yield levels and achievement of ASC certification with price premium. Also the area of farming is found to be important, i.e. farmers in saltwater intrusion areas are more likely to implement RAS. Main constraints are availability of finance and lack of trust in receiving the ASC price premium. To stimulate the adoption of RAS, policies can provide interest subsidies on loans to finance RAS investment, while retailers could ensure a price premium for ASC certified pangasius.

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1. Introduction

Pangasius has become one of the most important export products of Vietnam (SFP, 2013). In 2013, exports of pangasius were valued around 1.5 USD billion in which EU markets took a 24 per cent share of the exports (Globefish, 2013). In more recent years, the sustainability of pangasius production is increasingly questioned due to disease outbreaks (Phan, 2009; Le, 2010), water pollution (Anh, 2010; Bosma, 2009) and antibiotic pollution from untreated effluents into surrounding aquatic ecosystems (Rico, 2014; Andrieu, 2015). Furthermore, retailers and buyers from EU are increasingly requiring pangasius products from environmentally sustainable and socially equitable production systems, such as the Aquaculture Stewardship Council (ASC) certification (Bush, 2011; Halls, 2013).

To mitigate sustainability concerns and to keep up with the increasing demand for ASC certified pangasius, Recirculating Aquaculture Systems (RAS) was suggested as a possible solution (Martins, 2010). RAS separates solids (i.e. waste and sludge discharge) from the system into the septic tank for denitrification, thereby improving water quality inside ponds and reducing effluent discharge while supplying additional oxygen for the fish. This system reduces disease infestation and uses less antibiotics and chemicals (Gutierrez-Wing, 2006). However, initial investment costs for RAS are relatively high (Pham, 2013). Furthermore, several problems remain to be solved for RAS such as unsuitable initial designs of the system, poor management due to lack of skilled people, and mechanical maintenance problems (Badiola, 2012). As a consequence of these problems, future yields, prices and operating costs in RAS production systems are uncertain, and hence the economic feasibility of RAS (Pham, 2013) and its adoption.

RAS has already been successfully applied in many countries in Europe for different fish species such as salmon in France, sea bass in UK, trout in Denmark (Badiola et al., 2012, see Martins et al., 2010 for a review). Recently, RAS has also been developed for Vietnamese pangasius production as a farm-scale pilot. Various studies suggested technical improvements of RAS, including anaerobic digestion of sludge (Mirzoyan et al., 2010), nutrient flows (Schneider, 2005) and fish growth (Martins, 2009). However, to the best of the authors' knowledge, no previous studies have evaluated the willingness to adopt RAS.

In the light of the foregoing, the objective of this paper is to investigate the key determinants influencing the adoption of RAS by Vietnamese pangasius farmers. Key decision attributes are defined and decisions are analysed using a choice experiment. Outcomes are expected to provide useful insights to policy makers (such as Directorate of Fisheries, Ministry of Agriculture and Rural Development, and Local Aquaculture Departments) in designing policies that provide incentives for RAS adoption.

This paper proceeds with the conceptual framework in section 2. Section 3 presents the data collection, the choice experiment design and the empirical model. This is followed by the presentation of results and discussion in section 4. Conclusions and policy implications are presented in section 5.

2. Conceptual framework

Multifactor determines the adoption of an innovation and for that reason, this paper uses the Net Present Value (NPV) as a framework to identify the conceptual attributes. The conceptual framework asserts that a decision to invest is made when the expected present value of the investment cash flows exceeds the investment costs, i.e. when the NPV is positive (Purvis, 1995; Musshoff, 2012). NPV is defined as (Barry, 2010; Kay, 2012):

$$NPV = -INV + \sum_{t=1}^{T} \frac{NCF_t}{(1+i)^t} + \frac{V_T}{(1+i)^T} \tag{1}$$

Where INV is the initial investment, NCF is the annual net cash flow which equals annual cash inflow (i.e. annual revenues) minus annual operating cash expenses, V is the terminal value, i is the discount rate and T is the lifetime of the investment.

