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Public perceptions of antibiotic use on dairy farms in the United States

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ABSTRACT

There has been a global push for improved antimicrobial stewardship, including in animal agriculture, due to growing concerns about antimicrobial resistance. However, little is known about the general public's perceptions of antimicrobial use in animal agriculture. The aim of this study was to explore the US public's perceptions of antibiotic use in dairy farming and how these perceptions influence purchasing decisions. Data from the 2017 Cornell National Social Survey developed in collaboration with the Cornell Survey Research Institute were used to assess the public's perceptions. The Survey Research Institute of Cornell University (Ithaca, NY) administered the survey by telephone to a random sample of 1,000 adults in the continental United States. The survey collected information about perceptions of threat to human health posed by antibiotic use in cows on dairy farms and willingness to pay more for milk from cows raised without antibiotics, as well as several presumed explanatory variables, including respondents' knowledge of antibiotics, beliefs regarding cattle treatment in dairy farming, and 18 sociodemographic characteristics. Data were analyzed using logistic regression. Among respondents, 90.7% (n = 892/983) reported that antibiotic use on dairy farms posed some level of threat to human health and 71.5% (n = 580/811) indicated they would be willing to pay more for milk produced from cows raised without antibiotics. Respondents who believed that antibiotic use in dairy farming posed a moderate to high threat to human health were more likely to be female and report willingness to pay more for milk or not purchase milk. Additionally, consumers' willingness to pay more for milk from cattle raised without antibiotics was associated with the belief that antibiotic use posed some threat to human health, the belief that cows are treated better on organic dairy farms, an annual household income of $50,000 or greater, being born outside the United States, having a liberal social ideology, and being currently or formerly married. These results suggest that the general public's decisions as consumers of dairy products are associated with demographic factors in addition to perceptions of antibiotic use and cattle treatment in dairy farming. The rationale behind such perceptions should be further explored to facilitate consumers' informed decision making about antibiotic use in agriculture, links to cattle treatment, and associated willingness-to-pay attitudes.

Key words: antimicrobial resistance, antibiotic use, dairy farming, consumer perception

INTRODUCTION

There has been increased focus on mitigating the development of antibiotic resistance through antibiotic stewardship, including in animal agriculture in the United States (PCAST, 2014; The White House, 2015) and globally (WHO, 2015, 2017; OIE, 2016). Domestically, the effort to promote judicious antibiotic use in animal agriculture culminated in the full implementation of Guidance for Industry (**GFI**) no. 213 by the US Food and Drug Administration in 2017 (FDA, 2013, 2017a). Following complete implementation of GFI no. 213, the use of medically important antibiotics (antibiotics important for treating disease in humans) for production purposes (growth promotion, enhancing weight gain or feed efficiency) was prohibited and veterinary oversight was required for the use of medically important antibiotics administered to food animals through feed or water (FDA, 2017a). The Veterinary Feed Directive (**VFD**) final rule implements requirements for veterinarians to authorize the use of medically important antibiotics in animal feed through the issuance of a veterinary feed directive to farmers (FDA, 2017a).

According to a 2019 report on antibiotic resistance, 2.8 million antibiotic-resistant infections occur annu-

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ally in the United States, resulting in more than 35,000 deaths (CDC, 2019). It is unclear what proportion of these are the result of the transmission of antibiotic-resistant bacteria from food animals to humans. Potential transmission routes of antibiotic-resistant bacteria from animals to humans include direct contact, contaminated meat and dairy products, and the environment (CDC, 2019, 2020). Outbreaks of multidrug-resistant pathogens, particularly non-typhoidal *Salmonella* species, associated with food animal products have been reported and often result from the consumption of raw dairy products or undercooked meat or improper handling of raw meat (Kawakami et al., 2016; Burakoff et al., 2018; Plumb et al., 2019). The National Antimicrobial Resistance Monitoring System for Enteric Bacteria has been particularly helpful in conducting surveillance for and monitoring trends in antibiotic resistance among humans, animals, and retail meat (Karp et al., 2017). Systemic reviews have identified pathways through which antibiotic use in animal agriculture might influence human health (Hoelzer et al., 2017; Scott et al., 2018). However, there is no high-quality evidence quantifying the effects of antibiotic use in animal agriculture on public health or linking antibiotic use practices on farms to human health impacts.

Government and organizational concern surrounding antibiotic use in livestock production stems from a desire to minimize the development of antibiotic resistance. The public's concerns over antibiotic use may have a similar basis. In one survey study, 30% of respondents agreed or strongly agreed that antibiotic resistance is a significant problem, and 60% agreed or strongly agreed that the use of antibiotics in livestock can lead to the presence of resistant bacteria in meat that can sicken people (Carter et al., 2016). Research, however, has more frequently addressed general consumer concern about antibiotic use itself. Consumer concern about the use of antibiotics in animal agriculture is well documented (Hwang et al., 2005; Clark et al., 2016), and in a study pertaining to beef products, researchers found that on average participants rated the attribute "no antibiotics" as higher than desirable (Umberger et al., 2009). The public's perceptions about antibiotic use and resistance is important because research indicates that risk perceptions surrounding food products affect purchasing behavior (Yeung and Morris, 2001). In fact, a study of pork found that consumers are willing to pay a premium for pork products produced without antibiotics (Lusk et al., 2006). Finally, consumer demand and preferences can also drive policies and regulations as well as industry requirements.

