Journal of Agricultural and Applied Economics, 31,1(April 1999):177–184

Valuation of Water Quality in Livestock Regions: An Application to Rural Watersheds in Iowa

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ABSTRACT

This paper investigates rural residents' perceptions of the risk to water quality from large confinement facilities and their willingness to pay to delay nitrate contamination from these facilities. Rural residents are concerned about the environmental impact of confinement facilities and are willing to pay as much as $82 annually to delay nitrate contamination in their water for 20 years. These contingent valuation results are consistent with the result obtained in similar studies that used hedonic valuation methods.

Key Words: contingent valuation, livestock production, nitrate contamination, rural development, water quality

Value-added agriculture in the form of increased livestock feeding is often touted as a viable development strategy for rural, agriculturally dependent areas. Economic impact studies have suggested that livestock expansion strategies have the potential of adding new jobs and incomes in rural areas (Hayes, Otto, and Lawrence, 1996). In the case of the pork industry, which is currently experiencing dramatic structural change, any major expansion is likely to be in the form of a large-scale confinement production. These operations can be as large as 3,500 sows and have feeding facilities for as many as 75,000 hogs per year. These large-scale facilities can produce abundant amounts of manure and odor, creating a nuisance for nearby residents. In addition, several highly publicized spills at facilities in North Carolina and Iowa and recent reports indicating a higher potential for groundwater contamination in Iowa (Perry, 1996) have reinforced the concerns about the vulnerability of water resources to nitrate runoff from hog waste.

Recent studies have attempted to quantify the external costs of large-scale livestock production with somewhat mixed results. Studies from North Carolina (Palmquist, Roka, and Vukina, 1997) and Michigan (Abeles-Allison and Connor, 1990) indicate adjacent property values were adversely affected, while results from Minnesota (Taff, Tiffany, and Weisberg, 1996) curiously indicate no adverse effect. Each of these studies uses a hedonic framework based on the market price of residential housing. These studies incorporate measures of proximity to livestock facilities into the hedonic price equation and test whether these proximity measures significantly improve the explanatory power of their models.

The hedonic price methodology is useful in deriving the external costs or benefits associ-

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ated with livestock production. Unfortunately, the current applications of this method have not allowed researchers to distinguish which factors of livestock production are most bothersome: what portion of the change in housing price is attributable to the odor nuisance, what portion to the potential change in water quality, and what portion to the change in other environmental disamenities? Since many of the potential disamenities associated with large-scale livestock production may require wholly different solutions, it is useful to price various disamenities separately. For instance, odor control may require a different solution than water quality assurance. Knowing the value of odor control and water quality assurance can help local governments identify specific concerns and determine if the cost of addressing these concerns is worth the potential benefit.

The objective of this paper is to use the contingent valuation (CV) methodology to determine the willingness to pay (WTP) of rural Iowa residents to delay nitrate contamination in their water supply. Two small watersheds in predominantly agricultural areas of southern Iowa were selected for this CV study. Both areas are heavily dependent on surface water for household consumption and both have been concerned with agricultural pollutants for some time. Like many rural areas in the Midwest, Clarke and Adams Counties are very interested in promoting development to offset population and economic losses in the agricultural sector. Their economic development experiences, however, have been markedly different. Clarke County, located along an interstate, has been more successful in attracting employment opportunities than the more remote Adams County. These differences were expected to create a potential contrast in attitudes toward agricultural development from the expansion of large confinement livestock operations.

The reliability of the CV methodology remains a subject of debate as highlighted by Diamond and Hausman (1994), Hanemann (1994), and Portney (1994). Two issues are of particular concern. First, CV estimates seem to be subject to what has been labeled the "embedding effect," where estimates for distinctly different quantities of a good do not differ as expected. For instance, McFadden (1994) found that the difference in willingness to pay for preserving a single wilderness area did not differ from the value of preserving multiple wilderness areas. Second, seemingly irrelevant changes in the survey instrument can produce distinctly different estimates. For instance, McFadden (1994) finds that estimates of willingness to pay differed depending on whether open-ended, single-referendum, or double-referendum type questions were asked. Diamond and Hausman (1994) conclude that the problems with CV estimates do not arise from a flaw in the methodology, but, instead, from an absence of preferences for the good being valued, which is often the nonuse value of an unfamiliar environmental commodity. However, when respondents are more familiar with the good, CV methods can provide useful information to policy makers.