The NPV definition in (1) suggests that the adoption decision depends on any variable that is related to the initial investment costs, the size of net cash flows, the discount rate or the time horizon. We consider two main components of NPV framework that drive to adopt an innovation: the initial investment costs and the size of net cash flows. The initial investment costs are commonly hypothezied to be negatively related to adoption. It is assumed that the costs of the innovation attribute to the low level of adoption (Ofuoku, 2008). The size of net cash flows depends on the yield, the price premium and riskiness which come from the implementation of an innovation. Reviewing the research on the adoption of rural innovations, Pannell et al., (2006) has found that yields and output prices have a positive effect on adoption, thus indicating that farmers tend to more adopt an innovation driving higher net cash flows. Related to higher yield, empirical studies has shown that higher yield can be benefited from the extension services (Evenson, 2001; Ali, 2013).

Another important factor affects the size of net cash flows is riskiness. The riskiness has been found to be associated with an individual being male, more education, higher income and older (Grable, 2000). These socio-demographic characteristics of an individual are commonly expected to affect the innovation adoption decision (see Pannell et al., 2006 and Prokopy et al., 2008 for an overview). For instance, in traditional Vietnamese families, men mainly make the decisions and increasingly involve in household budget management (Knodel, 2005). Hence, a farmer being male is expected to positively affect innovation adoption. Education is expected to have a positive effect on adoption, as farmers with higher education levels are expected to have better access to information and are more capable of processing new information (Gebrezgabher, 2015); Prokopy, 2008).

Moreover, higher income is expected to increase the likelihood of adoption since having sufficient financial resources implies greater flexibility in investing into an innovation (Kim, 2005). The age of a farmer has been found to be both negatively and positively affecting the adoption of an innovation. Younger farmers are more innovative and prefer to keep up with new technologies, and have longer planning horizons (Koundouri, 2006; Oude Lansink, 2003). However, the age of a farmer may also represent experience, suggesting a positive impact on the decision to adopt an innovation (Deressa, 2009).

3. Materials and methods

3.1. Choice experiment

In order to evaluate the role of different factors in the adoption of RAS, a choice experiment was set up among pangasius farmers. The choice experiment requires determining attributes and their levels, designing choice cards and finally the collection of data.

3.1.1. Developing attributes and attributes levels

Firstly, a long-list of attributes was derived from the literature review which included in the conceptual framework. Secondly, four experts of the SUPA project[1] were consulted to scale down the long-list of attributes. The experts had different disciplinary backgrounds, i.e. economics, aquaculture and have knowledge of pangasius farming and RAS. Experts' consultation also defined potential attribute related to specific context with RAS adoption which might not exist in the literature such as ASC certification. As noted in the introduction, RAS contributes to an improved water quality, a key issue in achieving ASC certification to meet the European customers' demand. The short-list of attributes derived from the consensus of experts was considered the plausibility within the study context with RAS and the clarity for the respondents. A total of ten attributes was selected for the short-list. Thirdly, all selected attributes were then reworked into statements (Table 1). For further scaling down the attributes to a number manageable for a choice experiment, the short-list of nine attributes with their statements was evaluated by 29 farmers (i.e. 4 small (<1ha), 11 medium (1-3ha), 14 large farm scale (>3ha) and 6 experts (i.e. 5 local aquaculture specialists and 1 aquaculture researcher) during a workshop on economic feasibility of RAS in pangasius farming in December 2013. Statements were evaluated using Likert scales from 1 (strongly disagree) to 5 (strongly agree).

[INSERT TABLE 1]

The percentage agreement on the statements was calculated for each attribute (Table 1). The attributes with at least 60% of participants gave a score of 4 or 5 were selected for the final list of attributes (i.e. yield, riskiness, initial investment costs, extension services, price premium, ASC

[1] SUPA (Improving waste management for pangasius culture in the Mekong Delta of Vietnam), a public-private project funded by the Dutch Ministry of Economics, the Vietnamese Ministry of Agriculture and Rural Development and private companies, such as Queens, Marine Harvest, Vinh Hoan and Provimi.

certification). Riskiness, however, was left out because it was already reflected in the variation of yields, price premium and initial investment costs. ASC certification and price premium were merged to create a variable that fulfils the criteria that variables have to be mutually exclusive in choice experiments. Since RAS might contribute to fulfil the requirements of ASC certification, and hence an expected price premium for certified pangasius could be provided. Lastly, the final list of attributes includes (1) initial investment costs, (2) yield, (3) extension services and (4) ASC certification with price premium. The number of attributes are in line with recommendation of Abiiro et al., (2014), i.e. a relatively low number of attributes keeps the number of choice cards for respondents manageable.

