Factors Influencing Technology Adoption in a Louisiana Aquaculture System

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Abstract

A multinomial logit model was estimated and used to analyze the impact of various producer characteristics on the adoption of flow-through and recirculating technology in soft-shelled crab production. Because of the industry's geographic isolation and high turnover rate, data was collected by personal interviews in 1991. The results suggest that increased adoption might be fostered by targeting education programs towards full time, family operated businesses in non-traditional production regions. However, development of effective education programs may be hindered by the lack of a significant relationship between producer adoption decisions and the information provided by university or extension personnel.

Keywords: technology adoption, aquaculture, multinomial logit

Since its debut with oyster and trout farming in the 1850's, aquaculture has become one of the fastest growing sectors within North American agriculture. Production levels increased at an annual rate of 20 percent from 1980 to 1988, with the annual U.S. farm-gate value of aquacultural products reaching $1.0 billion in 1990 (Avault). Given increasing demand for seafood products and the fact that world fishery landings currently average more than 85 percent of the estimated maximum sustainable yield, the aquaculture industry would appear to have substantial expansion possibilities. In response, many land grant universities have developed comprehensive research and extension activities aimed at the enhancement of regionally based aquaculture industries. These research efforts have led to higher yields through improvements in feed nutrition, water chemistry, disease prevention and treatment, and stock selection. At the same time, research has focused on the need for high density culture practices that minimize the reliance on and degradation of water resources. A potential approach to avoiding environmental impacts is the use of artificial containment systems that incorporate relatively high levels of technological inputs to produce fish and shellfish at very high densities per unit of culture area (Spotte). These systems are generally known as recirculating aquaculture systems (RAS).

RAS use closed culture vessels through which water is continuously recycled by means of biological and mechanical filters. These systems received a great deal of research attention during the 1980s because of the potential for enhanced production control and quality monitoring. Previous examinations have focused on many aspects of the technology, including its implications for water chemistry, disease prevention and treatment, species selection, and general management practices (Mayo;

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Wheaton, Hochheimer, and Kaiser). Most studies have centered on the mechanical and biological aspects of water filtration because the efficacy of the water filter tends to be the limiting factor in recirculating systems from an engineering point of view (Lawson). However, the managerial difficulties associated with RAS may also be problematic, as suggested by the fact that there are few profitable commercial systems in operation (Losordo, Easley, and Westerman). Despite more than a decade of research activity and the construction of numerous prototype systems, there has been limited commercial adoption of RAS. One locally important segment of aquaculture that may be dramatically influenced by RAS technology adoption is the soft-shelled crab industry.

The production of soft-shelled blue crabs (*Callinectes sapidus*) is a well-established industry along the U.S. Atlantic and Gulf of Mexico coasts. While a large part of current soft-shelled crab production is centered around the Chesapeake Bay region of Maryland and Virginia, significant levels of production have occurred in other states in the recent past. Among the Gulf of Mexico states, Louisiana is the oldest producer of soft-shelled crabs, with production dating back to the early 1900s. However, Louisiana soft-shelled crab landings declined rapidly from a record of 2.37 million pounds in 1945 to 119,000 pounds in 1979 (Perry, Ogle, and Nicholson). This rapid collapse and persistent suppression of crab landings has been attributed to disease and loss of habitat, with the primary factor identified as the deterioration of water quality in traditional areas of soft-shelled crab production.

In response to water quality problems, RAS technology was presented to the soft-shelled crab industry at workshops and seminars from 1979 to 1985. RAS freed producers from a direct dependence on areas having water conditions that supported natural crab fisheries, thereby allowing the geographic expansion of the industry across most of coastal Louisiana (Horst). In fact, the advantages of RAS rapidly led an estimated one-third of Louisiana soft-shelled crab producers to adopt some variation of the technology. However, since 1985 there has been little interaction between researchers and the soft-shelled crab industry, and production remains more than 70 percent below peak levels. Despite the apparent advantages of RAS, anecdotal evidence suggests that the use of the technology may be stagnant or on the decline.

