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Processor Willingness to Adopt a Crawfish Peeling Machine: An Application of Technology Adoption under Uncertainty

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Crawfish processors' *ex ante* adoption rates of three hypothetical crawfish peeling machines are assessed using a polychotomous-choice elicitation format. Adoption rates would likely range from 23% to 70%, depending upon which machine was offered and whether it was purchased or leased. Processors most likely to adopt are determined using ordered probit analysis. Likely adopters would be larger, more diversified processors with greater resources and longer planning horizons.

Key Words: crawfish, *ex ante* technology adoption, peeling machine

JEL Classifications: D81, Q16

For at least three decades, crawfish industry leaders have voiced their desires for the development of a crawfish peeling machine. The need has resulted in at least 16 patents for peeling machines being granted since 1974.[1] Although each of these machines has shown potential, none has been made commercially available. Each has not accomplished one or more of the following when separating the tail meat from the shell: (1) deveining, (2) retaining the hepatopancreas, commonly called "fat," (3) the ability to peel fresh (versus frozen) meat, or (4) allowing for peeling without personal handling of each individual crawfish. Furthermore, most of the developers have had limited resources for introducing, promoting, and producing machines in sufficient volume for the processing market. Significantly large capital resources would be required for research, development, and distribution of a machine.

Seafood processing equipment developers and manufacturers have expressed to us the need for information about expected market volume for a crawfish peeling machine if resources were devoted to machine development. This information would have value given the significant investment required to develop and market a machine, as well as the uncertainty of volume expected in this relatively "small" industry.

In 2003, we were approached by crawfish industry leaders to conduct a feasibility study for the development of a crawfish peeling machine. Objectives of the portion of the study reported in this paper were to determine: (1) potential rates of adoption of three hypothetical machines, recognizing the role of uncertainty in adoption, and (2) the types of processors most likely to adopt each of the machines. In addition to the information this study provides to potential developers of a

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[1] A list of patents for crawfish-peeling technology is available from the authors.

crawfish peeling machine, agricultural economics researchers may benefit from the analysis in several ways. The paper provides an *ex ante* technology adoption analysis of an as-of-yet undeveloped technology that would require substantial investment in research and development for a limited market; thus, enticement of research and development by private firms provides significant challenges. In addition to providing a methodology for researching this situation, we discuss potential challenges, pitfalls, and recommendations to researchers conducting technology adoption studies of this type.

Background

The crawfish peeling segment has become more vocal in recent years about the need for a peeling machine, as increased foreign competition has placed downward pressure on the price of peeled crawfish tail meat. In the mid-1990s, China began exporting crawfish tail meat into the United States, resulting in frozen tail meat being sold in United States grocery stores at prices often lower than the U.S. cost of production. In 1997, the U.S. International Trade Commission determined that the U.S. crawfish tail meat industry had been "materially injured" by the import of tail meat from China: the meat had been sold at "less than fair value." An antidumping duty order was subsequently placed on imported tail meat from China, to be continued after a 5-year review in 2002. The duty partially offsets the competitive disadvantage experienced by the U.S. crawfish peeling industry (U.S. International Trade Commission).

Partially the result of increased foreign competition, U.S. crawfish peeling firms have decreased in number over the past decade. In 1996, Gillespie and Capdeboscq identified 80 processors of crawfish tail meat. The present study found less than half that number peeling crawfish in 2004. The U.S. International Trade Commission reports increased U.S. consumption of crawfish tail meat from 5.27 million pounds in 1994 to 10.55 million pounds in 2002, while the U.S. share of total production decreased from 42.4% to 13.1% over that period. Unit values of U.S. imports from China varied between $1.59 and $3.61 per pound, while those cited for the U.S.-produced crawfish varied from $5.13 to $8.28 per pound (U.S. International Trade Commission). The products are close substitutes, with the main differences being that the product from China cannot be sold as fresh and the golden-yellow hepatopancreas, which is generally considered by Louisiana consumers to provide flavor, is not included.

The U.S. crawfish peeling industry uses essentially the same technology it has used for three decades. Annually during February–June, processing firms hire peelers who work 4 to 8 hours per day peeling crawfish by hand. Peelers are paid on a piece-rate basis, by the pound. In 2004, the average wage per pound was $1.54. A typical peeler could peel 42 pounds per day, depending upon individual productivity and the size of the crawfish (Gillespie and Lewis).

Previous Literature on Factors Influencing Technology Adoption

The present study analyzes the adoption of an as-of-yet undeveloped technology. The agricultural economics literature on *ex post* technology adoption is extensive. Two studies providing extensive literature reviews on factors influencing technology adoption include Feder, Just, and Zilberman; and later Marra and Carlson. They provide insights on the influence of firm-specific factors on technology adoption.

The literature on *ex ante* technology adoption is less extensive. Four studies and the technologies for which potential adoption was examined include Hubbell, Marra, and Carlson, *Bacillus thuringiensis* (Bt) cotton adoption among southeastern cotton producers; Hudson and Hite, precision application/site-specific management technologies; Kinnucan et al., bovine somatotropin adoption among southeastern dairy producers; and Qiam and de Janvry, Bt cotton in Argentina. All use contingent valuation methods to determine nonadopter willingness to pay for technologies that had been introduced and

were in the diffusion stage. A fifth study, by Kenkel and Norris, uses contingent valuation to determine willingness to pay for an innovation, mesoscale weather information, that would require a relatively minor initial fixed investment, but had not been developed.