Attribute levels were defined consistently with the recommendation from Bateman et al., (2002) that they should be realistic, span the range of individuals' expectations and should be practically achievable. Using the traditional system as reference situation, levels were assigned to all attributes based on data from the survey and the workshop on economic feasibility of RAS for traditional system and RAS respectively (Pham, 2013). With regard to the levels of the price premium, an expected price premium with ASC certified pangasius from food services companies and retailers in EU varying from 3% (Pham, 2013) and 10 to 20% (Beukers, 2013). In order to ensure the trade-off between attributes while still being acceptable for the respondent, the extreme values for levels of ASC certification with price premium from study of Beukers et al., (2013) were adopted (Kløjgaard, 2012). The final attributes and their levels are reported in Table 2, both for the reference situation and a pond with RAS.

[INSERT TABLE 2]

3.1.2. Generation of choice cards

A combination of 2 attributes with 3 levels, and 2 attributes with 2 levels results in a full factorial design with 36 profiles. It would however be fairly impossible to ask each respondent to evaluate 36 profiles. Hence, using SPSS software, an orthogonal fractional factorial design (Addelman, 1972) was implemented to generate 22 (18 calibration, and 4 holdout) profiles which accounts for 61% of the total design. Those profiles allowed for unconfounded estimation of the four main effects (no interaction was assumed). Holdout profiles were designed to validate the outcomes, and were randomly mixed with other profiles. The profiles were presented as choice cards in which farmers were asked to choose either (1) RAS or (2) traditional system. Table 3 shows an example of a choice card presented to respondents.

[INSERT TABLE 3]

3.2. Data collection

RAS is costly and thus adoption is more likely by large farms {Pham, 2013 #314}. For this reason, choice experiments were conducted in a workshop among 95 large farms (≥ 3ha) originating from An Giang, Dong Thap, Can Tho, Vinh Long (main pangasius and freshwater region) and Soc Trang (newly developed and saltwater intrusion region). Data were collected using a structured questionnaire including (i) introductory questions (e.g., questions on know how familiar respondents are with RAS, how respondents perceive the water quality of their current fish pond, general information for traditional system), (ii) choice tasks, (iii) socio-economic characteristics of respondents, (iv) additional questions on reasons to adopt RAS. The farms in the workshop cover 12% of the total pangasius farming area in Mekong River Delta. Respondents in the workshops were either the managers of farms or the key technicians, who can make investment decisions in their farms.

The questionnaire was pre-tested with two farmers to ensure that respondents would understand the questions and the choice tasks were manageable. Then, a workshop in Can Tho was organised including participants from Can Tho, Vinh Long and Soc Trang provinces. The other workshops were in An Giang and Dong Thap. All workshops took place in September 2014.

The information presented to respondents in the workshops included three blocks. First, we presented the background of our research and information about establishment and operating mechanism of RAS. This was followed by about 20 minutes for further questions and discussions to enhance the understanding about RAS. Second, the choice experiment was conducted in small groups of 8 respondents. The enumerator asked and explained the questions one by one to ensure all respondents in the group could give a thoughtful answer. Third, a number of statements were selected for more information about reasons to adopt RAS.

Summary statistics of respondents' socio-economic and farm characteristics are shown in Table 4. The average age of farmers is fairly young, i.e. 43 years old, with completed high school and average household income is about 844 USD per month (applied exchange rate: 1 USD equals 20,000 VND). The respondents were mainly male (80%). 14% of the farms gained ASC certification with an average price premium of 0.04 USD per kilogram of pangasius fillet. Most farmers (63%) observed that the water quality in their current fish pond is neutral level which might be an obstacle to obtain ASC certification (i.e. 69% of farms with no ASC certification). The majority of the respondents (62%) never heard about RAS, 33% of respondents had some information about RAS, but were not sure whether RAS would be useful for their own farm and only 5% of respondents were considering investing RAS in their ponds.