Studies conducted before the VFD final rule indicate public and consumer support for limiting antibiotic use in food animals (Lusk et al., 2006; Wolf et al., 2016). The former study presented evidence suggesting that consumers value and would be willing to pay for a ban on subtherapeutic antibiotic use in swine (Lusk et al., 2006). A study of the public revealed that the majority of respondents would vote to restrict antibiotic use in dairy cattle to disease treatment and ban castration without pain control (Wolf et al., 2016). Because consumers can influence antibiotic use in dairy farming through their purchasing decisions and policy advocacy, it is important to understand their perceptions of it. This is particularly relevant given the recent implementation of the VFD final rule. The objective of this survey study was to explore how the general public's perceptions of threat to human health from antibiotic use in dairy farming and willingness to pay more for milk from cows raised without antibiotics are influenced by demographic factors, knowledge of antibiotics, beliefs about cattle treatment in different production systems, and each other.

MATERIALS AND METHODS

Survey Design and Sample Selection

The Cornell National Social Survey (**CNSS**) is an annual telephone survey of 1,000 adults in the United States conducted by the Survey Research Institute (**SRI**) of Cornell University. The 2017 CNSS was conducted from September 11, 2017, through December 11, 2017. Adults (18 yr of age or older) residing in the continental United States were eligible to participate. The survey sample was provided by Marketing Systems Group (Horsham, PA). The sample was randomly selected using random digit dialing and included listed households, unlisted households, and cell phones. Business telephone numbers, disconnected numbers, and non-household numbers were excluded. The selection process was performed by first randomly selecting a household and subsequently selecting the member of the household with the most recent birthday. All interviews were conducted in English using computer-assisted telephone interviewing software.

The study (protocol 1402004459) was approved by and conducted in accordance with guidelines set by the Cornell University Institutional Review Board for Human Participants. A pilot survey of 25 participants was conducted by the SRI before the actual survey. Data were collected for the pilot survey from August 10, 2017, to August 18, 2017, and participants were identified using the same approach that was used in the actual survey. Participant feedback for the questions proposed by our research team was used to improve

question clarity and response quality. This involved changing the response scales of questions 2 and 3.

Survey Questions

The 2017 CNSS consisted of a predetermined group of demographic questions and question sets contributed by Cornell University researchers selected by SRI through an application process, including a set of questions contributed by the authors of this study. The number of questions that researchers could contribute was restricted due to the length of the survey (meant to take no more than 20 min to complete). The 18 demographic variables considered in the current study were developed from and representative of the major sociodemographic questions included in this survey. All 2017 CNSS questions, methods, and results are publicly available (Cornell Institute for Social and Economic Research, 2017). The study's authors contributed the following 4 antibiotic use perception questions for inclusion in the survey:

1. Based on whatever you know, do you think antibiotics kill or stop growth of . . .? (options: (i) bacteria, (ii) viruses, (iii) fungi, (iv) all of the above, (v) do not know)
2. How big of a threat to human health is antibiotic use in cows on dairy farms? (options: (i) high threat, (ii) moderate threat, (iii) low threat, (iv) no threat, (v) do not know)
3. How much more would you be willing to pay for milk produced by cows raised without using antibiotics? (options: (i) I do not purchase milk, (ii) not willing to pay more, (iii) up to 10% more, (iv) up to 20% more, (v) up to 30% more, (vi) up to 40% more, (vii) up to 50% more, (viii) more than 50% more, (ix) do know know)
4. Do you think cows are generally treated better on conventional dairy farms, organic dairy farms, or about the same in both places? (options: (i) treated better on conventional dairy farms, (ii) treated better on organic dairy farms, (iii) treated about the same, (iv) do not know)

The 4 questions contributed by the study's authors were preceded and followed by questions contributed by other researchers. Questions preceding this study's questions covered a variety of topics, including geographic location, college education and training programs for prisoners, national leadership, contraceptive policies, men's rights and the alternative right, China's rise, resources used to find health care providers, experience with and rating of health care services and workplace wellness programs, parental access to teens' medical records, bariatric surgery, dog ownership and interest in partaking in a canine clinical study, and bee health. Among those topics, only the topic of bee health had some potential relevance to our study through the question "How much more, if anything, would you be willing to pay for organic food?" However, we do not believe that this question affected participants' responses to our questions in a particular way. The complete questionnaire is publicly available (Cornell University Survey Research Institute, 2017).

Statistical Analysis

The SRI-provided response and cooperation rates were calculated according to guidelines provided by the American Association for Public Opinion Research (2016). Descriptive statistical analysis of the 4 antibiotic use perception questions and 18 sociodemographic variables was performed. The 18 demographic variables, developed from sociodemographic questions in the survey, included age, sex, education level, income, census region, employment status, born in the United States, home ownership status, race, Hispanic/Latino, number of adults in household, children in household, marital status, political party affiliation, social ideology, religious practice, frequency of attendance at religious services, and whether the survey was taken via landline or cell phone. Age and number of adults in household were the only continuous variables. For analysis, responses of "do not know" and refused were excluded, with the exception of when participants were asked to define the term "antibiotic," for which "do not know" was categorized with incorrect responses. The demographic characteristics of the survey respondents were compared with the 2010 US Census and 2013 American Community Survey (**ACS**) 3-yr estimates (available in Trautman, 2018) using a 1-proportion Z-test.

Two separate predictive logistic regression models were developed, with threat to human health posed by antibiotic use in cows on dairy farms and willingness to pay more for milk from cows raised without antibiotics as dependent outcome variables. The association between each of these outcome variables and the remaining 3 antibiotic use perception variables and 18 demographic variables was investigated. In univariable analysis, simple logistic regression was used to screen the 21 independent variables for statistically significant ($P < 0.05$) associations with each of the 2 outcome variables. Independent variables found to be statistically associated with the outcome variable were included in a multivariable logistic regression model. Backward elimination was used to construct the final

model, and 2-way interactions were evaluated. Each variable elimination and interaction inclusion were followed by a likelihood ratio test and evaluation of the Akaike information criterion (**AIC**) estimator. Missing values were excluded before performing backward elimination, and only complete cases for variables in the model were included to ensure that only nested models were compared during the process of multivariable model building.