Survey Methodology

The survey instrument was sent to a random sample of 1,000 residents, 500 from Clarke County and 500 from Adams County in Iowa (O'Gorman, 1995).[1] In addition to demographic and economic variables, respondents were asked how they felt about the importance of environmental issues at the national and local level. Respondents were asked their reaction to the potential siting of a large-scale hog facility in their area, and a series of three questions designed to determine their willingness to pay to delay nitrate contamination in their water. A total of 447 surveys were returned, of which 332 were complete and consistent for final response rate of 33.2%.[2]

Analysis of the data indicated there were no statistically significant differences between

[1] A copy of the survey instrument is available from the authors on request.

[2] Out of the 447 surveys returned, 21 responses were inconsistent because they implied contradictory choices. For example, the respondent might have indicated that he or she was willing to pay $75 for a 10-year delay, but not for an even longer delay of 20 years.

the residents of Clarke and Adams Counties in their responses to questions regarding concern for water quality from the potential siting of a large confinement facility near their homes. Respondents from both counties indicated high levels of concern over the potential contamination of local drinking water. The level of concern about potential nitrate contamination, however, was related to occupation, age, and source of drinking water. In response to various attitudinal questions, farmers and retirees, municipal water users, and respondents 60 years of age or older expressed a higher degree of concern about drinking water contamination.

The survey instrument questioned respondents about their ranking of environmental issues as a national and local policy issue. Over half of the survey respondents indicated that environmental concerns were a high or top priority as a national and local policy issue. Rankings of environmental issues varied according to occupation and gender. Male respondents and farmers considered environmental issues to be much less of a priority than other respondent classifications. This is an interesting paradox since farmers indicated a greater concern over the potential for water contamination from large-scale confinement operations.[3]

Empirical Method

The survey mechanism asked respondents a series of three referendum questions in order to determine how much they were willing to pay to delay nitrate contamination in their drinking water for 10, 15, and 20 years, assuming new and existing hog facilities would result in contamination beyond legal limits within five years. Bid values were held constant for all three questions on a survey but varied across surveys.[4] While follow-up questioning can improve the efficiency of willingness-to-pay estimates, anchoring effects can reduce these efficiency gains and cause bias. Anchoring occurs when a respondent's follow-up responses to subsequent bids are influenced by the initial bid posed by the survey instrument. In order to control for anchoring, questions were asked in the one-way up and one-way down formats and the data were analyzed following Herriges and Shogren (1996).

We assume that the initial minimum time delay that an individual is willing to accept for a given program is a function of the amount he or she would have to pay for the program, the length of time he or she plans to remain in the area accruing benefits from the program, and other socio-economic factors such as gender, age, education, number of children, occupation, and income. Define the minimum initial time delay as $T = f(X; \beta, \epsilon)$ where X is a vector of regressors, β is a parameter vector, and ϵ is a random disturbance. Define T_i to be the time delay proposed by the ith question where $i = \{1, 2, 3\}$. The probability that a respondent says yes to the first question is $\Pr(T = f(X; \beta, \epsilon) \geq T_1)$. Furthermore, assume that a respondent anchors to T_1 in question 1 when responding to questions 2 and 3 because of uncertainty regarding T (Boyle, Bishop, and Welsh, 1995; or Mitchell and Carson, 1989). Specifically, the individual's responses to the follow-up questions are assumed to be evaluated based on a weighted average of the initial time preference and T_1 such that $\tilde{T} = (1 - \gamma)T + \gamma T_1$ where $\tilde{T}$ is the individual's updated, anchored time preference and γ is a weighting factor that lies on the unit interval. When $\gamma = 0$, the respondent places no importance on the initial question when responding to follow-up questions. When $\gamma = 1$, the respondent anchors completely to the initial question and places no importance on his or her initial preferences when responding to follow-up ques-

[3] One potential explanation for this paradox suggested by an anonymous reviewer is that many of the farmers in our survey could be small hog producers "masking concerns of economic survival in terms of water quality." Unfortunately the survey did not ask farmers detailed enough information to test this hypothesis.

[4] Specifically, 25% of the surveys asked if respondents were willing to pay an additional $35 a year on their water bill or in local taxes, 25% were asked $75, 25% were asked $150, and the remaining were asked $300.

tions. Therefore the probability of the respondent saying yes to the ith question is

$$(1)\quad \Pr(\tilde{T} = (1-\gamma)f(X;\beta,\epsilon) + \gamma T_1 \geq T_i) = \Pr\left(f(X;\beta,\epsilon) \geq \frac{T_i - \gamma T_1}{(1-\gamma)}\right)$$

for $i = \{1, 2, 3\}$.