[INSERT TABLE 4]

Additional questions were asked to the farmers in order to obtain a more complete explanation of farmers' choices between adopting RAS and traditional system. If a farmer preferred the traditional system without RAS in most of the choice sets (> 11 choice sets), he/she was requested to select at most three important reasons for the choice. Otherwise, he/she was asked to select at most three important reasons for RAS adoption's decision. In case of equalling 11 choice sets for both RAS and traditional system, a farmer is freely to elicit reasons for opting one of choice.

3.3. Binary probit model

A binary probit model was used to estimate the probability that respondents choose either the traditional system or RAS. The model was estimated by using STATA software. The probit model has been used in a number of adoption studies, for example Gracia and de Magistris (2008), Keelan, Thorne et al., (2009). Choice models are typically based on the theory of utility maximization of Lancaster (1966). Let U_{ia} represent the utility of respondent i for RAS and U_{ib} that for traditional system (i=1, 2,..., *I*). The linear random utility model is then:

$$U_{ia} = z'_{ia}\gamma_a + w'_i\beta_a + \varepsilon_{ia} \quad (1)$$

$$U_{ib} = z'_{ib}\gamma_b + w'_i\beta_b + \varepsilon_{ib} \quad (2)$$

Where: The observable vectors are w_i, z_{ia}, z_{ib}. The vectors z_{ia} and z_{ib} denote attributes of the RAS (i.e. *initial investment costs* (1,000 USD/ha), *yield* (ton/ha/year), *extension services* (1,000 USD/month), *ASC with price premium* (%)). The vector w_i denotes characteristics of respondents (e.g., *age* (years), *age*^{2} (years), *gender* (=1 if female, =0 if male), *education* (years), *income* (1,000 USD/month), *region* (=1 if saltwater intrusion region, =0 if freshwater region) and *farm with ASC* (=1 if yes, =0 if no). In this study, to capture the nonlinear impact of *age* on the probability of adopting RAS, we used the quadratic form *(age^2)*.

The two dummy variables, *region* and *farm with ASC*, were included to evaluate the impact of farm characteristics, such as the difference in the location of the farm and farm with already ASC certification going along with a price premium, on the willingness to adopt RAS. As RAS is designed to minimize waste and sludge discharge. We hypothesize that farmers with farms located in saltwater intrusion region are more willing to adopt RAS than those in freshwater region due to the reduction cost for saltwater treatment. Farms with already ASC certification may also want to adopt RAS for controlling disease infestation and water quality improvement purposes. For that reason, *farm with ASC*, which is expressed as a dummy variable (1 if yes) are hypothesized to have negative effect on adoption.

The random error terms, ε_{ia} and ε_{ib}, are assumed to be normally distributed and representing unobservable variables, measurement errors and specification errors. β and γ are the vectors of estimated parameters in the model. There might be possible interaction among independent variables such as that extension services which are not for free could provide better service, and hence higher yields. However, to keep the model simple, we assumed that there are no interactions among independent variables.

In particular, a respondent will select the choice that maximizes his or her utility (Louviere, 2000). We denote by $Y_i = 1$ the respondent choosing to adopt RAS, and $Y_i = 0$ indicating a respondent choosing the traditional system. The probability of a respondent to adopt RAS, inferring $U_a > U_b$, is:

$$Prob(Y_i = 1|x_i') = F(x_i'\beta) \quad (3)$$

$$Prob(Y_i = 0|x_i') = 1 - F(x_i'\beta) \quad (4)$$

x_i' denotes the observable vectors. And, F is the standard normal cumulative distribution function of which values ranges from 0 to 1.

As binary choice models are estimated using maximum likelihood estimation, the sign of estimated parameters can be directly interpreted. However, for interpretation purposes, the marginal effect is preferred. The marginal effect of a change in variable x_{ik} on the probability that $Y_i = 1$ is computed as the partial derivative of the probit function with respect to the x_{ik}.

$$\frac{\partial F(x_i'\beta)}{\partial x_k} = F'(x_i'\beta) * \beta_k \quad (5)$$

Where β_k indicates the estimated coefficient of each variable ($k = 1,2, \dots ,8$).