The literature on the *ex ante* adoption of an undeveloped technology that would require a substantial initial fixed capital investment is limited, or nonexistent in the extreme. This study, therefore, addresses a unique problem that is made even more unique by the very limited market (likely <40 firms) that would exist for the product.

Conceptual Framework

On the surface, crawfish peeling machine adoption analysis is straightforward: the processor will adopt if adoption is more profitable than nonadoption. Adoption thus occurs if additional revenues plus reduced costs associated with adoption exceed reduced revenues plus additional costs associated with adoption. This involves the use of partial budgeting, as described by Boehlje and Eidman. Additional revenue would include additional sales of crawfish resulting from less-binding factor constraints; reduced costs would include those associated with peeling labor; reduced revenues would include reduced sales of crawfish resulting from greater input constraints; and additional costs would include those associated with purchasing, installing, and operating the machine.

Gillespie and Capdeboscq, and later Gillespie and Lewis, provide partial budgeting analysis of crawfish peeling machines as described above. The latter study showed that total annual additional revenues plus reduced costs associated with a peeling machine averaged $234,662. Thus, for processors to adopt, additional costs associated with a peeling machine could not exceed this amount for the average-sized firm.

Although a partial budget associated with adoption may be developed for each firm, true willingness of each processor to adopt may not be as easily ascertained. Adoption would also depend upon additional factors such as firm diversification or future plans for the operation. For instance, although adoption would appear to be profitable for several of the processors interviewed for this study if they were assumed to continue operations for another decade, these processors answered that they would likely not adopt because they planned to retire in the near future, with no family member to take over the operation.

Discussion with processors before the survey suggested that they could respond to willingness-to-adopt questions for specific hypothetical machines if provided sufficient information. Some, however, would be unable to provide responses with 100% certainty. This was expected, given sizeable initial investments and a desire to "see" the machine operate before committing to adoption. Though the technology considered in this study is as-of-yet undeveloped in the form assumed, prototype crawfish peeling machines that have not accomplished all four of the tasks listed earlier have been developed and tested, with many processors having observed their operation. Thus, the authors were not concerned that the technology would be too abstract for the respondent to visualize if adequately described. Respondents could then provide assessments of willingness to adopt if uncertain responses were allowed.

The contingent valuation literature dealing with uncertain responses offers insights for this study. Arrow et al. suggested incorporating "do not know" responses into contingent valuation questions. Others incorporating uncertainty using contingent valuation with various question formats have included Alberini, Boyle and Welsh; Blamey, Bennett and Morrison; Caudill and Groothuis; Champ et al.; Groothuis and Whitehead; Li and Mattson; Ready, Navrud and Dubourg; Ready, Whitehead and Blomquist; van Kooten, Krcmar and Bulte; Wang; and Whitehead et al.

Two of the studies, Ready, Whitehead and Blomquist, and Whitehead et al., have compared the results of dichotomous-choice (yes or no) formats including follow-up questions to assess level of certainty with polychotomous-choice formats (where the initial contin-

gent valuation question includes greater than two responses, allowing for uncertainty or ambivalence). Ready, Whitehead, and Blomquist found that responses that did not indicate certainty in response were common, that polychotomous-choice questions resulted in higher response rates and generally more positive responses, and that dichotomous-choice respondents replied "yes" only if there was substantial certainty in the response. Whitehead et al. reduced the number of potential responses in their polychotomous-choice formats relative to Ready, Whitehead, and Blomquist and found construct validity for both polychotmous- and dichotomous-choice questions under the conditions utilized. They conclude on page 112 that, "The (polychotomous choice) valuation question is a potentially valuable technique for eliciting (willingness to pay), especially when the intensity or certainty of respondent preferences is an issue that must be considered."

For the crawfish processor determining whether to adopt a peeling machine with a relatively high associated initial investment, a polychotomous-choice willingness-to-adopt question is utilized. The processor would be provided with a detailed description of the hypothetical machine in question, including capacity, size, input requirements, cost, etc., and then asked, "Would you purchase (lease) this machine?" Respondents would then be provided with responses that would allow them to indicate their levels of certainty. The presence of multiple choices in response is expected to encourage the respondent to carefully consider his or her true willingness to adopt.

Data and Methods

During fall 2004, a list of all crawfish processors in Louisiana was obtained from the Louisiana Department of Agriculture and Forestry. This list was narrowed to those possibly peeling crawfish via discussion with Louisiana Department of Agriculture and Forestry staff who were involved in seafood processing work. In January and February 2005, all 53 firms from the narrowed list were sent letters requesting interviews. They were then phoned to arrange personal interviews. Of the 53 letters sent, five were returned as nondeliverable (and thus assumed no longer in business). Ten firms indicated they were no longer in business, three would not agree to the survey, one was not a crawfish peeling firm, and seven either were never reached after repeated attempts or a time could not be agreed upon for the survey. Three of the interviewed firms had peeled crawfish in the past, but had since discontinued peeling and dealt only with live crawfish. They were interviewed because they stated that they would have an interest in resuming crawfish peeling if a peeling machine were developed. Thirty firms were interviewed for the study. It is estimated that these firms represent $\geq$75% of the domestic crawfish peeling firms since (1) the authors are unaware of sizeable domestic crawfish peeling firms outside of Louisiana and (2) only 10 additional Louisiana firms were possibly peeling crawfish (the three not agreeing to the survey and seven not reached).