Specifying a functional form for T and the distribution of ϵ, we can operationalize the model in equation (1). Define $f(X; \beta, \epsilon) = X\beta + \epsilon$ where

$$(2)\quad X\beta = \beta_0 + \beta_1 \ln B + \beta_2 M + \beta_3 A + \beta_4 E + \beta_5 C + \beta_6 H + \beta_7 R_5 + \beta_8 W + \beta_9 F + \beta_{10} \ln I.$$

B is the proposed payment required to implement a program that would delay nitrate contamination. M is a dummy variable that is equal to one if the respondent is male and zero if the respondent is female; A is the respondent's age; E is the respondent's years of education; C is the number of children under the age of 18 currently living in the respondent's household; H is a dummy variable that is equal to one if the respondent owns his or her own home and zero otherwise; R_5 is the expected probability that the respondent will remain in the same community for five years; W is a dummy variable that is equal to one if the respondent's water source is municipal or rural or zero for other sources of water; F is a dummy variable equal to one if the respondent is a farmer and zero otherwise; and I is the respondent's income.[5] Assume ϵ is normally distributed with a mean of zero and variance of σ^2. The parameters in equation (2), γ and σ^2 can be estimated using maximum likelihood techniques.

The maximum likelihood estimates for equation (2) determine the likelihood that an individual will say "no" to all three time delays; "yes" to a 20-year delay but "no" to a 15- or 10-year delay; "yes" to a 20- and 15-year delay but not to a 10-year delay; and "yes" to all time delays. This estimation procedure is similar to an ordered probit specification with the exception that the thresholds are adjusted to account for potential anchoring. The estimates are based on an artificial index; therefore, the coefficients cannot be directly interpreted as the willingness to pay for marginal effects. A respondent's median bid for a time delay of T_j is implicitly defined by $T_j - X\beta = 0$. Solving for the WTP bid and substituting in the means of the socio-economic variables, the median bid for an average respondent and a time delay T_j can be written as

$$B(T_j) = \exp\{[T_j - (\beta_0 + \beta_2\bar{M} + \beta_3\bar{A} + \beta_4\bar{E} + \beta_5\bar{C} + \beta_6\bar{H} + \beta_7\bar{R}_5 + \beta_8\bar{W} + \beta_9\bar{F} + \beta_{10}\overline{\ln I})]\beta_1\}$$

where T_{10} is a 10-year delay, T_{15} is a 15-year delay, T_{20} is a 20-year delay, and bars indicate sample averages. $B(T_j)$ is the bid value that makes the average respondent equally likely to accept or reject the proposed time delay. Setting equation (2) equal to zero and using the implicit function theorem, the marginal change in the median willingness to pay for a delay of T_j years given a change in X is $(\partial XB(T_j)/\partial X) = -[(\partial X\beta/\partial X)]/[(\partial X\beta/\partial\beta)]$. For instance, $(\partial B(T_j)/\partial I)$ is interpreted as the change in the willingness to pay bid required such that the average respondent is equally likely to accept or reject the proposed time delay given a marginal change in income.

Table 1 reports the means and standard deviations of the regressors. Just over one in three respondents were willing to pay for a 10-year delay. Fewer than 10% were willing to pay for a 15- or 20-year delay. Almost half were not willing to pay to delay nitrate contamination. Respondents were almost equally distributed between counties. Almost two-thirds of the respondents were male. The average age was 52 years. Average education was equivalent to more than a two-year associate degree, but not quite a four-year college degree. The average number of children under 18 was just over two-thirds. Just over 80% of

[5] Taking the natural log of the bid value and income allows for non-linear income effects that improve the fit of the model.

Table 1. Means/Percentages and Standard Deviations of the Regressors

Variable	Mean/Percentage	Standard Deviation
Unwilling to pay to delay contamination	45.29%	
10-year delay	37.39%	
15-year delay	7.90%	
20-year delay	9.42%	
Adams County residents	44.99%	
Clarke County residents	55.02%	
Male	62.31%	
Age	51.50	14.70
Education	13.40	2.50
Children under 18	0.68	1.13
Homeowner	84.20%	
Remain for 5 years	81.99%	22.36%
Municipal/rural water	74.16%	
Farmer	10.64%	
Income	$32,135	$22,981
Number of observations	329	

respondents owned their own home. Respondents were on average 80% certain that they would remain in the area for five years. Nearly three-fourths used municipal or rural water. Almost 11% were farmers, and average income was just over $30,000.