This paper utilizes a multinomial logit approach to econometrically analyze the factors associated with technology adoption by soft-shelled crab producers in Louisiana. Included in the examination are three distinct production systems: float-car, flow-through, and recirculating shell or sand systems. The identification of the factors influencing technology adoption is an important first step in renewed efforts to promote the adoption of RAS, and can be used to help guide the development of new extension education programs.

Technology Use in Soft-shelled Crab Production

Soft-shelled crab production is dependent on a sequence of biological events that occur regardless of the specific level of technology employed by the producer. Pre-molt crabs must be caught or purchased and placed inside an enclosure where the crabs can be exposed to water of a relatively high quality. Within three days, the confined pre-molt crabs will shed their old shells as part of the normal growth process. After molting, the new shell will completely harden in one to four hours, depending on the water temperature. The producer must do all harvesting and processing during this period to obtain a marketable product. As a result, soft-shelled crab production tends to be labor intensive.

The systems in which pre-molt crabs are maintained can be either open or closed. Open systems use passive or active methods to supply the enclosure with water from a nearby source. The water is generally allowed to flow through the enclosure only once before it is discharged to the surrounding environment. Closed systems employ biological and/or mechanical filters to purify and recycle system water. Float-car and flow-through technologies are classified as open systems, while recirculating shell or sand filter technologies are classified as closed systems.

Float-car operations are the oldest known method of soft-shelled crab production in Louisiana. The process involves the use of floating pens or cages in which pre-molt crabs are placed until they molt. These enclosures float at the water's surface and allow a constant exchange of water through screened inlets. The producer must monitor each float-car hourly to harvest the freshly molted soft-shelled crabs. Monitoring float-car operations can be especially labor intensive when the cars are not easily accessible to the producer, as would be the case if the cars had to be located in remote areas to take advantage of relatively high water quality.

Flow-through technology was developed in response to the need to reduce labor expenditures. Enclosures in this system consist of tanks located above ground and grouped together in a centralized production area. A continuous water supply is pumped from an adjacent source, allowed to flow through the system, and is then discharged. Although flow-through technology is in many ways more convenient for the producer, it shares a disadvantage with float-car systems in that it requires large amounts of high quality water.

Recirculating shell and sand filter technologies were developed to (i) allow for soft-shelled crab production in areas where poor water quality restricted the use of open systems, (ii) permit more flexibility in siting production facilities, and (iii) allow high density production. Water in these RAS systems is constantly filtered through a substrate where bacterial colonies biologically purify the water. In addition, the substrate can act as a mechanical filter, removing suspended particulates from the water. In shell filters, water is allowed to filter by gravity through a coarse bed of oyster or clam shells. In sand filters, water is continuously pumped through a pressurized sand substrate.

Factors Affecting Technology Adoption

To the best of the authors' knowledge, the factors affecting technology adoption in aquaculture have received no formal examination in the literature. However, numerous studies have focused on product-specific and activity-specific technology adoption in other agricultural systems (Napit et al.; Harper et al.; Byerlee and de Polanco; Casewell and Zilberman). Researchers have also investigated the adoption of non-specific technology such as computers (Putler and Zilberman; Batte, Jones, and Schnitkey). These studies tend to support Rogers' contention that technology adoption should, in general, be positively related to producer education, size of operation, and the degree of operation specialization. Studies also suggest that early adopters of a new technology generally have a higher social status, more formal and informal information contacts, and a greater tolerance for the uncertainty associated with the implementation of new production methods (Hooks, Napier, and Carter; Feder, Just, and Zilberman; Binswanger). The differential ability of individuals to process these various influences generally leads to a situation where information spreads more rapidly than the actual adoption of the new technology (Tversky and Kahneman; Beal and Rogers).

If the actual possession of information about a new technology does not directly determine adoption, then efforts to promote the use of RAS cannot rely solely on information dissemination. Extension programs also need to account for the varying ability of individuals to use the information they collect. In fact, an ideal extension program attempts to manipulate the presentation of information so as to enhance the ability of an individual to process information, thereby enhancing the rate at which adoption will occur. However, these types of educational programs require some knowledge about the specific characteristics of individuals that are likely to adopt.