The questionnaire solicited information on current input usage and costs, volume processed, willingness to adopt specific hypothetical machines, and a conjoint analysis to determine the relative importance of specific machine attributes. The present paper reports on the section dealing with the willingness to adopt specific hypothetical machines. Each interview generally lasted 45 to 90 minutes.

Processors' willingness to adopt each of three hypothetical machines was elicited. Hypothetical machine profiles were developed by us on the basis of interaction with potential developers of peeling machines. The developers had extensive experience with developing and marketing seafood processing equipment and understanding of the unique characteristics of crawfish. For the two larger machines, specifications of existing shrimp-peeling machines were modified according to expectations for crawfish.

Once hypothetical machine profiles were developed, they were sent to potential developers. Their reactions were requested to ensure that the machines were realistic possibilities if research and development resources

were devoted. The potential machines were: (1) a 1,000-pound-per-hour "medium-sized" machine, (2) a 2,000-pound-per-hour "large-sized" machine, and (3) a small, individually fed machine.

Handouts with specifications for each of the machines were developed and provided to each of the respondents during the interview. Descriptions, specifications, and prices of the machines provided on the handouts are included in Appendix 1. Each machine was described by the interviewer. Respondents were encouraged to examine the machines carefully, including consideration of operating costs, before questioning.

After examination of the medium-sized machine, respondents were asked, "Would you purchase this machine?" Respondents were to indicate one of the following responses: (1) I am 100% certain I would purchase this machine; (2) I am almost certain I would purchase this machine (with 81% to 99% certainty); (3) I would more than likely purchase this machine (with 61% to 80% certainty); (4) I am not at all certain whether or not I would purchase this machine (with 41% to 60% certainty); (5) I would more than likely not purchase this machine (with 61% to 80% certainty); (6) I am almost certain I would not purchase this machine (with 81% to 99% certainty); and (7) I am 100% certain I would not purchase this machine.

Following this question, respondents were asked for the medium-sized machine, "Alternatively, would you lease this machine at a comparable rate on an annual basis?" The same responses were provided except that the word "purchase" was replaced with "lease" in each of the responses. After asking these questions for the medium-sized machine, both sets were repeated for the large-sized machine. Only the purchase question was then asked for the small-sized machine since its purchase cost was relatively low ($2,000). All respondents were first asked about the medium-sized machine, followed by the large, and finally the small-sized machine.

Before eliciting responses for each machine, it was made clear to the respondent to assume the machine and purchase/lease option being assessed would be the only product available. We were attempting to eliminate the possibility that the respondent would reduce his willingness to adopt a less-favored machine because of a belief that another favored machine would be available. Because the crawfish processing industry has so few firms, it is unlikely that multiple machines would be made available. For the lease option for the medium- and large-sized machines, it was assumed that a lease at a "comparable rate on an annual basis" would be understood by respondents since other crawfish processing machinery (such as cookers, etc.) is routinely leased by processors. Thus, they would be familiar with typical lease arrangements offered by seafood processing equipment distributors. Because of the complexity of the existing questions and the respondents' familiarity with typical leases, it was decided by the researchers to not discuss the leases in greater detail for fear that respondents would become fatigued by being provided too much information.[2] Split samples were not used to assess preferences for only one machine per respondent because of the small sample size and the result that too few observations would be available for each machine.

During machine description, most respondents calculated total cost and compared it with current labor costs. The authors' calculations for the large-sized machine suggest the cost per pound peeled would be $1.09 per pound plus water cost, assuming $37,000/year straight-line depreciation over 10 years, $11,470/year interest on an average investment at 6.2%, $115,905/year for electricity, labor, and repairs, and 75,600 pounds/year of peeled

[2] A "comparable rate" would likely be determined that would cover depreciation and interest, plus a premium for the risk associated with the firm discontinuing use before the conclusion of its useful life. An anonymous reviewer questioned our referring to the lease price as at a "comparable rate on an annual basis." Although the processors were generally familiar with lease terms for processing equipment, in many cases researchers conducting similar *ex ante* technology research along these lines would need to be more specific about lease terms to reduce the potential for different interpretations of the lease by respondents.

crawfish tail meat produced. Similarly, the medium-sized and small-sized machine costs per pound would be, respectively, \$1.57/lb. plus water cost and \$1.41/lb. plus water and electricity costs. These, however, were not provided to respondents, as they were to make calculations on the basis of their firm's unique situations.

This study is not a contingent valuation study; contingent valuation studies are designed to estimate demand. Willingness to adopt in the present study is elicited on the basis of one price for each machine. Thus, demand cannot be estimated. The authors chose not to offer multiple price levels (different prices for different respondents for a given machine) for two reasons. First, reasonable lower and upper bounds on offered prices could not be determined since the machines were hypothetical in nature; only a reasonable price on the basis of prices charged for similar seafood processing machines were considered good estimates for price. Second, only 30 firms were to be surveyed. Dividing the group into subgroups, each offered a machine at a different price in a single-bounded question format, would have provided few observations for each price level. Likewise, the authors judged that using a payment card or other more complex contingent valuation methods would have made the task overly difficult for respondents given the extensive information provided on the machines. Uncertainty in response would have been very difficult if not impossible to gauge using one of these methods.