Finally, to ensure that the final multivariable logistic regression models fit the data adequately, likelihood ratio tests, AIC, and Hosmer-Lemeshow tests were used, and receiver operating characteristic (**ROC**) curves were constructed. R software (R Core Team, 2017) was used to perform all statistical analyses. Correction for multiple comparisons was not performed because of the exploratory character of the research to make sure that all important associations were identified. Results of logistic regression were expressed as odds ratio (**OR**) and the associated 95% confidence interval (**CI**). Odds ratio is a statistic (ranging from zero to infinity) that quantifies the strength of the association between an exposure (independent variable) and an outcome; it describes the odds that an outcome will occur given a particular exposure compared with the odds of the same outcome occurring in the absence of that exposure. There is no consensus about what constitutes a large or small value of OR (i.e., a strong or weak association). To provide a potentially useful reference, a group of researchers interpreted OR with respect to Cohen's d and reported that, for example, when the prevalence of an outcome is 1% in the nonexposed group and larger than that in the exposed group, OR = 1.68, 3.47, and 6.71 are equivalent to Cohen's d = 0.2 (small), 0.5 (medium), and 0.8 (large) effect size, respectively (Chen et al., 2010). The presence of confounding among selected variables in the final model was determined based on a more than 20 to 30% change in the OR (Dohoo et al., 2003) between the estimate obtained from the final model with the suspected confounder removed and the estimate obtained from the final model with the effect of the suspected confounder controlled for.

RESULTS

The total sample consisted of 14,500 phone numbers. However, a successful contact was made with only 1,703 eligible potential interviewees, which resulted in 703 refusals and 1,000 completed surveys (Trautman, 2018). Final call dispositions were categorized (Table 1), and response and cooperation rates were calculated according to American Association of Public Opinion guidelines (Trautman, 2018). The survey had a cooperation rate (the number of completed surveys divided by the number of potential interviews) of 58.7% (Trautman, 2018). The response rate (number of completed surveys divided by the total eligible sample) for the survey was 23.9% (Trautman, 2018). Interviews lasted an average of 25 min in length (Trautman, 2018).

Respondent Demographics

Demographic characteristics of respondents are displayed in Table 2. The median age of survey respondents was 48 yr, and the percentage of male and female participants was almost evenly split. Among respondents, 45.8% were college graduates who had completed at least a 4-yr degree. For household income, 65.0% of respondents reported having an income of $50,000 or greater. Other demographic variables investigated are listed in Table 2. Demographic characteristics of CNSS respondents differed from those of the US population (Table 3). Compared with US Census and ACS data, CNSS respondents were older, had higher annual household incomes, and had higher levels of education, and a higher percentage of them were employed. Additionally, fewer CNSS respondents identified as Hispanic and more identified as White. Therefore, the survey sample is not fully representative of the US population.

Responses to Questions on Antibiotic Use and Cattle Treatment on Dairy Farms

Just over half of the 1,000 survey respondents (51.5%) correctly identified that antibiotics kill or stop the growth of bacteria only (Table 4). Among respondents, 90.7% believed that antibiotic use on dairy farms posed some level of threat to human health. Approximately

Table 1. Final call dispositions for the 2017 Cornell National Social Survey (data obtained from Trautman, 2018)

Item	No.
Total sample	14,500
Total ineligible contacts	10,318
Unknown eligibility[1]	3,907
Non-working number	6,015
Non-residence	257
Age ineligible	139
Total eligible sample	4,182
Potential interviews	1,703
Non-contact[2]	2,297
Physically or mentally incapable of participating	10
Language problem	172
Completed surveys	1,000

[1]Refers to cases where eligibility at the household or household resident level was not determined and no contact was made with an actual person or by leaving a voicemail during contact attempts.

[2]Refers to cases where contact was made with an actual person or a voicemail was left, but the survey was never completed, and the case was not evaluated enough to determine ineligibility.

Table 2. Categorical variables describing demographic characteristics of 2017 Cornell National Social Survey respondents[1] (sample size = 1,000)

Characteristic	No.	%[2]
Sex		
Male	498	49.8
Female	502	50.2
Education (highest level completed)		
High school (grade 12 or GED certificate) or less	257	25.7
Some college (no 4-yr degree) or technical trade or vocational school after high school	284	28.4
College graduate (4-yr degree)	266	26.6
Post-graduate training or professional	192	19.2
Refused	1	—
Household income		
<$50,000	345	35.0
≥$50,000	641	65.0
Refused	14	—
Census region		
Northeast	188	18.8
Midwest	230	23.0
South	386	38.6
West	196	19.6
Employment status		
Employed	652	65.2
Unemployed	117	11.7
Not in labor force (retired, disabled, unable to work)	231	23.1
Hispanic		
Yes	127	12.7
No	872	87.3
Refused	1	—
Race		
White only	731	73.8
Black only	107	10.8
Other only	61	6.2
More than 1 race	92	9.3
Refused	9	—
Children in household		
No	665	66.6
Yes	333	33.4
Refused	2	—
Marital status		
Single	315	31.5
Married, formerly married (divorced, separated, widowed), other non-single	684	68.5
Refused	1	—
Political party affiliation		
Democratic	290	29.1
Independent or other	479	48.1
Republican	227	22.8
Refused	4	—
Social ideology		
Liberal	302	30.4
Moderate	363	36.6
Conservative	327	33.0
Refused	8	—
Religious		
No	234	23.5
Yes	762	76.5
Refused	4	—
Frequency of attendance at religious services		
Once a week or more often	313	31.4
Once a month to once a year	301	30.2
Seldom to never	382	38.4
Refused	4	—
Born in United States		
No	102	10.2
Yes	898	89.8
Home ownership status		
Own	629	63.0
Rent or live there rent free	369	37.0
Refused	2	—
Cell or landline phone for survey		
Landline	233	23.3
Cell phone or voice over IP	766	76.7
Refused	1	—

[1]In terms of continuous variables, the median (interquartile range) for age of participants (n = 1,000) was 48.0 (33–62) yr and for the number of adults (≥18 yr, n = 999) in household was 2 (2–3).