For the case of *age* with both a linear and a quadratic term, the composite marginal effect at average age is estimated as:

$$\frac{\partial F(x_i'\beta)}{\partial age_{ik}} = F'(x_i'\beta) * (\beta_{k-1} + 2\beta_k age) \quad (6)$$

4. Results and discussion

4.1. Results of determinants affecting RAS adoption

The regression results of binary probit model and marginal effects of independent variables are shown in Table 5. Goodness-of-fit of model is reflected in Pseudo-R^2 (0.21) at 1% significant level with an overall corrected prediction rate of 78.5%, suggesting the independent variables in the model explain the choices well.

The probit model predicts 17.5% of all respondents who opt for RAS while the adoption rate from the sample is 26%. In other words, the probit model underestimated the actual adoption rate by 8.5%. An important consideration is how the main attributes (e.g., initial investment costs, yield, extension services and ASC certification with price premium) and respondents' socio-economic characteristics affect a farmer's decision.

The results of the binary probit model show that all parameters associated with the attribute variables are statistically significant at the 5% critical level, except for *extension services* and *farm with ASC*. The insignificance of *extension services* suggests that farmers may rely on their own experience, learn from others in their neighbourhood instead of from extension services. Hence, they likely less consider the extension services as the main source for technical support. *Farm with ASC* showed no statistically significant impact on adoption, implying that no matter of already obtaining ASC certification or not, farmers may still consider adopting RAS for better water quality and disease control. Water quality improvement is also found the major reason for most of farmers (52%) adopting RAS (as shown in Table 6).

The signs of regression coefficients in the binary probit model are in agreement with our priori expectation. The results show that *initial investment cost*s have a negative and significant impact on RAS adoption. This indicates that a one unit increase in initial investment costs decreases the probability of adopting RAS by 0.05%. This suggests that increased initial investment costs of RAS reduce the likelihood of adopting RAS. As investing in a new technology entails sunk costs related to irreversibility in the decision (Koundouri, 2006). Innovations with high establishment costs are less attractiveness to the farmers (see e.g., Pannell et al., 2006).

In contrast, *yield*, and *ASC certification with price premium* have a positive and significant impact on RAS adoption. Specifically, a one unit increase in yield and ASC certification with price premium increases the probability of RAS adoption by 0.02% and 1.2% respectively. According to Pham et al., (2013), yield and ASC certification with price premium are positively associated with profitability of RAS, and hence its adoption. This result is in line with Pannell et al., (2006) and Sunding and Zilberman (2001) who found that the adoption of an innovation is positively affected by the profitability in the agricultural sector.

Age in quadratic form (age^2) is statistically significant at 5% level of significance and has a negative sign as expected. The composite marginal effect at average *age* (43) is minus 0.003. Age has a diminishing marginal effect on the probability of adopting RAS. However, when a farmer is aged beyond the threshold level of 35, his/her willingness to adopt RAS decreases with age (with negative marginal effects of age). This means that young farmers (under 35) are more likely to face the risks associated with innovations (uncertainty in yield and unfamiliar in technology) and to adopt them than their older counterparts (Asfaw, 2004).

Education has a positive effect, showing that one year more education increases the probability of adopting RAS by 0.5%.This result reveals that education plays an important role in increasing the probability the farmers to adopt RAS. This might due to the fact that higher educated farmers are more open mind in receiving new technological information as well as having better capability to access and process new technological information. Higher education induces increases in probability of adopting RAS is in line with the studies by Prokopy et al., (2008) and Gebrezgabher et al., (2015).

Household income has a positive effect on the adoption of RAS, implying that an increase of the household income one unit will lead to an increase of the likelihood of RAS adoption by 6.6%. According to Madukwe (1993) wealth and adoption of innovation go hand in hand. This is the reason why even when new technologies are costly to adopt because it requires large amount of money initially, the wealthy farmers readily adopt them. This is especially true for the fish farmers (Ofuoku, 2008; Bosma, 2012).