Upon the collection of willingness-to-adopt responses for all 30 individuals, the expected number of machines j to be purchased (or leased) was estimated as

$$\text{(1)} \quad \text{Expected number adopted} = \sum_{i=1}^{7} n_{ij} p_{ij},$$

where n_i indicates the number of respondents indicating response i (how certain the individual is of adopting or not adopting) a machine, and p_i indicates the probability of purchasing (or leasing) the machine, determined as the midpoint in the range of certainty for each response level. Likewise, the expected adoption rate was estimated as

$$\text{(2)} \quad \text{Expected adoption rate} = \frac{\sum_{i=1}^{7} n_{ij} p_{ij}}{R_j} \times 100,$$

where R is the number of respondents answering the question.

Ordered probit analysis was used to determine the types of processors most likely to adopt. Ordered probit is suitable when the dependent variable is inherently ordered and takes on more than two values. Limited dependent variables that are ordinal in nature, rather than cardinal, call for models that allow the intervals to vary among responses. The ordered probit allows for this type of dependent variable. In this study, seven potential responses that were ordinal in nature were provided, ordered from 0 = [I am 100% certain I would not purchase (lease) this machine] to 6 = [I am 100% certain that I would purchase (lease) this machine]. Probabilities in the ordered probit were estimated as in Greene:

$$\text{(3)} \quad \begin{aligned} &\Pr(y = 0) = \Phi(-\beta' x), \\ &\Pr(y = 1) = \Phi(\mu_1 - \beta' x) - \Phi(-\beta' x), \\ &\Pr(y = 2) = \Phi(\mu_2 - \beta' x) - \Phi(\mu_1 - \beta' x), \\ &\vdots \\ &\Pr(y = J) = 1 - \Phi(\mu_{J-1} - \beta' x) \end{aligned}$$

where Pr(.) represents probability, y are the values the dependent variable may take, $\Phi(.)$ denotes the standard normal distribution, μ are threshold levels *associated with the responses*, β are estimates, and x is the vector of independent variables. For positive probabilities, the following condition holds: $0 < \mu_1 < \mu_2 < \ldots < \mu_{J-1}$. One ordered probit model was run for each machine, and an additional aggregate model was run including all three machines. The LIMDEP program was used to run the ordered probit models.

Factors x are expected to influence adoption and the certainty associated with adoption. Factors may be categorized into those dealing with (1) firm size and structure, (2)

Table 1. Descriptive Statistics of 30 Surveyed Processing Firms

Variable Name	Definition	Units	Mean	Std Dev	Minimum	Maximum
Peeled Meat	Amount of crawfish tail meat peeled annually.	lbs./1,000	59.233	43.794	0.000	200.000
Value Added	Whether the firm was vertically integrated with the production of value-added products. Yes = 1, No = 0.	0/1	0.100	0.301	0.000	1.000
Percent Peeled	The percentage of purchased live crawfish peeled.	%	43.833	35.726	0.000	100.000
Diversified	Whether the firm was diversified into processing other seafood species. Yes = 1, No = 0.	0/1	0.533	0.501	0.000	1.000
Labor	"Do you have enough labor available to you throughout the peeling season for peeling crawfish?" Yes = 1, No = 0.	0/1	0.400	0.492	0.000	1.000
Cooker Capacity	"How many pounds of live crawfish can your cooking facilities handle in one day?"	lbs.	14,358	133	1,200	40,000
Continuous Cook	Whether the firm owns a continuous cooker. Yes = 1, No = 0.	0/1	0.233	0.424	0.000	1.000
Alter	Would you have to alter your facility to introduce a machine requiring 35 ft. × 50 ft.? Yes = 1, No = 0.	0/1	0.448	0.499	0.000	1.000
Wage	Price per pound paid to peeling labor.	Dollars	1.54	0.162	1.30	2.00
Years	How many more years do you expect to be peeling crawfish if the market remains favorable for peeling?	Number	15.033	10.977	1.000	50.000
Family	Do you have a close family member to take over when you retire from crawfish processing? Yes = 1, No = 0.	0/1	0.6000	0.492	0.000	1.000

resource availability, (3) machine attributes, and (4) producer plans for the future. Table 1 lists and defines the variables, to be discussed in the following sections.

Firm Size and Structure and Adoption

Operators of larger firms were expected to more likely adopt machines, as they can spread the fixed investment cost over greater volume, as shown in previous studies including Feder, Just, and Zilberman. These operators were likewise expected to be more certain of eventual adoption if there were greater certainty about whether its capacity could be fully utilized. Firm size was measured as *Peeled Meat*.

A firm's vertical integration with upstream or downstream firms was expected to influence adoption. Some peeling firms vertically integrate with downstream segments that add value to peeled crawfish with products such as

crawfish etouffee, gumbo, or crawfish stuffing. The downstream segment was expected to prefer to reduce the uncertainty associated with acquiring a stable supply of input (peeled crawfish tail meat), enabling it to increase its technical efficiency. Crawfish processors have consistently conveyed to the authors that uncertainty associated with labor availability would positively affect their demand for a crawfish peeling machine. Thus, firms vertically integrated with downstream segments, indicated by *Value Added*, were expected to more likely adopt peeling machines and to be more certain of adoption.