[2]Excluding refused and do not know.

Table 3. Comparison of demographic characteristics (%) of the 2017 Cornell National Social Survey (CNSS) sample with those of the US population using a 1-proportion Z-test (analysis of data obtained from Trautman, 2018)

Characteristic	CNSS (n = 1,000)	US population[1]	*P*-value
Age (yr)			
18–24	12	13	0.37
25–34	15	18	0.02
35–44	16	18	0.11
45–54	18	19	0.44
55–64	20	16	<0.01
≥65	20	17	0.01
Sex			
Male	50	49	0.55
Female	50	51	0.55
Race			
White	82	72	<0.01
Black	15	13	0.07
Other	14	15	0.40
Ethnicity			
Hispanic	13	16	0.01
Non-Hispanic	87	83	<0.01
Employment status			
Employed	65	59	<0.01
Unemployed	12	6	<0.01
Not in labor force	23	35	<0.01
Annual household income ($)			
<10,000	3	7	<0.01
10,000–49,999	32	41	<0.01
50,000–99,999	39	31	<0.01
≥100,000	26	21	<0.01
Education (age 18+ yr)			
Less than bachelor's degree	54	72	<0.01
Bachelor's degree or higher	46	28	<0.01

[1]Based on the 2010 US Census and 2013 American Community Survey 3-yr estimates from the US Census and Bureau of Labor Statistics (US Census Bureau, 2010, 2013).

one-quarter of respondents (25.6%) reported it posed a high level of threat, whereas 44.3% reported it posed a moderate threat, and 20.9% reported it posed a low threat. In regard to willingness to pay more for milk from cows raised without antibiotics, among respondents who purchased milk, 71.5% were willing to pay some amount more, with 27.0% reporting willingness to spend over 20% more. Some respondents (18.6%) reported not purchasing milk. Finally, respondents were asked to compare cattle treatment on organic and conventional farms. Most respondents reported that cows were treated either better on organic farms (46.1%) or the same on both conventional and organic farms (48.4%).

Predictors of Perceiving Antibiotic Use on Dairy Farms as Moderate to High Threat to Human Health

In univariable analysis (Table 5), the perception that antibiotic use on dairy farms is a moderate to high threat to human health was significantly associated with willingness to pay more for milk (all levels) from cows raised without antibiotics and not purchasing milk, the belief that cows are treated better on organic farms, being female, and having a liberal social ideology. When these variables were tested in a multivariable logistic regression model (Table 6), respondents who perceived antibiotic use on dairy farms as a moderate to high threat were more likely to be female (OR = 2.16, 95% CI: 1.58–2.97), willing to pay more for milk from cows raised without antibiotics (up to 10%: OR = 3.69, 95% CI: 2.47–5.58; up to 20%: OR = 7.20, 95% CI: 4.38–12.15; above 20% more: OR = 18.91, 95% CI: 11.03–34.12), and willing to not purchase milk (OR = 5.95, 95% CI: 3.79–9.51). The remaining variables that were significant in univariable analysis were not significant in the model. The final model had an AIC of 981.8 and residual deviance of 969.8 on 952 df. In comparison, the null/intercept had an AIC of 1,171.7 and a residual deviance of 1,169.7 on 957 df. A likelihood ratio test confirmed that the fit of these models differed significantly ($P < 2.2 \times 10^{-16}$). The results of a Hosmer-Lemeshow test (8 bins/intervals, $\chi^2 = 1.09$, df = 6, $P = 0.98$) and construction of an ROC (area under curve = 0.77) also suggested a good fit. Based on Youden's index, the optimal predicted probability cutoff point was 0.70. No interaction was identified, and sex did not confound the relationship between willingness to pay more for cows raised without antibiotics and perception of antibiotic use on dairy farms as a moderate to high threat to human health in the final model.

Predictors of Willingness to Pay More for Milk from Cows Raised Without Antibiotics

In univariable analysis (Table 7), willingness to pay more for milk from cows raised without antibiotics was significantly associated with correctly identifying that antibiotics kill or stop the growth of bacteria, perceiving antibiotic use in dairy farming as posing at least some threat to human health, believing that cows are treated better on organic farms, having some college education or vocational or technical training, being a college graduate (4-yr program), having a postgraduate or professional school education, a household income of $50,000 or greater, not being single, being liberal, being born outside the United States, and home ownership. When these variables were tested in a multivariable logistic regression model (Table 8), respondents who reported willingness to pay more for milk from cows raised without antibiotics were more likely to perceive antibiotic use in dairy farming as a low (OR = 2.92, 95% CI: 1.58–5.56), moderate (OR = 13.87, 95% CI: 7.62–26.19), or high (OR = 15.12, 95% CI:

Table 4. Responses to questions about perceptions of antibiotic use in dairy farming, cattle treatment, and dairy product purchasing decisions (sample size = 1,000)

Characteristic	No.	%[1]
Definition of term "antibiotic"		
Correct	513	51.5
Incorrect or did not know	483	48.5
Refused	4	—
Perceived threat to human health from antibiotic use in dairy cows		
No threat	91	9.3
Low threat	205	20.9
Moderate threat	435	44.3
High threat	252	25.6
Do not know	14	—
Refused	3	—
Willingness to pay more for milk from cows raised without antibiotics		
Not willing to pay more	231	23.2
Willing to pay up to 10% more	219	22.0
Willing to pay up to 20% more	142	14.3
Willing to pay more than 20% more	219	22.0
Don't purchase milk	185	18.6
Do not know	1	—
Refused	3	—
Cow treatment on organic versus conventional farms		
Same on both	475	48.4
Better on organic	453	46.1
Better on conventional	54	5.5
Do not know	16	—
Refused	2	—

[1]Excluding refused and do not know.