Analysis Procedure

The decision to adopt a certain level of technology for soft-shelled crab production can be analyzed with a probabilistic choice model. But, because the probability that a producer has adopted a specific technology is bounded by zero and one, limited dependent variable techniques are required. In situations where the number of choices is greater than two, a commonly used model is the multinomial logit. In this approach, the probability associated with the *i*th individual's adoption of the *j*th technology is assumed to follow an underlying logistic distribution and can be described as (Maddala):

$$P_{ij} = \frac{e^{X_i'\beta_j}}{1 + \sum_{k=1}^{m-1} e^{X_i'\beta_k}} \quad j=1, 2, ..., m-1,$$

where X is the set of characteristics describing the adopter, β a set of estimated parameters that describe the influence of X on the probability of adoption, and m is the number of technologies. Maximum likelihood is the preferred estimation technique for the inherently heteroscedastic logit models because of its reliance on individual observations and because it assures the large-sample properties of consistency and asymptotic normality of the parameter estimates (Capps and Kramer). Given the residual nature of the calculation for P_{im}, implementation of this model usually involves iteratively solving a set of m-1 equations of the form

$$\sum_{i=1}^{n} (f_{ik}-P_{ik})X_i = 0 \qquad (2)$$

$$k=1, 2, ..., m-1$$

where f_{ik}=1 if the ith individuals chooses the kth technology, and zero otherwise.

Both multinomial and binary logit models have been extensively used to examine the characteristics associated with adoption behavior. For example, Jones, Batte, and Schnitkey used a logit analysis to describe how Ohio fruit producers attempted to mitigate risks by utilizing reliable information. Reynolds illustrated the impact of socioeconomic factors on vegetable expenditures by using data from household surveys. Adoption decisions regarding computer use have also been examined using logit and multinomial logit models (Putler and Zilberman; Batte, Jones, and Schnitkey).

Statistical analyses for this study were conducted using the LIMDEP econometric computer package (Greene). Given that little is known about the relationship between producer characteristics and aquaculture technology adoption, a 20 percent significance level was used to identify potentially important coefficients (Manderscheid; Harper et al.). The goodness-of-fit for our estimated model was evaluated using McFadden's R^2, Aldrich and Nelson's pseudo-R^2, and the log-likelihood ratio test (Maddala). Although widely used, McFadden's R^2 does not lie on the interval [0,1] and thus cannot be interpreted in the same way as the R^2 from a linear regression model. Aldrich and Nelson's pseudo-R^2, which does lie on the interval [0,1], can be somewhat easier to interpret, although it does not adjust for changes in degrees-of-freedom. In general, there is no universally accepted measure for goodness-of-fit evaluation in adoption modeling. Thus, our results will be compared to those obtained from similar studies. In addition, statistics covering the number of correct classifications of predicted choices will be reported because the ultimate test of a model's goodness-of-fit is its ability to predict actual choices.

Marginal probabilities of adoption were calculated from the estimated multinomial logit model by employing the following formulation (Greene):

$$\frac{\partial P_j}{\partial X} = P_j\left(\beta_j - \sum_{i=1}^{m} P_i\beta_i\right) \qquad (3)$$

$$j=0, 1, ..., m$$

Standard errors for the calculated marginal probabilities were determined using the parametric bootstrap method of Krinsky and Robb. This simulation approach to determining the statistical significance of values calculated from an estimated model was recently used to develop confidence intervals for elasticities (Dorfman, Kling, and Sexton) and estimates of willingness-to-pay in a contingent valuation study (Park, Loomis, and Creel).

Data Sources

In contrast to the coasts of some soft-shelled crab producing states, Louisiana's coast is an intricate network of marshlands. Most fishing communities are situated at the end of rural roads on coastal peninsulas and are relatively isolated. This geographic isolation and its potential impact on data collection was compounded in this study by the lack of a current list of producer names and addresses. A small list was compiled during extension efforts in the early 1980s, but it was of limited use because over half of the listed individuals no longer produced soft-shelled crabs. This high turnover rate is a common phenomena in the Louisiana soft-shelled crab industry and it makes the use of mail surveys problematic. Instead, researchers have found that personal interviews are more reliable than mail surveys as a means of collecting data from Louisiana commercial fishermen (Louisiana Blue Crab Task Force). Therefore, personal interviews were used to obtain information for this study.