Vertical integration exists with the upstream segment, live crawfish sales, for most peelers. Most purchase live crawfish and then grade it, selling the large grades live to consumers, seafood markets, or restaurants (or all three), and cooking and peeling the small grades. Some processors termed the peeling segment a "salvage" operation through which small crawfish that could not be profitably sold in the live market could be utilized. Processors receiving higher percentages of revenue from peeled, packaged crawfish tail meat relative to live crawfish, measured as *% Peeled*, were expected to be more likely to adopt a peeling machine and more certain of their willingness to adopt.

Diversification via the processing of other seafood species (*Diversified*) was expected to influence peeling machine adoption. Most seafood processing is relatively labor intensive, especially for species such as crab, where peeling is done largely by hand. Discussion with processors diversified into crab peeling revealed that, since crab and crawfish peeling seasons did not coincide, labor could be allocated across seasons accordingly, effectively reducing the attractiveness of a peeling machine. Alternatively, the diversified firm's span of control is wider, a factor that might lead to greater mechanization as the firm grows.

Resource Availability and Adoption

A firm's resource endowment was expected to influence its willingness to adopt and its certainty of adoption. Direction of influence would depend upon the substitutive or complementary relationship of the resource of interest with the technology. Given the substitute relationship between a peeling machine and labor, firms with an adequate, consistent supply of labor (measured as *Labor*) for peeling crawfish were expected to be less favorable toward a peeling machine and, hence, less prone to adopt. Likewise, those currently paying higher wages (measured as *Wage*) were expected to more likely adopt.

The complementary relationship between cooking capacity (*Cooker Capacity*) and a medium- to large-sized peeling machine suggests that processors with greater cooking capacity would be greater peeling machine adopters. Several processors suggested that product consistency resulting from the continuous cooker technology would be complementary with successful utilization of a peeling machine. Thus, those with continuous cookers (*Continuous Cook*) were expected to be greater adopters.

A complementary relationship between existing facilities and a peeling machine would positively influence adoption. Respondents were asked, "Suppose a crawfish peeling machine were made available to you. It is assumed that the machine would replace your current peeling labor. Suppose this peeling machine required a space of 900 square feet, or a space of 35 feet by 50 feet. This does not include the space for cooking the product or packaging it. Would you have to alter your current facility significantly in order to introduce this machine?" This was the space estimated as needed to adopt the large-sized machine. Respondents answering "no" were expected to be less likely to adopt the large-sized, and to a lesser degree the medium-sized, machines. *Alter* indicates whether space was a constraint.

Machine Attributes and Adoption

Machines meeting certain specifications or conducting specific tasks were expected to be more attractive to processors. Some attributes were not varied among the machines, such as

Table 2. Frequency of Responses and Expected Adoption Rate, Crawfish Peeling Machine

Response	All Responses	Purchase Large	Lease Large	Purchase Medium	Lease Medium	Purchase Small
I am 100% certain I would purchase (lease) this machine.	24	1	3	3	7	10
I am almost certain I would purchase (lease) this machine (with 81% to 99% certainty).	19	2	6	2	6	3
I would more than likely purchase (lease) this machine (with 61% to 80% certainty).	30	4	3	8	9	6
I am not at all certain whether I would purchase (lease) this machine (with 41% to 60% certainty).	10	0	3	6	1	0
I would more than likely not purchase (lease) this machine (with 61% to 80% certainty).	10	4	2	3	1	0
I would more than likely not purchase (lease) this machine (with 81% to 99% certainty).	4	0	0	1	1	2
I am 100% certain I would not purchase (lease) this machine.	49	18	12	7	3	9
Total responses	146	29	29	30	28	30
Expected number of firms adopting	n/a	7	13	14	20	17
Expected adoption rate, %	n/a	23	43	48	70	57

n/a is not applicable.

whether they deveined, retained the backstrap, or retained the hepatopancreas; each of the machines was assumed to conduct these. One attribute was varied within machine (purchase or lease), and a second across machines (capacity). Processors were expected to less likely adopt if they were required to purchase a machine than if leased at a comparable rate on an annual basis (designated as *Purchase*). The lease would allow producers to test the machine before investing in its purchase, thus its preferred status if offered at a comparable rate. The machine's processing capacity would be a second attribute to be assessed (designated as variables *Large* and *Small*). These two variables were included only in the aggregate model.

Processor Plans for Future and Adoption

Processors expecting to remain in crawfish peeling longer were expected to be the greater adopters of peeling machines. Producers with longer planning horizons, measured as *Years*, may more fully realize the stream of benefits associated with the investment, especially if used machinery is undervalued in a limited market. Likewise, producers expecting a family member to take over the operation upon the producer's retirement (designated as *Family*) were expected to be greater adopters.