7.48–31.99) threat to human health, believe that cows are treated better on organic farms (OR = 2.83, 95% CI: 1.88–4.29), have an annual household income of $50,000 or more (OR = 1.56, 95% CI: 1.04–2.33), and have a liberal social ideology (OR = 1.73, 95% CI: 1.05–2.88). Respondents who reported willingness to pay more were less likely to be single (OR = 0.47, 95% CI: 0.30–0.73) or born in the United States (OR = 0.41, 95% CI: 0.19–0.85). The remaining variables that were significant in univariable analysis were not significant in the multivariable model. The final model had an AIC of 712.8 and residual deviance of 690.8 on 757 df.

Table 5. Characteristics of 2017 Cornell National Social Survey respondents that were different ($P < 0.05$) among those perceiving a moderate to high threat to human health from antibiotic use in dairy cows compared with those perceiving no to low threat (reference level) in univariable analysis

Characteristic	Odds ratio	95% CI
Dairy farming and antibiotic use		
Willingness to pay more for milk from cows raised without antibiotics (n = 979)		
Not willing to pay more	1 (ref[1])	
Willing to pay up to 10% more	3.59	2.43–5.35
Willing to pay up to 20% more	6.82	4.21–11.34
Willing to pay more than 20% more	17.36	10.30–30.70
Don't purchase milk	6.14	3.96–9.69
Cow treatment on organic versus conventional farms (n = 968)		
Same on both	1 (ref)	
Better on organic	2.21	1.65–2.96
Better on conventional	1.02	0.58–1.86
Demographics		
Sex (n = 983)		
Male	1 (ref)	
Female	2.17	1.64–2.87
Social ideology (n = 975)		
Moderate	1 (ref)	
Liberal	1.51	1.06–2.16
Conservative	0.74	0.54–1.02

[1]Reference level of odds ratio.

Table 6. Final multivariable model for perceiving a moderate to high threat to human health from antibiotic use in dairy cows (compared with respondents perceiving no to low threat) among 958 respondents

Predictor	Odds ratio	95% CI
Dairy farming and antibiotic use		
Willingness to pay more for milk from cows raised without antibiotics[1]		
Not willing to pay more	1 (ref[2])	
Willing to pay up to 10% more	3.69	2.47–5.58
Willing to pay up to 20% more	7.20	4.38–12.15
Willing to pay above 20% more	18.91	11.03–34.12
Don't purchase milk	5.95	3.79–9.51
Demographics		
Sex		
Male	1 (ref)	
Female	2.16	1.58–2.97

[1]The relationship between willingness to pay more for milk cows raised without antibiotics and perception of moderate to high threat to human health from antibiotic use in dairy cows remained significant when controlling for household income and education level, but those variables were dropped from the final because they were not significant and did not significantly contribute to the overall fit of the model.

[2]Reference level of odds ratio.

In comparison, the null/intercept had an AIC of 910.8 and a residual deviance of 909.8 on 767 df. A likelihood ratio test confirmed that the fit of these models differed significantly. The results of a Hosmer-Lemeshow test (10 bins/intervals, $\chi^2 = 6.25$, df = 8, $P = 0.62$) and construction of an ROC (area under the curve = 0.82)

Table 7. Characteristics of 2017 Cornell National Social Survey respondents that were different ($P < 0.05$) among those reporting willingness to pay more for milk from cows raised with antibiotics compared with those unwilling to pay more (reference level) in univariable analysis

Characteristic	Odds ratio	95% CI
Dairy farming and antibiotic use		
Definition of term "antibiotic" (n = 807)		
Incorrect or didn't know	1 (ref[1])	
Correct	1.48	1.09–2.01
Perceived threat to human health from antibiotic use in dairy cows (n = 797)		
No threat	1 (ref)	
Low threat	3.44	1.95–6.24
Moderate threat	13.73	7.91–24.69
High threat	21.90	11.41–44.04
Cow treatment on organic versus conventional farms (n = 795)		
Same on both	1 (ref)	
Better on organic	3.78	2.66–5.45
Better on conventional	0.80	0.43–1.50
Demographic		
Education (highest level completed; n = 810)		
High school (grade 12 or GED certificate) or less	1 (ref)	
Some college (no 4-yr degree) or technical trade or vocational school after high school	1.77	1.18–2.66
College graduate (4-yr degree)	1.68	1.11–2.56
Post-graduate training or professional	2.29	1.44–3.69
Household income (n = 801)		
<Under $50,000	1 (ref)	
≥$50,000	1.90	1.38–2.61
Marital status (n = 810)		
Married, formerly married (divorced, separated, widowed), other non-single	1 (ref)	
Single	0.63	0.45–0.87
Social ideology (n = 806)		
Moderate	1 (ref)	
Liberal	1.79	1.18–2.73
Conservative	0.69	0.48–0.97
Born in United States (n = 811)		
No	1 (ref)	
Yes	0.43	0.23–0.78
Home ownership status (n = 810)		
Rent or live there rent free	1 (ref)	
Own	1.56	1.14–2.13

[1]Reference level of odds ratio.