Initial interview contacts with soft-shelled crab producers from each major coastal region were identified with the assistance of Marine Advisory Service agents and specialists, permitting authorities, seafood distributors, and industry associations. The names and addresses of additional producers were obtained during the course of each interview. The primary decision makers in all the firms interviewed for this study were caucasian and male. While it is possible that non-white and/or female individuals may be commercially producing soft-shelled crabs in Louisiana, none were known to exist at the time the study was conducted. Thus, while the research results can be generalized to the overall soft-shelled crab producer population as it was known to exist at the time of the study, care must be taken when drawing implications for future non-white, non-male producer groups.

The interviews were conducted during 1991, with each producer asked to answer a standard 30 question survey pertaining to the physical, economic, and social characteristics of their enterprise. This survey process resulted in usable responses from 61 producers who were responsible for marketing 63,843 dozen soft-shelled crabs in 1991. This response represented approximately 20 percent of the estimated producer population and 31 percent of total production in 1991 (Caffey, Culley, and Roberts; Lorio, Lutz, and Avery).

Model of Technology Adoption

The empirical multinomial logit model used to analyze technology adoption in soft-shelled crab production was

$$\begin{aligned} TECH &= \beta_1 YEARS + \beta_2 FULLTIME \\ &+ \beta_3 COMPETE + \beta_4 SIZE + \beta_5 FINFO \\ &+ \beta_6 LABOR + \beta_7 FAMLABOR + \beta_8 NONSFJ \\ &+ \beta_9 MORTALITY \\ &+ \beta_{10} REGION + \varepsilon \end{aligned} \tag{4}$$

where the variables are defined in table 1. Because all known producers were caucasian, race was not used as an explanatory socioeconomic variable. In addition, all known firms were controlled by males or male dominated households. As a result, sex was not used as an explanatory variable. In initial interviews, producers strongly resisted attempts to gather direct information concerning their levels of education. Thus, questions concerning a producer's level of formal education were considered sensitive and harmful to the response rate of producers, and were not included in the questionnaire. However, eliminating a measure of education from the empirical model raised the possibility of omitted variable misspecification, which can lead to both inconsistent and biased parameter estimates (Godfrey). Considering that education variables are generally used to capture the effects of differing management capabilities, we included two alternate proxies. A related measure of practical education, the length of time in business *(YEARS)*, was used as a proxy for the general level of a producers education. The direct management ability of producers was proxied in this study by a variable that accounted for pre-harvest crab mortality *(MORTALITY)*. While increased use of technology might be directly related to decreased mortality in some production systems, this linkage has yet to manifest itself in aquaculture because of the skill required to successfully manage a complex system.

Although knowledge about soft-shelled crab producers in Louisiana was insufficient to generate specific hypotheses concerning all the coefficients of individual explanatory variables, it was generally expected that higher levels of technology adoption would be positively related to producer experience *(YEARS)*, size of operation *(SIZE)*, use of formal information sources *(FINFO)*, perceptions of local competition *(COMPETE)*, and commitment to the

Table 1. Definitions of Variables Used in the Multinomial Logit Analysis of Technology Adoption in Louisiana Soft-Shelled Crab Aquaculture

Variable Name	Description
TECH	0 if the producer adopted float-car, 1 if the producer adopted flow-through, and 2 if the producer adopted recirculating filter technology
YEARS	Number of years the individual has produced soft-shelled crabs
FULLTIME	1 if the individual considered themselves to be employed full time in soft-shelled crab production, 0 otherwise
COMPETE	The producer's estimate of the number of individuals involved in soft-shelled crab production in their area
SIZE	The number of container square-feet an individual has devoted to soft-shelled crab production
FINFO	1 if the producer's major source of direct information on aquaculture technology was family and friends, 0 otherwise
LABOR	1 if the producer considered labor to be the major variable cost in soft-shelled crab production, 0 otherwise
FAMLABOR	1 if the producer's sole source of labor was the family, 0 otherwise
NONSFJ	1 if the producer was employed in a non-seafood job, 0 otherwise
MORTALITY	Average percent crab mortality experienced during the year
REGION	1 if the producer lived in the traditional soft-shelled crab production region of Louisiana (St Bernard, Plaquemines, Jefferson, and St. Charles parishes), 0 otherwise

soft-shelled crab industry *(FULLTIME)*. Technology adoption was hypothesized to be negatively related to evidence of poor management *(MORTALITY)* and employment outside the soft-shelled crab industry *(NONSFJ)*.