The dummy variable, *gender*, is found to be negatively related to RAS adoption, indicating that the probability of male farmers adopting RAS is, ceteris paribus 8.5% higher than the probability of female famers adopting RAS. The result is consistent with the current structure of male-headed household in traditional Vietnamese family. Males are also found to more likely best management practices in beef cattle industry (Gillespie, 2007). Furthermore, there is a positive relationship between the dummy variable, *region*, and RAS adoption, suggesting that farmers with farms located in saltwater intrusion region are more willing to adopt RAS than those in freshwater region by 20%.

[INSERT TABLE 5]

4.2. Additional questions on reasons to adopt RAS

Table 6 shows that farmers who consider adopting RAS mostly do so because of improved in-pond water quality (52%), better disease management (32%) and the ASC certification (20%). In contrast, farmers who prefer the traditional system, indicate that lack of trust to receive the ASC certified pangasius price premium (60%), financial constraints (46%) and increased electricity cost (43%) are the main reasons for their choice. These results are confirmed in findings from the binary probit model, where ASC certification with price premium, higher yield due to better disease and water management are the main effects on the willingness to adopt RAS.

[INSERT TABLE 6]

5. Conclusions and policy implications

This study analyses the attributes and socio-economics factors affecting RAS adoption using a choice experiment. Data were derived from 95 pangasius farms following a structured questionnaire. Results from the binary probit model suggest that male farmers with below 35 years old, higher income, higher education and with farms located in saltwater intrusion region are more likely to implement RAS on their pangasius farms. Moreover, results showed that the likelihood of a farmer adopting RAS increases with price premium (positive) for ASC certified pangasius (as most important attribute), followed by initial investment costs (negative) and yield (positive). Overall, the predicted level of adoption is 17.5% for RAS. Those who consider investing in RAS mentioned improved in-pond water quality, better disease management and the ASC certification as the main reasons. Farmers who do not consider adopting RAS mentioned disbelief in the presence of price premium, financial constraints and increased electricity costs as main arguments.

According to the results, outcomes can be used by policy makers, RAS developers and business executives. As the willingness to adopt RAS is negatively affected by the initial investment costs, policies can provide interest subsidies on loans to finance RAS investment to stimulate the adoption for RAS. This especially targets to those farmers who have limited financial resources. Additionally, RAS developers could further optimise improved levels of yield to make RAS becomes more attractive to pangasius farmers. Finally, businesses (e.g., processors, retailers) could provide (and guarantee) price premiums with ASC certified pangasius, as the most crucial incentive for farmers to adopt RAS.

Policies enhancing farmers' education and household income could also enhance the RAS adoption. For example, awareness-building, such as workshops, media, communication, makes potential farmers more knowledgeable about RAS, its benefits and costs. At the early stage of adoption, targeting male farmers below 35 years old with higher education level, higher household income and with farms located in saltwater intrusion region is probably advisable.

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Tables and figures

Table 1 Percentage agreement on statements on RAS adoption (%) (n= 35)

Attribute by category	Statement	1	2	3	4	5
i. Economic						
Yield	With RAS I expect higher yields due to a decreased fish mortality rate	0	0	3	74	23
Price premium	I expect that with RAS I will get a price premium	0	6	3	71	20
Access to credit	I can not invest in RAS due to insufficient access to credit	3	23	20	51	3
Cost of initial investment	I expect that RAS adoption costs are too high	0	14	9	60	36
Farm size	My farm is too small to adopt RAS	23	43	14	20	0
ii-Product						
Fish quality	With RAS I expect better pangasius quality	0	0	26	49	26
iii-Attitude						
Riskiness	I believe that the RAS investment is too risky	3	11	23	60	3
iv-Social						
Extension services	I expect that extension services will help me in working with RAS	0	3	6	60	34
Neighbour effect	I will invest in RAS if other farms applied RAS successfully	3	6	9	52	23
v-Institution						
ASC certification	I expect that by adopting RAS, I am better able to fulfil ASC requirements	0	0	0	83	17