Table 8. Final multivariable model for willingness to pay more for milk from dairy cows raised without antibiotics (compared with not willing to pay more) among 768 respondents

Predictor	Odds ratio	95% CI
Dairy farming and antibiotic use		
Perceived threat to human health from antibiotic use in dairy cows		
No threat	1 (ref[1])	
Low threat	2.92	1.58–5.56
Moderate threat	13.87	7.62–26.19
High threat	15.12	7.48–31.99
Cow treatment on organic vs. conventional farms		
Same on both	1 (ref)	
Better on organic	2.83	1.88–4.29
Better on conventional	0.78	0.37–1.69
Demographic		
Household income		
Less than $50,000	1 (ref)	
$50,000 or more	1.56	1.04–2.33
Born in the United States		
No	1 (ref)	
Yes	0.41	0.19–0.85
Social ideology		
Moderate	1 (ref)	
Liberal	1.73	1.05–2.88
Conservative	0.73	0.48–1.12
Marital status		
Married, formerly married (divorced, separated, widowed), other non-single	1 (ref)	
Single	0.47	0.30–0.73

[1]Reference level of odds ratio.

also suggested a good fit. Based on Youden's index, the optimal predicted probability cutoff point was 0.68. No interaction was identified.

Confounders of the relationship between perceived threat of antibiotic use and the outcome in the final model were explored. The relationship between the belief that antibiotic use on dairy farms poses a high threat to human health and the outcome was confounded by the perception of animal treatment on organic versus conventional farms. When the confounder was removed from the final model, high threat had an OR of 19.38 (95% CI: 9.78–40.27). When perception of animal treatment was adjusted for in the final model, high threat had an OR of 15.12 (95% CI: 7.48–31.99), meaning that the animal treatment perception confounded the relationship between the willingness to pay and the threat perception by making the effect of the threat perception appear stronger than it actually was.

DISCUSSION

Deeper insight into consumer perceptions of risk surrounding antibiotic use in dairy farming may inform consumer education, outreach, and marketing by sectors of the dairy industry to consumers and further scientific research. Consumers exert influence on the dairy industry through their purchasing decisions and can advocate for policies, regulations, and industry standards (Barkema et al., 2015). In this study, we investigated the general public's perceptions of the threat of antibiotic use in dairy farming to human health and of cattle treatment on organic versus conventional farms and how these perceptions influenced their willingness to pay more for milk from cows raised without antibiotics.

Limited Knowledge of Antibiotic Purpose

About half of the participants had misconceptions or lack of knowledge about what antibiotics are used to treat. This finding is generally consistent with previous studies (Vanden Eng et al., 2003; Carter et al., 2016; Davis et al., 2017) showing that a sizeable portion of the public is uncertain about what pathogens antibiotics effectively kill and when they should be used. These findings indicate a need for improved public understanding of how to use antibiotics effectively. Addressing this confusion could be beneficial for both the public health and agricultural sectors. From a public health perspective, it is essential for the public to understand what an antibiotic is so they can in turn understand how to use them appropriately (i.e., not use to treat a viral infection) and why proper use is necessary to minimize the development of antibiotic resistance. From an agricultural perspective, public understanding of what an antibiotic is and why they are vital tools in animal agriculture is central to the public's understanding of farming practices.

Perceived Association Between Farming Practices and Cattle Treatment

We assessed perceptions about cattle treatment on conventional and organic farms, specifically whether consumers viewed cattle treatment as better on one or the other. Understanding the public's perception of cattle treatment on livestock operations is valuable because it may influence their decision to consume dairy products (Cardoso et al., 2016; McCarthy et al., 2017). In fact, changes in consumer and stakeholder acceptance of various production practices have driven the dairy industry to offer animal welfare assurances, reduce their use of antibiotics and hormones, and make other modifications to their management practices (Barkema et al., 2015).

Although the term "animal treatment" is not equivalent to "animal welfare," in qualitative research regarding public perceptions of dairy cattle welfare, participants have used the term "treatment" in response to open-ended questions (Cardoso et al., 2016; Ventura et al., 2016). In one study, participants were asked to describe characteristics of an ideal dairy farm and provide reasons these characteristics were important (Cardoso et al., 2016). Thematic analysis of their responses revealed that animal welfare was the most cited theme for reasons their given characteristics of an ideal farm were important, with many responses referring to the ethical treatment of animals as part of the welfare reason (Cardoso et al., 2016). Research has suggested that 63.4% of the general public has concerns about dairy cattle welfare in the United States (Wolf et al., 2016), and 46% of the general public has concerns about the welfare of livestock animals in general in the United States (McKendree et al., 2014). Higher levels of concern regarding the welfare of livestock were more frequently reported among participants who were female, younger, and members of the Democratic Party (McKendree et al., 2014).

There has been recent discussion about how using less antibiotics may have negative implications for animal health and welfare (McEwen et al., 2018; Tang et al., 2019), though it is unclear to what extent the public is aware of this potential conflict. Consumers have been shown to associate improved animal welfare with other attributes such safety, quality, and reduced antibiotic use (Clark et al., 2016). Our goal was to assess how the public views organic versus conventional production in terms of cattle treatment and whether this view is associated with willingness to pay for antibiotic-free items. Any identified differences in public views of these 2 production practices were intended to be used as a basis for future work on dynamics shaping these differences. In our study, an almost-even division of respondents believed that cows were treated better on organic farms (46.1%) or the same on both conventional and organic farms (48.4%), whereas very few participants believed that cattle were treated better on conventional farms (5.5%). Previous research has explored consumers' associations with terms such as "organic" and "all natural" used in product labeling. Such research suggests that purchasers of organic poultry perceive it to be associated with improved animal welfare standards (Van Loo et al., 2010) and that consumers perceive "all natural" labeling on pork products to indicate improved animal welfare (Abrams et al., 2010). Overall, this body of research suggests that consumers' perceptions of animal treatment, and more broadly animal welfare, on agricultural operations may be associated with a variety of product attributes that are not directly related to animal welfare.