Results and Discussion

The summary statistics for the technology adoption model are presented in table 2. The likelihood ratio test indicates that the amount of variation explained by the model is significantly different from zero. In terms of goodness-of-fit, both McFadden's and Aldrich and Nelson's R^2 were calculated to be at the high end of the range typically reported for logit models (Sonka, Hornbaker, and Hudson; Harper et al.; Putler and Zilberman). It is interesting to note that although McFadden's R^2 is usually criticized because it is not restricted to the [0,1] interval (Maddala), the restricted R^2 of Aldrich and Nelson was similar to McFadden's measure. The estimated model's within-sample predictive accuracy was also high, correctly predicting 70 percent of float-car, 55 percent of flow-through, and 77 percent of recirculating (RAS) adoption decisions (table 3). Thus, the estimated model appears to adequately describe adoption decision making in Louisiana's soft-shelled crab industry.

The influence of explanatory variables on the probability of adoption varied depending on the technologies being compared, although five variables were significant in at least one comparison (table 2). Producers who consider themselves to be employed full-time in the soft-shelled crab industry were significantly more likely to adopt either flow-through or recirculating versus float-car technology. The size of a producer's operation was positively and significantly related to the adoption of recirculating versus flow-through methods and negatively related to the adoption of flow-through versus float-car production methods. Producers who's sole labor source was their family were significantly more likely to adopt either flow-through or recirculating technology over float-car methods. The management ability of a producer, as measured by *MORTALITY*, was significantly related

Table 2. Multinomial Logit Model of Technology Adoption in Louisiana Soft-shelled Crab Production

		Flow-through vs Float-car		Recirculating vs Float-car		Recirculating vs. Flow-through	
Variable	Mean	β	Prob [a]	β	Prob	β	Prob
YEARS	7.61	-0.144	[b]	- 0.147		- 0.003	
FULLTIME	0.36	3.587	0.0931	3.095	0.1398	- 0.493	
COMPETE	36.89	- 0.024		- 0.003		0.021	
SIZE	309.66	- 0.007	0.1457	- 0.001		0.008	0.0460
FINFO	0.36	-1.620		-1.126		0.494	
LABOR	0.67	- 0.725		- 0.617		0.108	
FAMLABOR	0.91	4.406	0.0395	5.957	0.0116	1.551	
NONSFJ	0.20	0.082		0.909		0.827	
MORTALITY	24.03	0.105	0.0567	- 0.039		- 0.145	0.0030
REGION	0.48	- 1.504		- 2.716	0.1223	- 1.213	0.2000
N				61			
Log likelihood				-36.422			
Log likelihood, restricted				-61.369			
Model chi-square (18 D.F.)				49.895			
Significance Level				0.00008			
McFadden's R^2				0.407			
Aldrich and Nelson's R^2				0.450			

[a] Test significance, or the probability of the estimated coefficient not being significantly different from zero.

[b] Blanks indicate a probability level greater than 0.20.

Table 3. Predicted versus Actual Adoption of Technology in Louisiana Soft-shelled Crab Aquaculture

		Predicted Technology		
Actual Technology	Float-car	Flow-through	Recirculating	Percent Correct Predictions
Float-car	7	2	1	70
Flow-through	2	11	7	55
Recirculating	3	4	24	77

to the adoption of recirculating versus flow-through systems and flow-through versus float-car technology. As mortality levels decreased, indicating increasing management skills on the part of the producer, adoption of recirculating technology increased. However, increasing management skill reduced the adoption of flow-through versus float-car methods. Lastly, the location of an operation in Louisiana's traditional soft-shelled crab production region was weakly and negatively related to the adoption of recirculating versus float-car and flow-through technology. The numbers of years involved in soft-shelled crab production, perception of competition, source of information, reliance on the industry, and opinions about the importance of labor were not significant in any technology comparison.