Table 2 Final attributes and levels for traditional system and RAS

Attribute	**Unit**	**Description**	**Traditional system (reference situation)**	**RAS levels**
Initial investment	1,000 USD per ha	Costs for pond construction and RAS/traditional system establishment	110	180; 380; 720
Yield	Ton per ha per yr	Yield comes from RAS/traditional system	650	360; 790; 2,000
Extension services	USD per month	Extension service provided by local aquaculture department/ specific RAS service	For free	800; for free
ASC with price premium	Percent	ASC certified pangasius is expected for a price premium	ASC with 0% price premium	ASC with 10% price premium; ASC with 20% price premium

Table 3 Example of a choice card

Question: Which of the two farming situations below do you prefer most? (Tick your option)

Attribute	**Pond with traditional system**	**Pond with RAS**
Initial investment	110 (1,000 USD per ha)	180 (1,000 USD per ha)
Yield	650 (ton per ha per year)	790 (ton per ha per year)
Extension services	For free	800 (USD per month)
Price premium	ASC with 0% price premium	ASC with 10% price premium
Please select option you prefer most	☐	☐

Table 4 Summary statistics of respondents' socio-economic and farm characteristics (n=95)

Characteristic	**Mean**	**Standard deviation**	**Minimum**	**Maximum**
Socio-economic				
Age (years)	42.6	12.1	24	70
Education (years)	12.6	3.9	5	16
Household Income (USD/month)	844	524	250	1,750
Male (dummy =1 if male)	0.8	0.3	0	1
Farms				
Farms in freshwater region (number)	85			
Farms in saltwater intrusion region (numbers)	10			
ASC certification status (% of respondent)				
- ASC certification	14			
- No ASC certification	69			
- In ASC certification application process	17			
Current price premium with ASC (USD/kg)	0.04	0.02	0.02	0.05
In-pond water quality status own farm (% of respondents)				
- Very bad	0			
- Bad	3			
- Neutral	63			
- Good	32			
- Very good	2			

Table 5 Parameter estimates and marginal effect of the binary probit model on the probability of RAS adoption

Variable	**Coefficient**	**Marginal effect**	**Standard error**[a]	**P value**[a]
Constant	-2.16***		0.49	0.000
Attribute				
Initial investment cost	-0.002***	-0.0005	0.00	0.000
Yield	0.0008***	0.0002	0.00	0.000
Extension services	-0.053	-0.016	0.09	0.573
ASC with price premium	0.042***	0.012	0.00	0.000
Farmers and farms characteristics				
Age	0.039*	-0.003[b]	0.00[b]	0.013[b]
Age^2	-0.0006**			
Gender	-0.321***	-0.085	0.18	0.002
Education	0.016*	0.005	0.10	0.067
Income	0.225***	0.066	0.06	0.000
Region	0.591***	0.200	0.09	0.000
Farm with ASC	0.127	0.038	0.10	0.204
Log-likelihood	-953.80			
χ^2 (p-value)	517.79 (0.000***)			
Pseudo-R^2	0.21			
Calculated probability (Y=1)	17.50%			
Overall correctly predicted	78.50%			
Total # observations	2090			

*Notes: ***Values significant at 1% level, **Values significant at 5% level and * at 10% level; [a]Values for coefficient; [b]Values for compile age*

Table 6 Motivation for opting for RAS or traditional system (with percentage of agreement)

Statement of reason	**%**
Not adopting RAS (maintain traditional system)	
a) I don't have the financial capability to adopt RAS	46
b) I don't think I will get a price premium with ASC certified pangasius	60
c) RAS uses a lot of electricity	43
d) I don't believe that RAS would be successful on my farm	19
e) I don't see any concerns regarding the water quality in my pangasius pond	10
f) I don't believe that RAS would help us to fulfil the requirements of ASC certification	26
g) I don't care about obtaining ASC certification	34
h) I don't care about environmental issues, such as in-pond water quality and pond effluents	33
i) Establishing and operating RAS seems complex to me	20
Adopting RAS	
a) I expect ASC certified pangasius will get a price premium	32
b) I expect that with RAS water quality in my fish pond will substantially improve	52
c) I expect that by adopting RAS, I am better able to fulfil ASC requirements	36
d) I believe that RAS would be successful on my farm	12
e) I have the financial capacity to adopt RAS	16
f) RAS may help reducing discharge volumes leading to lower environmental taxes in the near future	32
g) I expect that with RAS, disease can be controlled	36