Perceived Threat from Antibiotic Use in Dairy Farming

We sought to quantify consumers' perceptions of the threat of antibiotic use in dairy farming to human health and identify variables associated with perceived level of threat. It is informative to understand how consumers perceive antibiotic use in the dairy industry because such perceptions, whether they are correct or not, may influence their purchasing decisions and support for related regulation and policies. Almost 70% of respondents believed that antibiotic use in dairy cattle posed a moderate to high threat to human health. This concern is congruent with that noted in other studies (Hwang et al., 2005; Clark et al., 2016), with consumers expressing specific concern over antibiotic overuse and use for preventative purposes (Clark et al., 2016). In one study, 27.7% of Canadians surveyed reported that they were unwilling to consume animal products from animals raised with antibiotics (Goddard et al., 2017). In multivariable analysis, the perception of a moderate to high threat from antibiotic use in dairy farming was associated with being female, willingness to pay more for milk from cows raised without antibiotics, and not purchasing milk. The association between willingness to pay more and perceived risk is a logical one as people who perceive greater risk will take measures to minimize or avoid such risk. This is supported by research on consumers perceptions and purchasing behaviors as they related to food safety risk (Yeung and Morris, 2001).

We asked about perceived threat; however, it is unclear exactly what aspect of antibiotic use in dairy farming consumers find threatening. The available

literature suggests that consumers may, among other reasons, be concerned about the presence of antibiotic residues in milk (Abrams et al., 2010; Van Loo et al., 2010) and the contribution of antibiotic use to antibiotic resistance (Lusk et al., 2006; Umberger et al., 2009). Although we cannot delineate with certainty the contribution of each of these factors in shaping public perceptions, existing research does suggest that there is public concern about antibiotic residues. Research has shown that buyers of organic poultry perceive it to contain less residues (pesticides, hormones, antibiotics; Van Loo et al., 2010), and consumers perceive pork products labeled as "all natural" to indicate that pork was free from hormones, antibiotics, and chemicals, which they perceived as a potential risk to their health (Abrams et al., 2010). In regards to personal risk from antibiotic resistance, a systemic review of the public's knowledge and beliefs about antibiotic resistance in general (not specifically due to antibiotic use in animal agriculture) suggested that the public believes they are at low risk (McCullough et al., 2016). However, consumers have demonstrated willingness to pay for prevention of antibiotic resistance (Lusk et al., 2006; Umberger et al., 2009). Future research might seek to elucidate what aspects of antibiotic use on dairy farms consumers find threatening. Such information could justify the need for consumer education if their perceptions are inaccurate.

Willingness to Pay for Organic Dairy Products and Associated Factors

In economic studies of consumer willingness to pay for food products, prevention of antibiotic resistance is often regarded as an indirect benefit (Lusk et al., 2006) or altruistic factor (Umberger et al., 2009), which consumers have expressed a willingness to pay for in studies of pork and beef products (Lusk et al., 2006; Umberger et al., 2009). This in contrast to personal (Umberger et al., 2009) or direct (Lusk et al., 2006) benefits, which consumers have also expressed willingness to pay for. Consumer concern for antibiotic residues would fall under this latter category, although the concern does not seem to match the actual risks. Minimum standards for the production, processing, pasteurization, and distribution of grade A milk are set by the Pasteurized Milk Ordinance (**PMO**; FDA, 2017b). Based on these standards, industry must screen all bulk milk pickup tanks and raw milk supplies for β-lactam antibiotic residues, and milk testing positive for β-lactam residues cannot be sold for human consumption (FDA, 2017b). Future research might specifically examine consumers' knowledge of regulations surrounding grade A milk (PMO) and antibiotic use (VFD final rule), or lack thereof, and how this influences their perception of the threat to human health from antibiotic use in dairy farming.

Because the dairy industry is dependent on consumer support, we directly inquired about respondents' willingness to pay more for milk from cows raised without antibiotics and elucidated factors associated with that willingness. Among respondents who purchased milk, almost three-fourths (71.5%) were willing to pay some amount more. Previous research has shown that consumers are willing to pay more for products from animals raised without antibiotics, specifically in pork (Lusk et al., 2006). Research examining milk specifically found that consumers would be willing to pay more for the verification of the credence attribute "no antibiotic use" by the USDA compared with self-verification, verification by private third parties, or verification by consumer groups (Olynk et al., 2010).

In multivariable analysis, respondents reporting willingness to pay more for milk from cows raised without antibiotics were more likely to perceive antibiotic use in dairy farming as at least a low threat to human health, and that association was significant even after controlling for level of education and household income. Specifically, those willing to pay more believe that cows are treated better on organic farms, have an annual household income of $50,000 or more, have a liberal social ideology, and are less likely to be single or born in the United States. The relationship between perceived threat of antibiotic use in dairy farming to human health and willingness to pay more for milk from cattle raised without antibiotic use is clear, as participants who perceive something as a threat may be willing to pay more to avoid it, an idea supported by previous food safety research (Yeung and Morris, 2001). Consistent with this, a 2009 study found that increased willingness to pay for milk from cows not treated with antibiotics was associated with consumers' belief that conventional milk comes from cows treated with antibiotics (Bernard and Bernard, 2009).

The relationship between the belief that cattle are treated better on organic compared with conventional farms and our outcome variable (willingness to pay) may be because consumers associate organic farming with other attributes such as reduced antibiotic use (Clark et al., 2016). Some consumers who believe that cattle are treated better on organic than conventional farms may be willing to pay more for organic milk to support better cattle treatment. Although willingness to pay more for milk from cows raised without antibiotics is not the same as consumer willingness to pay more for organic products, a 2009 study of organic milk attributes found that that the 2 attributes "recombinant bovine somatotropin (rbST)-free" and "no antibiotics"

were important factors in consumer demand for organic milk (Bernard and Bernard, 2009). However, it should be noted that these and other factors were not additive in calculating willingness to pay for organic products overall (Bernard and Bernard, 2009). Finally, the relationship between higher household income and willingness to pay is likely due to the increased ability of higher income households to pay a premium price for milk raised without antibiotics. The role of liberal social ideology, being single, or being born in the United States is less clear. Testing of an association between income and marital status indicated that single individuals represented a younger demographic with fewer financial resources. Being born outside the United States was not associated with income. It is possible that place of birth is a proxy for some other unmeasured variable.