Results

Crawfish Peeling Machine Adoption Rates

Table 2 provides frequencies of response, expected numbers of machines adopted, and expected adoption rates. The top four most frequently provided responses, in descending order, were: (1) I am 100% certain I would not purchase (lease) this machine, (2) I would more than likely purchase (lease) this machine (with 61% to 80% certainty), (3) I am 100% certain I would purchase (lease) this machine, and (4) I am almost certain I would purchase (lease) this machine (with 81% to 99% certainty). Relatively few responded that they were not at all certain about purchasing the machine or that they were 61% to 99% certain they would not purchase the machine. Discussion with respondents indicated that those generally positive toward the machines were reluctant to provide 100% certain responses

because they would need to examine an actual machine and conduct more rigorous investment analysis before committing. A dichotomous-choice question would likely have led many of those who were not 100% certain of adopting to indicate "no" answers if a strict conservatism rule were used, as discussed by Ready, Whitehead and Blomquist. The relatively high number of respondents who were certain they would not adopt is attributed mainly to the large machine, which was too large for many of the smaller firms to effectively use at full capacity.

Adoption rates among machines, from highest to lowest according to the calculation in Equation (2), are (1) lease the medium-sized machine, (2) purchase the small-sized machine, (3) purchase the medium-sized machine, (4) lease the large-sized machine, and (5) purchase the large-sized machine. Of interest is that, assuming a machine would be purchased, the small-sized machine would be the most extensively adopted. This is due in large part to adoption not only by large processors, but also by the smallest processors. If a small-sized machine were to be offered for lease, results from the other machines suggest that its adoption rate would exceed that for purchasing the small-sized machine and, perhaps, leasing the medium-sized machine.

Expected adoption rate varies greatly from the adoption rate if only those who were 100% certain of adopting are considered. Seven to 20 firms would adopt, depending upon the machine and terms offered, using Equation (2). On the other hand, 1 to 10 would adopt if only those who were 100% certain of adopting were considered adopters. The more risk-averse developer would tend to focus on the latter adoption rate.

Descriptive Statistics of Independent Variables

Table 1 provides statistics of the independent variables. The average-sized firm peeled 59,233 pounds of meat annually, and peeling accounted for about 43.8% of the firm's receipts. Just over half the firms were diversified into the processing of another seafood species, and few were involved in value-added crawfish activities. Only 40% felt they had enough labor available throughout the peeling season. Most were not utilizing their full cooking capacity, so this was rarely a constraint to adoption. Only 23% owned continuous cookers, a constraint if consistency resulting from a continuous cooker is needed to effectively adopt a peeling machine.

Nearly half (45%) of the firms would have to alter facilities extensively to introduce a large-sized peeling machine. The average wage paid per pound of peeled crawfish was $1.54, ranging from $1.30 to $2.00. The average operator planned to remain in the peeling business for ≥15 years, and 60% expected a family member to take over the operation upon their retirement.

Ordered Probit Results

Table 3 provides ordered probit results. For the individual machine runs, response categories were combined because of having zero or very few responses in some of the categories; hence, fewer μ threshold estimates are estimated. For the large-sized machine, categories "I would more than likely not purchase (lease) this machine (with 61% to 80% certainty)" was combined with "I am almost certain I would not purchase (lease) this machine (with 81% to 99% certainty)." For the medium-sized machine, categories "I am 100% certain I would not purchase (lease) this machine" was combined with "I am almost certain I would not purchase (lease) this machine (with 81% to 99% certainty);" and "I am not at all certain whether I would purchase (lease) this machine (with 41% to 60% certainty)" was combined with "I would more than likely not purchase (lease) this machine (with 61% to 80% certainty)." For the small-sized machine, three categories were combined: "I would more than likely purchase (lease) this machine (with 61% to 80% certainty)," "I am not at all certain whether I would purchase (lease) this machine (with 41% to 60% certainty)," and "I would more than likely not purchase (lease) this machine (with 61% to 80% certainty)."

Processors of greater volumes of meat were more likely than smaller ones to adopt the

Table 3. Ordered Probit Results, Aggregate and Individual Adoption Models

	Aggregate Model		Large-Sized Machine		Medium-Sized Machine		Small-Sized Machine	
Variable	Beta	Std Error	Beta	Std Error	Beta	Std Error	Beta	Std Error
Constant	1.1421	1.2518	5.7255**	2.7635	1.5395	1.9334	−2.7826	2.9323
Peeled Meat	0.0034	0.0043	0.0198***	0.0068	0.0041	0.0046	−0.0120	0.0085
Value Added	0.3582	0.3800	−0.3175	0.7080	0.4611	0.6064	1.4303	0.9122
Percent Peeled	0.0085**	0.0038	0.0128	0.0084	0.0085	0.0063	0.0065	0.0084
Diversified	0.6956**	0.3472	2.1167*	1.1168	1.0071*	0.5394	−0.0035	0.7167
Labor	−0.4184	0.2597	−0.4164	0.5736	−0.5080	0.3987	−1.7315**	0.7058
Cooking Capacity	0.0000*	0.0000	0.0001**	0.0000	0.0000*	0.0000	−0.0000	0.0000
Continuous Cook	−0.3341	0.3884	−0.9130	1.0859	−0.5361	0.6307	−0.5432	0.7864
Alter	−0.5262*	0.2735	−1.6897**	0.7465	−0.5662	0.4250		
Wage	−0.9417	0.7088	−7.2859**	2.2681	−1.3774	1.1016	3.8186**	1.8124
Purchase	−0.5778**	0.2351	−1.0496**	0.4093	−0.7433**	0.3282		
Large	−1.3141***	0.5017						
Small	1.4035**	0.6098						
*Peeled*Large*	0.0076	0.0060						
*Peeled*Small*	−0.0187**	0.0080						
Years	0.0300***	0.0112	0.0848***	0.0295	0.0294*	0.0176	0.0221	0.0280
Family	0.1764	0.3180	1.8590*	1.1196	0.8293*	0.4893	−1.7824**	0.8014
μ_1	0.0958*	0.0528	0.6695***	0.2138	0.8383***	0.2119	0.5211*	0.2862
μ_2	0.3950***	0.0921	0.7674***	0.2200	2.0058***	0.2356	1.2392***	0.3046
μ_3	0.5704***	0.1034	1.4458***	0.2703	2.5979***	0.2765	1.5349***	0.3246
μ_4	1.2644***	0.1298	2.9307***	0.4743				
μ_5	1.8320***	0.1586						
Pseudo R^2	0.1334		0.3735		0.1978		0.2971	
% Correct prediction	35.3448		58.6957		45.6522		60.0000	