Results

We find that residents of Clarke and Adams Counties are willing to pay to delay nitrate contamination in their water source. Statistically significant differences between counties were not detected.[6] Table 2 reports the median bids and marginal effects for time delays of 10, 15, and 20 years. At the bottom of Table 2, γ is reported along with the maximized value of the log-likelihood function. The maximized value of the restricted log-likelihood function when β_2 through β_{10} are constrained to zero is also reported along with a likelihood ratio test for these restrictions. Diagnostic tests indicated no significant concerns with multicollinearity among the regressors. Anchoring was significant and indicated that respondents weighted their initial bid just as much as their original preferences which may suggest a high degree of uncertainty regarding their preferences. By controlling for this anchoring, the willingness-to-pay estimates reflect a respondent's initial assessment of the proposed time delay.

The estimated median willingness to pay was just over $50 a year for a 10-year delay, just under $65 a year for a 15-year delay, and just over $80 a year for a 20-year delay. While these estimates were statistically different from zero, the values, while increasing as expected, were not statistically different from each other. This result, combined with the fact that over 80% of the sample either accepted or rejected all time delays, indicates that respondents were generally either for or against the program at the proposed bid values.

Male respondents were less willing than were female respondents to pay for a delay in nitrate contamination. On average, their median WTP bids were $34 to $56 lower than were female respondents. This suggests that female respondents are more concerned about

[6] The test for differences between counties was constructed using a log-likelihood ratio test. Estimating coefficients for each county separately led to a maximized log-likelihood of −340.68. Restricting the coefficients to be equal across counties led to a maximized log-likelihood of −348.69. The log-likelihood ratio test resulted in a $\chi^2 = 16.03$ with 13 degrees of freedom. This χ^2 is not significant at the 10% level, and indicates that restricting coefficients to be equal across counties does not significantly reduce the explanatory power of the model.

Table 2. Median Willingness to Pay and Marginal Effects

	10 Years	15 Years	20 Years
Median WTP	\$50.71***	\$64.44***	\$81.88***
	(4.42)[a]	(7.06)	(5.22)
Male	−\$34.39**	−\$43.70**	−\$55.53*
	(2.03)	(2.03)	(1.86)
Age[b]	\$0.69	\$0.87	\$1.11
	(0.11)	(0.11)	(0.11)
Education	\$7.28**	\$9.25**	\$11.75**
	(2.04)	(2.18)	(2.09)
Children under 18	−\$8.62	−\$10.96	−\$13.92
	(1.12)	(1.11)	(1.08)
Homeowner	−\$14.23	−\$18.09	−\$22.98
	(0.67)	(0.68)	(0.67)
Remain for 5 years[c]	\$0.70*	\$0.89*	\$1.13*
	(1.80)	(1.89)	(1.83)
Municipal/rural water	−\$10.86	−\$13.80	−\$17.54
	(0.61)	(0.61)	(0.61)
Farmer	−\$34.23	−\$43.49	−\$55.27
	(1.24)	(1.27)	(1.25)
Income[d]	\$1.22**	\$1.55**	\$1.97**
	(2.72)	(2.77)	(2.40)
γ	0.53		
	(1.94)*		
Restricted log-likelihood	−376.55		
Log-likelihood	−348.69		
$\chi^2(10)$	55.72***		
Number of observations	329		

[a] Absolute t-statistics are reported in parentheses.
[b] Tens of years.
[c] For a one-percentage-point increase in the probability of remaining in the area an additional five years.
[d] Thousands of dollars.
* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

the potential for nitrate contamination than their male counterparts.

The education level of a respondent positively influences his or her willingness to pay to delay nitrate contamination. An additional year of schooling results in an increase of \$7 to \$12 in the median WTP bids. This implies that respondents with higher levels of education may be more aware of the risks associated with nitrate contamination from large confinement operations.

The likelihood of a respondent remaining in the area for another five years positively influences the median willingness to pay to delay nitrate contamination. Residents who are 1% more likely to remain in the area for five years are willing to pay an additional \$0.70 to \$1.13.