The significant marginal probabilities of adoption given the estimated model are presented in table 4. In terms of the largest impacts, the probability of adopting recirculating systems increased by more than 50 percent for producers whose sole source of labor was the family, and by more than 17 percent for producers who were also employed in a non-seafood industry. The marginal probability of adopting recirculating technology was also positively and significantly related to the size of a producer's operation and their perception of competition, although both effects were relatively small. Producing in Louisiana's traditional soft-shelled crab region decreased the probability of adopting recirculating methods by over 31 percent even though the area has experienced some of the greatest declines in water quality. In addition, there was a negative marginal probability of recirculating system use as crab mortality increased during production.

In contrast to recirculating systems, the probability of adopting a flow-through system increased over 18 percent for producers who operated in Louisiana's traditional soft-shelled crab production region. A positive and significant marginal probability of flow-through adoption was also related to the incidence of crab mortality experienced during production. The marginal probability of flow-through system use was negatively related to the size of a producer's operation and the perception of competition, although both effects were quite small in magnitude. The probability of float-car use decreased over 30 percent as producers relied solely on family labor, while a negative marginal probability for float-car adoption was associated with the being employed full time in the soft-crab industry. A positive marginal probability for float-car adoption was associated with production in Louisiana's traditional production regions,

Conclusions

The results of this study provide some insight into the factors that influence the adoption of technology in aquaculture production systems. In particular, the analysis indicated that adoption of flow-through or RAS technology was significantly related to a producer's involvement in a full-time soft-shelled crab operation that relied solely on family labor. At the same time, the marginal probability of adopting RAS was directly related to employment outside the seafood industry. Because of their reliance on the industry and family labor, full-time soft-shelled crab operations may have a higher stake in the ultimate success of the enterprise and thus be more willing to adopt a new, potentially more profitable technology. The influence of outside income may be related to the ability to mitigate the initial risks associated with employing a new technology.

Experience in the industry did not appear to be related to the adoption decision, but more effective management of the production process was associated with the use of recirculating systems. Interestingly, the positive relationship between management ability and technology use did not hold for flow-through systems, suggesting that producers may not completely possess or understand the additional skills necessary to successfully replace float-cars with these systems.

Because of the apparent strong influence of the traditional production region on the way in which soft-shelled crabs are produced, the promotion of RAS may be most successful in non-traditional production regions. This suggests that these newer systems may ultimately lead to expanded supply and marketing opportunities for the industry. No significant relationship was found between university or extension information and technology adoption, a result that is not surprising considering the amount of time since the last formal educational programs were conducted. This lack of formal information use

Table 4 Marginal Probability of Adoption With Respect to a Change in an Independent Variable.

	Marginal Probability for:		
Variable	Float-car	Flow-through	Recirculating
YEARS	[a]		
FULLTIME	-0 17737 (0.15233)[b]		
COMPETE		-0 00388 (0.00365)	0.00342 (0.00383)
SIZE		-0.00152**[c] (0.00058)	0.00148** (0.00056)
FINFO			
LABOR			
FAMLABOR	-0.30592* (0 18896)		0.50663* (0 32892)
NONSFJ			0.17755 (0.19889)
MORTALITY		0 02611** (0.01015)	-0.02623** (0.01065)
REGION	0.13233 (0 13701)	0.18448 (0 17103)	-0.31681* (0.20358)

[a] Blanks indicate that the probability of the estimated marginal value not being significantly different from zero was greater than 0.20.

[b] Values in parentheses are the standard errors of the estimated marginal probability as determined by parametric bootstrap (Krinsky and Robb) using 2000 simulated draws

[c] * indicates significance at an alpha level = 0.10; ** indicates significance at an alpha level = 0.01; all other reported marginal probabilities significant at an alpha level = 0 20

suggests that university research and extension personnel may be able to enhance the adoption of flow-through and recirculating technology by developing focused educational programs. However, development of effective education programs for RAS may be hindered by the insular nature of the communities in which most producers live. Part of the reluctance to seek out formal sources of information about advanced aquaculture technology may also be related to the complexity of the technical information, but a more detailed study would be required to fully examine this question.

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