***, **, and * indicate significance at the 0.01, 0.05, and 0.10 levels, respectively.

large-sized machine, as expected. Volume, however, did not significantly affect adoption of the medium- or small-sized machines, as a wider range of processor sizes could effectively adopt these machines without increasing operation size.

Vertical integration into value-added products did not significantly affect adoption. As expected, those peeling higher percentages of purchased live crawfish, however, were more likely to adopt machines, on the basis of results of the aggregate model. Diversification into other seafood products positively affected the probability of adopting the large-sized and medium-sized machines. This result tends to support the argument that those with greater spans of control will mechanize to reduce uncertainty.

Resource availability influenced willingness to adopt. Those having sufficient labor available throughout the peeling season were less prone to adopt the small-sized machine. On the other hand, those paying higher wages were more likely to adopt the small-sized machine. These results suggest that labor issues, particularly labor costs, are important in the adoption decision of the small-sized machine. Surprisingly, those paying higher wages were less likely to adopt a large-sized machine. This may be partially explained if paying higher wages results in more productive and reliable labor.

Processors with greater cooking capacity were more likely to adopt the large-sized and medium-sized machines. Cooking capacity would have to be sufficiently high to effectively adopt these machines relative to the small-sized machine. The need to alter facilities to accommodate a machine requiring 35 ft. $\times$ 50 ft. would constrain adoption of the large-sized machine. This variable was not included in the small-sized machine equation since the small-sized machine could be adopted in any of the facilities visited.

Machine attributes and terms influenced adoption. Leasing was more attractive to processors in adopting the large- and medium-sized machines, allowing processors to "try out" the machine before purchasing. Since the lease option was not considered for the small-sized machine, it was not included in the small-sized machine equation.

Four variables were included only in the aggregate model to examine differences in willingness to adopt by machine. If the machine was large versus medium sized, processors were less willing to adopt. If the machine was small versus medium sized, processors were more willing to adopt. Interaction variables between amount peeled and machine size adds further insight. As expected, larger peelers offered the small-sized machine were less willing to adopt.

Future plans for the operation significantly influenced adoption. Those expecting to continue peeling longer were more likely to adopt. This relationship was highly significant for the large-sized machine, and to a lesser degree (at the 0.10 level) for the medium-sized machine. Those with family expected to take over the operation upon the operator's retirement were more likely to adopt the large- and medium-sized machines. They were less likely, however, to adopt the small-sized machine. This unexpected result could indicate processors' feelings that the small-sized machine will not be "frontier technology" in the long run.

Conclusions and Discussion

Results of this study suggest that, of the 30 firms, adoption rates of 23% to 70% would be expected, depending upon the machine and terms offered. The lowest adoption rates were for the large-sized machine and the highest rates for the small-sized machine. A relatively small number of existing firms in the industry could utilize the large-sized machine to full capacity without increasing peeling operations substantially. If uncertain responses were not considered as potential adopters, expected adoption rates would be much lower, with adoption rates of approximately 3% to 33%.

A large-sized machine would provide significant economies of size. Thus, its introduction would likely significantly alter the structure of the crawfish peeling segment. The segment would likely narrow to fewer firms, each with large-sized machines. These firms might contract with smaller processors to peel

crawfish, as mentioned by several respondents during interviews. Introduction of a small-sized machine would be expected to have minimal impact on concentration, with little change in economies of size. Although development of a large-sized machine would lead to fewer machines being sold, lower unit costs would likely result in more crawfish being peeled by fewer firms.

Though the description of firms adopting varies somewhat by the type of machine developed and marketed, a number of general conclusions can be drawn. Larger firms peeling higher percentages of purchased live crawfish and that are diversified into the processing of other seafood species would be the greater adopters. Those with extensive resources would be the greater adopters. Finally, those with longer planning horizons would be the greater adopters. Overall, this analysis suggests that the larger processors in family businesses with more extensive resource bases will more likely adopt, an expected result given previous research and general microeconomic theory.