Income also positively affects the median WTP bids. An additional \$1,000 in income results in higher WTP bids of \$1.22 to \$1.97 per year. Respondents who have higher incomes are better able to afford an increase in their water bill and are more willing to do so to protect their drinking water.

The WTP estimates can be aggregated to the county level to estimate the total value that residents in the two counties are willing to pay for water quality protection. One interpretation is that these amounts represent the value residents would be willing to pay for technologies to protect water quality. Adams County,

with an adult population of 3,677 in 1990, could expect revenue amounts of $186,461 to $301,073 per year. The more populous Clarke County, with 6,119 adults, could expect revenues of $310,294 to $501,024 per year. These estimates may be inflated if the survey respondents were not answering as individuals as requested, but rather were considering their household when answering the survey. The estimates could also be interpreted as the value the communities assign to the perceived environmental cost and the amount that livestock benefits need to exceed for an expansion to be implemented.

We can also use our regression results to calculate the additional property taxes a family would be willing to pay in order to delay nitrate contamination. The relocation of a large-scale confinement operation could threaten water supplies, reducing the value of residential property. The WTP estimates are one indication of this potential change in property values because they represent the increase in taxes respondents are willing to pay in exchange for water quality assurance. For example, suppose there is an owner occupied home with a 50-year-old mother, a 50-year-old father, and one child under 18 years of age. Also assume that both the mother and father have two years of education beyond a high school diploma, are 80% certain they will remain in their community for five more years, use municipal water, and have an annual family income of just over $32,000. These assumptions and the regression equation imply that this family would be willing to pay between $118.13 and $190.75 in additional annual property taxes. If these annual property taxes were capitalized into the value of the family home over the life of the program, the value of a median price home would fall by between 2.9% and 6.8% in Adams County, and 2.3% and 5.4% in Clarke County, assuming a discount rate of 8.5%.[7]

These percentages are similar to those found by Palmquist et al in their study of the effects on property values from the environmental impacts from swine operations in North Carolina (Palmquist et al, 1995). Their percentages ranged from 7.06% to 1.9% at low levels of hog proximity when a new 2,400-head finishing unit located within half a mile to two miles of a median-priced home. The Palmquist study included the effects of odor and other disamenities as well as changes in water quality associated with hog confinement facilities; therefore, a direct comparison with our results is not possible. However, our results support their findings that residential property values are likely to be negatively impacted by large hog confinement operations. Abeles-Allison and Connor (1990) also found that proximity to large hog confinements adversely affected property values in Michigan. Since their study focused on areas with multiple odor complaints, their results are likely to be related more to odor than to water quality, though potential changes in water quality are not completely controlled for in their analysis. Therefore, our results suggest that part of the negative impact found by Abeles-Allison and Connor is possibly attributable to the potential for changes in water quality.

Conclusion

This study investigated rural residents' perceptions of the risk to their water from the potential siting of a large hog confinement facility in their area and their willingness to pay to maintain water quality. The results indicate that rural residents are very concerned about the environmental impact of confinement facilities and that they are willing to pay higher water bills to delay contamination. Greater education and income levels were positively associated with willingness-to-pay estimates, as was the length of time a resident expected to remain in the community. Male respondents were much less inclined to pay for water protection than females. From a community perspective, the aggregated WTP values provide some idea of the value of water quality assurance.

Rural residents do value water quality, and local governments need to consider their con-

[7] The median price of residential housing from the 1990 census was $28,700 in Adams County and $36,400 in Clarke County.

cerns when evaluating the benefits of economic development associated with attracting large-scale livestock operations. As the debate over the potential economic benefits and environmental consequences of large-scale confinement operations continues, it is critical that rural residents remain informed and consulted about proposals for the siting of these types of facilities in their area. Although the results can be generalized only to Clarke and Adams Counties, the absence of any difference between these two counties suggests that similar opinions may be found in other rural counties.

Finally, our results can be contrasted with previous attempts to ascertain the external costs and benefits of livestock production using hedonic pricing equations combined with residential property values. One drawback to this hedonic valuation method is that it is hard to distinguish what factors of livestock production are of most concern to neighbors. Carefully focused contingent valuation surveys provide an alternative method for evaluating the value that residents place on the odor nuisance, the potential for groundwater contamination, and other potential disamenities. These surveys can also help to determine the degree to which respondents view alternative disamenities as joint products. Future studies may find useful comparisons between contingent valuation and hedonic pricing methods when evaluating the effects of livestock confinement. These comparisons may help to further identify the advantages and limitations of each method.

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