Possible Effects of Consumer Education

It would be revealing to see whether consumer education on the VFD final rule, PMO, potential conflict of reduced antibiotic use with animal welfare, or dairy farm production practices would change their perception of the threat posed by antibiotic use in dairy farming, treatment of cattle on organic versus conventional farms, and willingness to pay more for milk from cows not treated with antibiotics. This is particularly important because regulations such as the VFD final rule are relatively recent and not accounted for in earlier research. The results of such research might be valuable in guiding consumer outreach and marketing strategies by dairy industry stakeholders, policy making, and future research. In suggesting public or consumer education, it is important to highlight that in previous studies increased public knowledge of production practices as they relate to animal welfare, including in dairy farming, has not always led to greater public acceptance of them (Vanhonacker et al., 2008; Ryan et al., 2015; Ventura et al., 2016). In relation to agriculture, the knowledge deficit model attributes public concern regarding food production practices to a lack of knowledge and understanding of them (Hansen et al., 2003). However, there is general recognition that the knowledge deficit model alone is insufficient in explaining the public's attitudes toward food risks (Hansen et al., 2003), and the results of the aforementioned studies are consistent with that. Instead, values held by the public regarding naturalness and what constitutes humane animal care appear to play an important role in shaping public perception of farming practices (Vanhonacker et al., 2008; Cardoso et al., 2016; Ventura et al., 2016). Although the outcome of increased public knowledge on this topic may be unpredictable, it is still important to help provide accurate information to the public.

Limitations and Considerations

This study had several limitations. The survey mechanism allowed only 4 questions with a limited number of response options. This precluded the use of a multidimensional scale to assess the different components of attitudes inquired about in questions 2 and 4 and establish content validity. The scope of this study was to establish an initial, current picture of US views after VFD final rule to provide preliminary data for a more nuanced evaluation in the future by our group and others. Additionally, some sociodemographic characteristics of our survey sample varied from those of the US population. These included age, annual household income, level of education, employment status, race, and ethnicity. Therefore, our sample was not fully representative of the US population, which limits generalizability of our findings.

The survey questions themselves had some limitations. In the willingness-to-pay question, we offered responses for "not willing to pay more" and several levels of willing to pay more but no option to indicate preference to pay less for milk produced without the use of antibiotics. Because of that, it is possible that the participants who selected "not willing to pay more" actually also included those who would pay less for such milk; this is important to keep in mind when interpreting the results that used unwilling to pay more as the reference level. Additionally, our survey did not—nor was it within the scope to—include questions to explore what aspects of antibiotic use on dairy farms respondents perceived as a threat to human health.

It is unclear whether our respondents knew that organic milk production does not involve the use of antibiotics, so the ability to draw direct conclusions from views of organic products as they relate to antibiotic use is limited. Likewise, although the question about treatment of animals on organic versus conventional dairy farms revealed how participants perceive a potential aspect of animal welfare in one management system relative to the other, their understood or perceived level of animal welfare could not be inferred from that question.

This study, like other cross-sectional telephones surveys, was susceptible to several types of bias and limitations related to study design. The presence of selection, social desirability, and hypothetical bias cannot be ruled out. In regard to selection bias, although the total sample of phone numbers obtained to yield a sample size of 1,000 was quite large, the cooperation

rate was also relatively high. However, comparison with the US Census and ACS data did identify differences in sociodemographic characteristics such as age, annual household income, level of education, employment status, race, and ethnicity. Social desirability bias was identified in a study assessing willingness to pay for verification of credence attributes (such as "pasture access" and "no antibiotics use") of animal products, including milk (Olynk et al., 2010), and may have affected this study. Finally, participants may have overreported how much more they were willing to pay for milk from dairy cows raised without antibiotics in the survey compared with reality, resulting in hypothetical bias. This survey, like many, is based on self-report and can only measure intention—an important precursor to behavior—but not observed behavior. This is an important consideration because research indicates that intentions do not always translate into behavioral action, a phenomenon termed the intention–behavior gap (Sheeran and Webb, 2016). Given the cross-sectional design of this study, our findings are associations; we cannot determine causality between variables or its direction or explore reverse causality.

It is important that research in this field is continually updated, particularly considering changes in antibiotic use regulations and production practices. For instance, following complete implementation of GFI no. 213 in 2017, medically important antibiotics were no longer allowed to be used for growth promotion. However, much of the literature addressing consumers' perceptions of antibiotic use in animal agriculture was conducted before that.

CONCLUSIONS

The findings of this study indicate that a large fraction of participants in the 2017 CNSS perceive a threat from the use of antibiotics in dairy farming and believe that cattle treatment is better on organic or conventional farms and indicate that both of these beliefs as well as demographic factors are related to their purchasing attitudes. Elucidating the source of this perceived threat from antibiotic use may allow for fuller exploration of the factors that influence it and contribute to the development of consumer education aimed at enabling consumers to develop informed opinions about risks. Information on consumers' perceptions of antibiotic use risk and animal welfare combined with data on consumer behavior would allow for improved characterization of consumer purchasing decisions. Maintaining consumer confidence in the wholesomeness and safety of both conventionally and alternatively produced dairy products is critical to the industry's future. Even more importantly, consumers represent a great force that can shape antibiotic use in dairy farming and in animal agriculture in general, and it is important that they are well informed.

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