From a methodological standpoint, we were generally pleased with the performance of the willingness-to-adopt methodology used. Likely because this is an important topic that the industry has discussed widely for many years, the willingness of processors to participate in the survey was relatively high. Likewise, they generally paid close attention to descriptions of the machines and carefully considered their responses before answering questions about their willingness to adopt. This high level of interest and the importance of the topic are believed to have played key roles in the success of the polychotomous-choice question method.

We acknowledge that, theoretically, high interest in the subject area might be expected to bias some respondents' responses, generally upward if there were extensive support. It is our contention, however, that the polychotomous-choice method caused the respondents to pause and carefully consider their true responses, minimizing response bias. This is plausible on the basis of the questions asked by respondents during the interviews and our general observance of concentration efforts of respondents during the interviews. We urge, however, future research on whether this method provides more accurate responses when complex adoption questioning is used, relative to dichotomous-choice frameworks that allow for follow-up certainty questioning. This type of comparison would have to be made with a larger number of respondents than could be done with the current study.

Suggestions for Ex Ante Adoption Studies on Technologies with Limited Markets

Because the potential market (and thus number of potential respondents to the survey) was so small, 30, dividing the sample and eliciting responses for only one machine for each respondent would not have resulted in enough responses for each machine to adequately assess willingness to adopt for the industry. If designing the survey today, we would examine different orderings of presentation of the machines, perhaps one-third receiving the medium–large–small machine sequence, one-third receiving the small–medium–large machine sequence, and so forth. Although our observations during the interviews do not lead us to believe that the order of questions biased responses, dividing the sample as discussed would have allowed for testing as to whether the order sequence influenced response. We suggest others conducting this type of research consider the ordering of questions accordingly.

We also suggest that, in cases where it is expected that there will be enough responses to warrant it, multiple prices be offered to respondents. If uncertainty is to be assumed with a single-bounded question, as with this study, the researchers might consider splitting the sample such that respondents receive different prices for the machine. This would allow for demand to be estimated.

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Appendix. Descriptions of Machines Used in the Questionnaire

1,000-Pound-per-Hour "Medium-Sized" Machine

This machine does the following things:

1. Peels 1,000 lbs. of shell-on, cooked crawfish per hour (8,000 lbs./8-hr. day, 40,000 lbs./40-hr. week, 168,000 lbs./21-d. month, or 504,000 lbs./3 mo.).
2. Allows an individual to pour 500-lb. totes of shell-on, cooked crawfish into a hopper at a time, and at the end of an "assembly line," peeled crawfish are delivered.
3. Crawfish are deveined, the backstrap is saved, and the fat is recovered.
4. Wastewater is filtered and recirculated, reducing water consumption. With this system, water usage is 28 gal./min. (1,680 gal./hr., 13,440 gal./d., 675,200 gal./wk., 282,240 gal./mo., or 846,720 gal./3 mo.).
5. The machine may be purchased for $250,000.
6. Electrical usage is based on 22 hp of use. As the machines are running, the charge is $1/hr. ($8/d., $40/wk., $168/mo., or $504/3 mo.).
7. Five workers are required to run this system. These include people familiar with the machinery and those who can inspect the product upon peeling. At a rate of $10/hr., this would cost $400/d. ($2,000/wk., $8,400/mo., or $25,200/3 mo.).
8. Assume the useful life of this machine is 10 years. Maintenance cost would be approximately $60,000/yr.

2000-Pound-per-Hour "Large-Sized" Machine

This machine does the following things:

1. Peels 2,000 lbs. of shell-on, cooked crawfish per hour (16,000 lbs./8-hr. day, 80,000 lbs./40-hr. week, 336,000 lbs./21-d. month, or 1,008,000 lbs./3 mo.).
2. Allows an individual to pour 500-lb. totes of shell-on, cooked crawfish into a hopper at a time, and at the end of an "assembly line," peeled crawfish are delivered.
3. Crawfish are deveined, the backstrap is saved, and the fat is recovered.
4. Wastewater is filtered and recirculated, reducing water consumption. Thus, water usage is 46 gal./min. (2,760 gal./hr., 22,080 gal./d., 110,400 gal./wk., 463,680 gal./mo., or 1,391,040 gal./3 mo.).
5. The machines may be purchased for $370,000.
6. Electrical usage is based on 29 hp of use. As the machines are running, the charge is $1.40/hr. ($11/d., $56/wk., $235/mo., or $705/3 mo.).
7. Five workers are required to run this system. These include people familiar with the machinery and those who can inspect the product upon peeling. At a rate of $10/hr., this would cost $400/d. ($2,000/wk., $8,400/mo., or $25,200/3 mo.).
8. Assume the useful life of this machine is 10 years. Maintenance cost would be approximately $90,000/yr.

Small, Individually Fed Machine

The machine does the following things:

1. The machine can sit on a table top. Its dimensions are 1 ft. × 2 ft.
2. Two people are needed to operate the machine, one to feed the individual crawfish into the machine and one to visually inspect them when they are peeled.
3. Crawfish are peeled and deveined. The backstrap is saved.
4. Crawfish fat may be recovered.
5. The machine can process 45 crawfish per minute.
6. The machine is electric.
7. The machine costs $2,000.
8. Assume the useful life of this machine is 10 years.

If the respondent answered that he or she would purchase this machine, the number of machines to be purchased was then asked.